Final report on the Australian Flora Foundation funded project:

The effect of nitrogen fertility and mowing frequency on the persistence of twelve Australian perennial forbs in a planted grassland community

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Summary

Australian temperate native grasslands are critically endangered plant communities that typically comprise complex associations of tussock grasses interspersed with seasonally colourful forbs. Previous research has shown that the periodic reduction of the dominant grass biomass through agents such as fire and mowing has helped maintain species diversity within grassland remnants.

This project investigated the effect of two factors, soil nitrogen levels and the frequency of biomass removal, on the survival and productivity of a range of perennial native forbs in a planted grassland community.

A native grassland community comprising Kangaroo Grass (*Themeda triandra*), Common Wallaby Grass (*Austrodanthonia caespitosa*) and twelve perennial forbs was planted (using small, nursery-grown transplants) in a pre-determined pattern into a constructed, weed free, low nutrient sub-soil plot. Two frequencies of late summer biomass removal (annual; two-yearly) and two levels of nitrogen application (none; two-monthly applications of 10 g m^{-2} ammonium nitrate) were combined into four factorial treatments and maintained for four years. Biomass production of each of the planted species, and the phenology and survival of each of the forb transplants, were recorded and analysed for the duration of the experiment.

All species established well following a late autumn planting. Initially, the experimental plots were dominated by Wallaby Grass, to be replaced by Kangaroo Grass in the later years of the experiment. The survival and growth of the various forbs varied between species, depending on their life form and growth habit. Only one forb species, the geophytic monocotyledon Bulbine Lily (*Bulbine bulbosa*), survived in all treatments. Several forb species survived within one or more treatments, usually on annually harvested plots with no applied nitrogen. The diversity of the forb species dropped rapidly in the later years in those plots that received nitrogen. The combination of applied nitrogen and two-yearly biomass removal quickly developed a more-or-less continuous canopy of Kangaroo Grass that excluded most other species. Two forbs, Bulbine Lily and Native Flax (*Linum marginale*) recruited heavily from seed during the course of the experiment and each became an established component of the constructed grassland. No other forb recruitment was recorded.

Despite the on-going presence of a colourful and diverse perennial native forb component in some burnt or mown remnants, their reliable, long term persistence in planted grassland communities remains problematic. Future research might focus on the density of planting of grasses and forbs, the frequency and seasonal timing of biomass removal and the species composition and population size of the planted forb components.

Introduction

The native temperate grasslands

Temperate lowland grasslands are among Australia's most threatened ecosystems (Kirkpatrick *et al.* 1995). Following European settlement, these mainly treeless tracts of land were quickly modified, initially by grazing of sheep and cattle, and later by pasture improvement and large-scale cultivation. In rural areas, these processes continue to impact on the fragmented and isolated remnants that still exist. In and around urban areas, remnant and depleted communities are reduced in area and quality through invasion by alien species, or they are eliminated by housing and commercial developments (Williams *et al.* 2005). Efforts to protect and conserve native grasslands have generally focussed on understanding their ecology, particularly the role of periodic disturbance in maintaining and improving the diversity and health of existing remnants. During recent decades much has been learnt about the historical and current distribution of temperate grasslands, the autecology of their component species and the management options for remnants. It has become clear that, over much of their range, the periodic removal of accumulated biomass is necessary if species diversity is to be maintained. The means, seasonal timing, frequency and intensity of this removal are subjects of on-going research. Each factor is likely to vary with the location, species composition and productivity of specific remnants (Lunt and Morgan 2002).

Early European explorers and settlers in south-eastern Australia reported both the agricultural potential and the seasonal beauty of the grasslands they quickly occupied. Some also commented on how these areas were modified when grazed by sheep and cattle. Jane Williams (nee Reid) arrived in Tasmania as a child on 1 March 1822 (Brown 1941). Reminiscing in 1840, following her return to Scotland, on her observations of the impact of settlement and grazing on native vegetation, she wrote: *"… the plains of Van Diemen's Land presented at the period I speak of as beautiful a floral sight as the imagination can conceive. The spring and summer still offer much to please the eye, but since the large flocks and herds which have been the real sources of wealth were introduced, the flowers have become comparatively rare; for there as elsewhere beauty is sacrificed to utility - a more than human power alone can combine both. In the new colonies of Port Phillip and Adelaide the country now presents the same lovely scene which I have alluded to in Van Diemen's Land for some years after our arrival"* (Brown 1941).

Jane Williams' nostalgia for the seasonal displays of wildflowers she recalled from her childhood, less than two decades earlier, provides an insight into the rate at which these diverse plant communities were altered under European pastoral systems. Her conviction that to combine their beauty with their new forms of management would take "*… a more than human power alone*" issues a powerful challenge to those in the early twenty-first century who work to understand, preserve and even reconstruct such complex biological communities.

Vegetation structure

Australia's native temperate lowland grasslands are comprised of a number of competitive tussock grass species from genera such as *Themeda*, *Poa*, *Austrodanthonia* and *Austrostipa*, amongst which grow a diverse suite of herbaceous species other than grasses (forbs) (Mott and Groves 1994). In the absence of periodic canopy reduction by agents such as fire and grazing, the grasses tend to form a more or less continuous canopy, which suppresses and ultimately excludes most other plant species. When the grass canopy is removed from time to time, as it was during the thousands of years of aboriginal management, the gaps between the tussocks are exposed and become suitable habitat for the forbs. Because of their wide range of life forms and relatively small stature, the forbs are able to grow in close association with each other and the grasses, leading to the species diversity and visual complexity for which these communities are renowned. The frequency of canopy reduction that best favours the maintenance of species diversity varies between communities and depends on factors such as soil nutrition and rainfall (Lunt *et al.* 1998).

Landscape applications

Early European descriptions of the grasslands and open woodlands of southern Australia likened them to parklands and commented on the care with which indigenous people managed and utilised the landscape. Once the management of these landscapes changed, so did their structure and species composition. Only relatively small remnant areas were preserved, when contemporary management simulated earlier practices. This usually related to the use of routine burning of areas such as road and rail reserves, village commons and unimproved farmland, for the control of summer fires (Lunt *et al.* 1998, Lunt and Morgan 2002).

In more recent times, the potential of these plant communities and their component species for horticulture and wider landscape applications has been recognised and discussed (Hitchmough 1994).

Options for enhancement and reconstruction

There are two broad options for the re-construction of diverse plant communities; direct sowing of complex seed mixtures and the transplanting of nursery grown seedlings.

Direct sowing is likely to be the only cost-effective method of treating large areas because of the need, in herbaceous communities, for relatively large numbers of established plants per unit area when compared with the establishment of woody vegetation. Taking into account the field factors associated with direct sowing and the difficulty in sourcing reliable quantities of good quality seed for many grassland species, this technique is still in its early phases of development (Gibson-Roy *et al.* 2004).

Because of the efficiencies of nursery production, transplanting of established seedlings has the advantage, at least for smaller areas, of requiring smaller quantities of seed. Also, direct transplanting ensures that known numbers of plants of each species are introduced onto the site.

Project objectives

This project investigated the following questions.

Within a planting of native grasses and forbs:

1. What effect does the frequency of biomass removal have on the survival and productivity of a range of perennial native forbs;
2. What effect does nitrogen availability have on the survival and productivity of a range of perennial native forbs;
3. What effects do combinations of frequency of biomass removal and nitrogen availability have on the survival and productivity of a range of perennial native forbs?

Materials and methods

Plot construction

The experimental area was located in the Field Station of the Burnley Campus of the University of Melbourne. It was constructed to provide a weed-free, low nutrient soil environment for establishing nursery-grown seedlings. A 10 m by 10 m area was excavated to a depth of 200 mm. This removed the existing topsoil and its associated nutrients, seed bank and bud bank. The soil was replaced with an imported clay sub-soil that was low in major plant nutrients and free from seeds and other plant parts. The sub-soil was laid to a depth of 300 mm at the edges of the site and mounded to a depth of 400 mm at the centre. A raised timber border 120 mm high surrounded the site. A 1 m wide ground-level gravel pathway was laid outside the timber border to provide a weed free buffer between the experimental area and the surrounding mown turf (Fig. 1). A pop-up irrigation spray was installed within the pathway at each corner of the experimental area to provide adequate watering during the plant establishment phase.

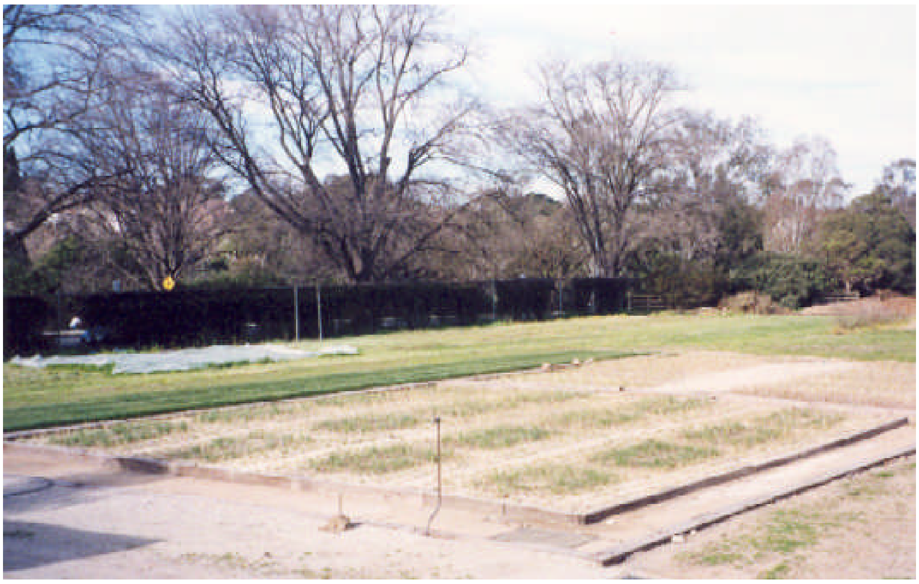


Figure 1 The newly constructed and planted experimental area in August, 1998. The sixteen experimental plots can be seen, each surrounded by a border planting of Weeping Grass (*Microlaena stipoides*).

Species

Fifteen perennial grassland species were planted into each plot in an identical pattern (Fig. 1, Table 1). Kangaroo Grass (*Themeda triandra,* syn. *Themeda australis*), a C4 grass and Common Wallaby Grass (*Austrodanthonia caespitose*), a C3 grass formed the grass matrix into which each of twelve forb species was planted. The forb species, of various life forms, were typical components of native temperate lowland grasslands. Weeping Grass (*Microlaena stipoides*), also a C3 grass, was planted around the perimeter of each plot to form a pathway and to differentiate each experimental area from those adjacent to it.

Plant production

All experimental plants were grown from seed. On 21 June 1997, three grass species and twelve forb species were sown into a pine bark based seed raising medium in the Burnley Campus plant nursery. During subsequent weeks, seedlings were transplanted into 100-cell seedling trays, one seedling per cell. Sufficient seedlings of each species were produced to meet the requirements of the experimental design. The trays were placed on glasshouse benches and irrigated daily. Subsequently, the trays were relocated to a shade house. The production schedule was designed to meet a field planting date in September of that year but delays in the construction of the experimental site caused the transplants to remain in their trays until May 1998. From January 1998, the plants were maintained with a weekly liquid application of a complete fertiliser. In January, 1998 the foliage of grass species *Austrodanthonia caespitosa* and *Microlaena stipoides* was cut to a height of 50 mm.

Table 1 Twelve native perennial forbs of varying life forms included in the planted grassland community.

Species	Family	Life form
Arthropodium strictum	Anthericaceae	tuberous perennial monocot. forb
Bulbine bulbosa	Asphodelaceae	bulbous perennial monocot. forb
Calocephalus citreus	Asteraceae	shrub-like perennial dicot. forb
Chrysocephalum apiculatum	Asteraceae	prostrate perennial dicot. forb
Craspedia variabilis	Asteraceae	rosette perennial dicot. forb
Helichrysum scorpioides	Asteraceae	lightly stoloniferous dicot. forb
Leucochrysum albicans ssp. *albicans* var. *tricolor*	Asteraceae	short-lived compact perennial dicot. forb
Linum marginale	Linaceae	shrub-like perennial dicot. forb
Podolepis jaceoides	Asteraceae	rosette perennial dicot. forb
Pycnosorus chrysanthes	Asteraceae	shrub-like perennial dicot. forb
Velleia paradoxa	Goodeniaceae	compact perennial dicot. forb
Wahlenbergia stricta	Campanulaceae	compact perennial dicot. forb

Experimental design

The experiment was designed as a 4 X 4 Latin Square of four treatments with four replications. There were two experimental variables, nutrient availability and frequency of biomass removal, in factorial combinations. Half the plots received a fertiliser application of 10 g m^{-2} of ammonium nitrate at two-monthly intervals, first applied on 1 September 1998. Half the plots had all biomass harvested to a height of 100 mm every year in late summer, with the other half being harvested every second year (Table 2). Each of the sixteen plots was 1.7 m long and 1.0 m wide. A planted pathway surrounded each plot (Figs. 2, 3).

Within the experimental plot a grass matrix was planted consisting of *Themeda triandra* at each corner with two *Austrodanthonia caespitosa* planted between each *Themeda triandra*. Four seedlings of a particular wild flower species were planted within this square. This pattern of planting was repeated for all twelve forbs. All seedlings were planted 110 mm apart. Each completed plot contained 24 *Themeda triandra*, 72 *Austrodanthonia caespitosa* and four of each of twelve forb species (Fig. 2). The position of each forb species within the plot was randomly allocated and the identical planting pattern was used for each of the sixteen plots. Each plant was 110 mm from its neighbouring plants. An unplanted area remained at the centre of each plot, allowing access for operations such as two-monthly fertiliser applications to relevant plots, data collection and biomass harvesting. The pathway that surrounded each experimental area was planted with *Microlaena stipoides* to easily distinguish the pathways from the experimental area (Fig. 2).

From September 1998 until the completion of monitoring in February 2002, data were collected intermittently on the individual forbs, recording the presence of living above ground foliage and the presence of buds, flowers and dispersing fruit. At each harvest, the dry weight of material harvested from each species, from each plot, was recorded.

Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms
Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms
Ms	Ms	Ms	T	A	A	T	A	A	T	A	A	T	Ms	Ms	Ms
Ms	Ms	Ms	A	Vp	Vp	A	Pj	Pj	A	Ws	Ws	A	Ms	Ms	Ms
Ms	Ms	Ms	A	Vp	Vp	A	Pj	Pj	A	Ws	Ws	A	Ms	Ms	Ms
Ms	Ms	Ms	T	A	A	T	A	A	T	A	A	T	Ms	Ms	Ms
Ms	Ms	Ms	A	Cv	Cv	A			A	Pc	Pc	A	Ms	Ms	Ms
Ms	Ms	Ms	A	Cv	Cv	A			A	Pc	Pc	A	Ms	Ms	Ms
Ms	Ms	Ms	T	A	A	T			T	A	A	T	Ms	Ms	Ms
Ms	Ms	Ms	A	Cc	Cc	A			A	La	La	A	Ms	Ms	Ms
Ms	Ms	Ms	A	Cc	Cc	A			A	La	La	A	Ms	Ms	Ms
Ms	Ms	Ms	T	A	A	T			T	A	A	T	Ms	Ms	Ms
Ms	Ms	Ms	A	Ca	Ca	A			A	Hs	Hs	A	Ms	Ms	Ms
Ms	Ms	Ms	A	Ca	Ca	A			A	Hs	Hs	A	Ms	Ms	Ms
Ms	Ms	Ms	T	A	A	T	A	A	T	A	A	T	Ms	Ms	Ms
Ms	Ms	Ms	A	As	As	A	Lm	Lm	A	Bb	Bb	A	Ms	Ms	Ms
Ms	Ms	Ms	A	As	As	A	Lm	Lm	A	Bb	Bb	A	Ms	Ms	Ms
Ms	Ms	Ms	T	A	A	T	A	A	T	A	A	T	Ms	Ms	Ms
Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms
Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms	Ms

Figure 2 Planting layout for each of 16 experimental plots: Ms, *Microlaena stipoides*; T, *Themeda triandra*; A, *Austrodanthonia caespitosa*; As, *Arthropodium strictum*; Bb, *Bulbine bulbosa*; Cc, *Calocephalus citreus*, Ca, *Chrysocephalum apiculatum*; Cv, *Craspedia variabilis*, Hs, *Helichrysum scorpiodes*, La, *Leucochrysum albicans*; Lm, *Linum marginale*; Pj, *Podolepis jaceoides*; Pc, *Pycnosorus chrysanthes*; Vp, *Velleia paradoxa*; Ws, *Wahlenbergia stricta.* All seedlings were planted 110 mm apart.

Table 2 Factorial treatments applied to the planted grassland community. Nutrient treatments; 2 monthly application of ammonium nitrate (10 g m^{-2}) (H), no nutrient application (L): Mowing treatments; all biomass above 100 mm cut and removed annually (H), all biomass cut and removed every 2 years (L).

Treatment	Nutrient application	Mowing
A	H	H
B	H	L
C	L	H
D	L	L

Plant establishment

The experimental area was planted on 30 May 1998. A stringline was used to place each plant in its correct position. The planting hole was formed in the damp clay surface with a sharpened stake and the seedling cell was pressed into this hole. Following planting, the area was irrigated as required to ensure adequate water was available to the establishing seedlings (Figs. 1 & 3).

Figure 3 An individual plot is in the foreground, comprising a matrix planting of *Themeda triandra* and *Austrodanthonia caespitosa* into which are planted blocks of four seedlings of twelve grassland forbs.

Results

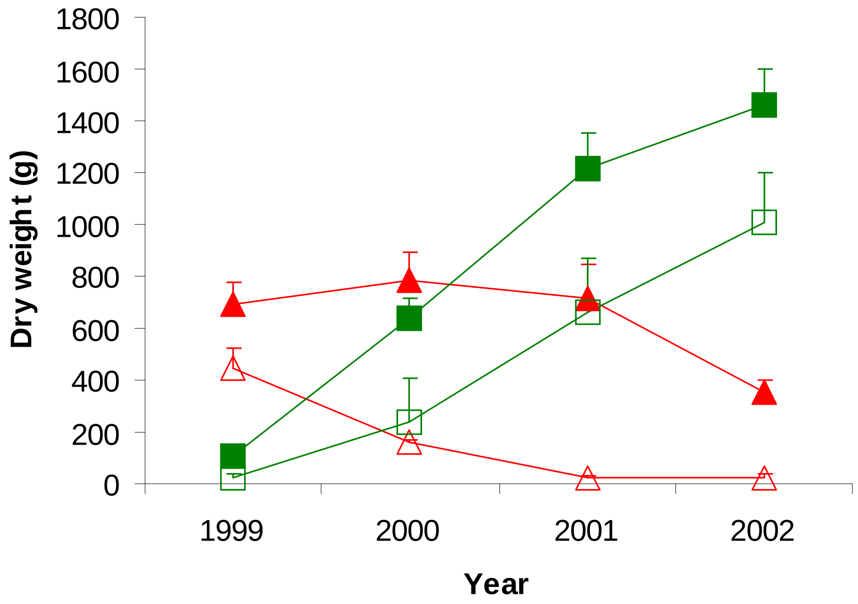
Two interacting factors, biomass production and plant survival, had a strong influence on the direction of development of the plant community replicated on each of the sixteen experimental plots. Total biomass production differed significantly between treatments at all harvests and had an important impact on the relative competitiveness of the various species represented in these plantings. This factor will be considered first, followed by plant survival.

Biomass production

The application of ammonium nitrate every two months began two months after planting. The effect was obvious within one month, with those plots receiving fertiliser becoming greener and appearing to grow more vigorously. These effects were confined to the treated plots, and there was no visual indication throughout the experiment that nitrogen was moving into untreated plots. By the time of the first harvest five months later, there was a significant increase in biomass harvested from the fertilised plots for *Themeda triandra* ($p = 0.003$), combined forbs ($p = 0.03$) and a weakly significant increase for *Austrodanthonia caespitosa* ($p = 0.08$). Initially the dominant biomass producer on all plots was *Austrodanthonia caespitosa* (Figs. 4 & 5). However, in both fertilised and unfertilised plots, *Themeda triandra* became the dominant species by the third year (Fig. 5).

Figure 4 A harvested plot beginning to re-grow in March, 1999. The plot immediately behind was not due for harvest until the second year and carries a dense stand of *Austrodanthonia caespitosa* as the dominant species.

a



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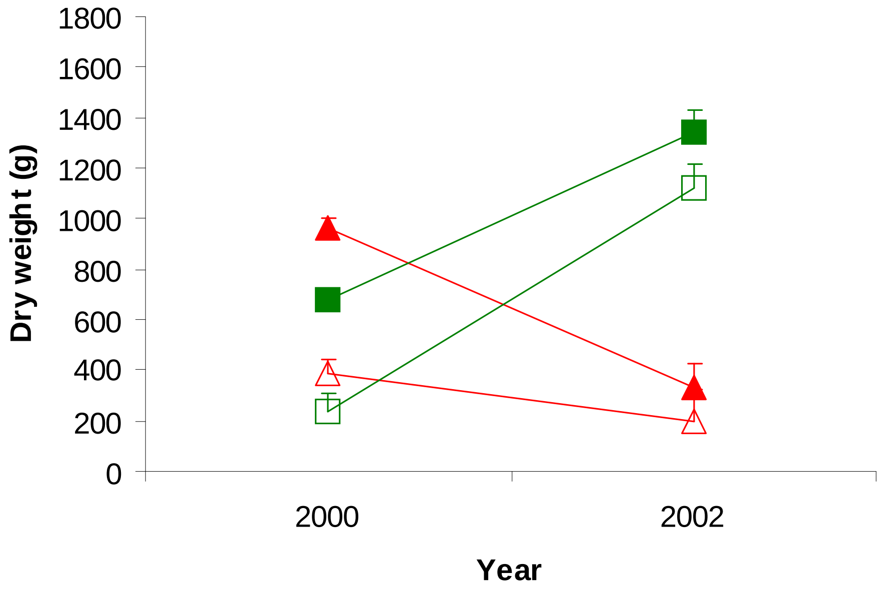


Figure 5 Dry matter harvested from two planted perennial grasses when cut in late summer 100 mm above soil level; (a) harvested annually and (b) harvested every second year. Δ *Austrodanthonia caespitosa*, no applied nitrogen; ▲ *A. caespitosa*, nitrogen applied two-monthly; □ *Themeda triandra*, no applied nitrogen; ■ *T. triandra*, nitrogen applied two-monthly. Error bars = + 1 S.E.

When annual and two-yearly harvests coincided in years two and four, plots that were harvested annually produced similar quantities of *Themeda triandra* biomass to those that had not been harvested the previous year (Fig. 6 (a)). In the second year (2000), average dry matter production of *Themeda triandra* in unfertilised plots, also harvested the previous year, was 238 g while there was an average yield of 241 g from those plots being harvested for the first time. For the fertilised plots, the average yield was 635 g from plots harvested the previous year and 680 g from plots not previously harvested.

For year four, the equivalent dry matter production for *Themeda triandra* on annually harvested, unfertilised plots was 1010 g and 1120 g from plots harvested every second year. On fertilised plots, the average harvest of *Themeda triandra* dry matter from annually harvested plots (1469 g) exceeded that cut from plots that had not been harvested for two years (1340 g) (Fig. 6 (a)).

Following the first growing season, dry matter production in *Austrodanthonia caespitosa* in unfertilised plots declined steadily over the course of the experiment (Fig. 6 (b)). In annually harvested plots, the average yield of 446 g recorded in the first year reduced to 162 g in the second year and to 26 g and 25 g in the third and fourth years respectively. On unfertilised plots harvested every second year, a dry matter yield of 391 g in year two (initial harvest) reduced to 196 g in year four (second harvest). In fertilised, annually harvested plots, dry matter yield for *Austrodanthonia caespitosa* was similar for the first three years (692 g, 788 g, 713 g), but halved in the fourth year (350 g). In fertilised plots harvested every two years, an average of 962 g of dry matter was recorded at the first harvest, but this had declined to 329 g by the time of the second and final harvest (Fig. 6 (b)).

The productivity of the forbs in response to increased availability of nitrogen was specific to the species and it also depended on whether their plot was harvested annually or every two years (Fig. 7 (a) & (b)).

On the fertilised, annually harvested plots, the combined biomass produced by the forbs increased rapidly in the first one to two years from 78 g to 181 g. Harvested dry matter declined in years three and four to 1 and 0 g respectively as most of the forbs from the initial planting senesced, or were suppressed by competition from the dominant grasses, so that their above-ground biomass was below the harvest height of 100 mm. In fertilised plots harvested every second year the forbs produced 344 g of dry matter at their first harvest but they also had declined by their second and final harvest with an average yield of 1 g.

In the absence of fertiliser, the forbs grew more slowly (Fig. 7 (b)). Most species did not experience the rapid decline in biomass production recorded in the fertilised plots. They reached a maximum dry matter harvest in the second year (55 g). This was maintained the following year (54 g) and declined to 27 g by year 4.

Most of the forb biomass was harvested from three species (*Pycnosorus chrysanthes*, *Linum marginale* and *Calocephalus citreus*). A number of species (*Arthropodium strictum*, *Bulbine bulbosa*, *Velleia paradoxa*) contributed little or nothing to the combined forb biomass, even though they were still present on the plots. At the time of harvest each year (late summer) these species had completed flowering and their reproductive stems had senesced, leaving any remaining plant parts below the cutting height of 100 mm.

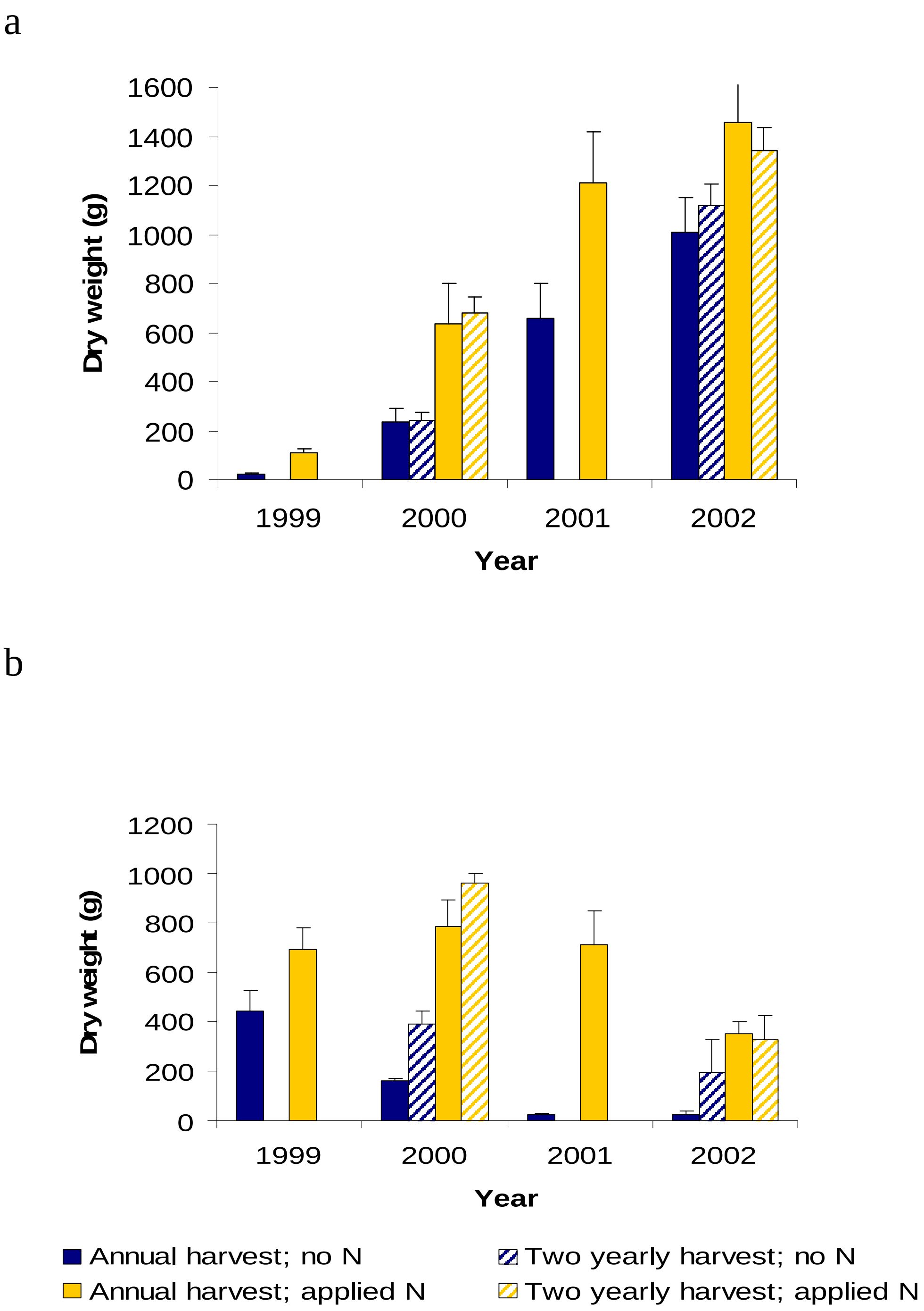
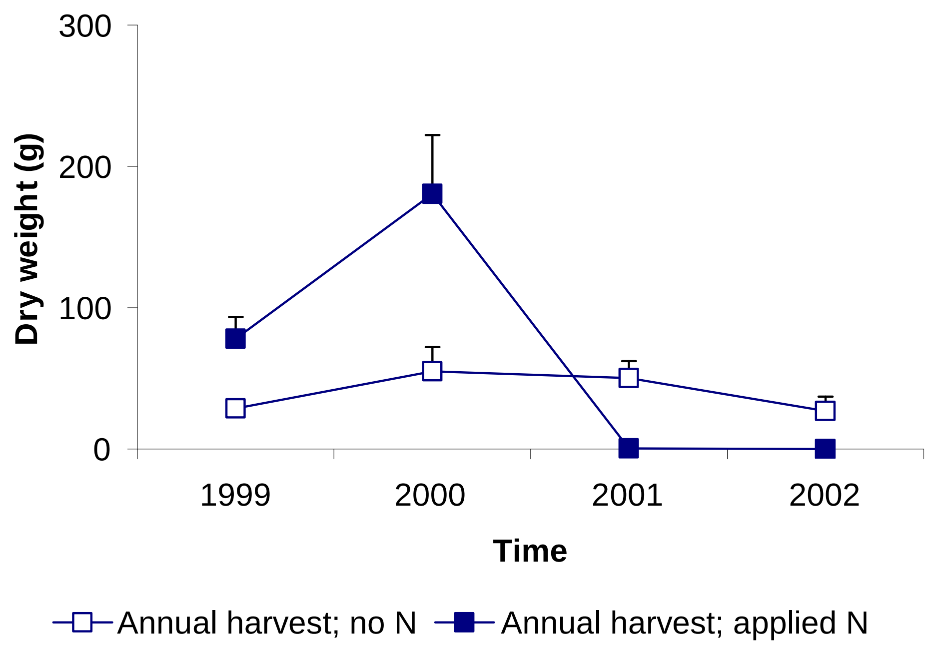


Figure 6 Dry matter harvested from two planted perennial grasses, grown on sub-soil with and without the application of nitrogen, when cut in late summer 100 mm above soil level; (a) *Themeda triandra* and (b) *Austrodanthonia caespitosa.* Error bars = + 1 S.E.

a



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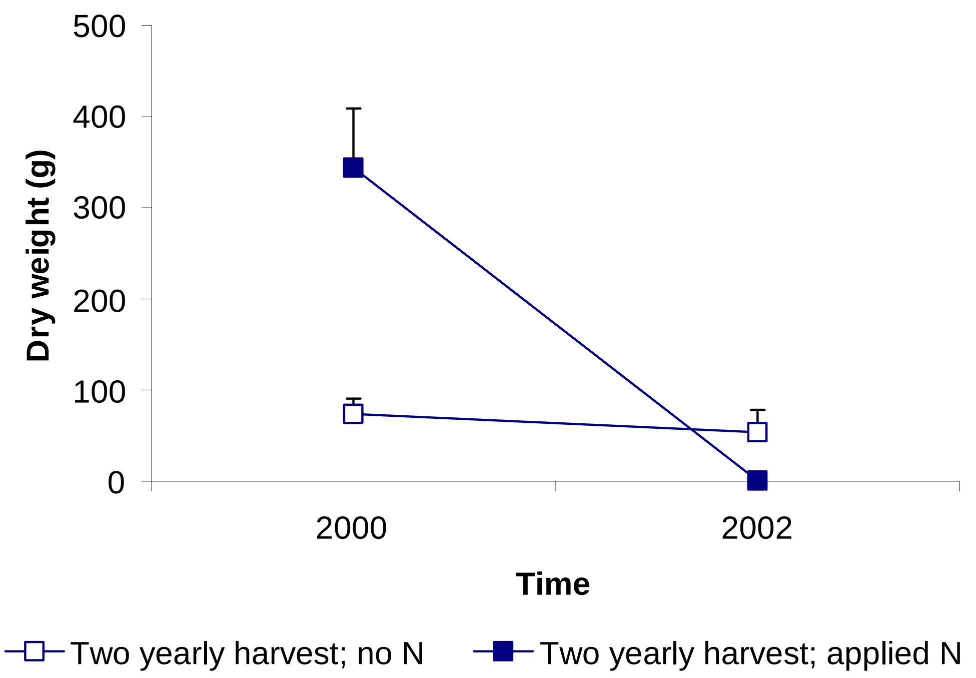

Figure 7 Dry matter harvested from twelve planted perennial forb species, grown on sub-soil with and without the application of nitrogen, when cut in late summer 100 mm above soil level; (a) harvested annually and (b) harvested every second year. Error bars = + 1 S.E.

Plant survival

At planting, each of the 16 plots contained 72 seedlings of *Austrodanthonia caespitosa*, 24 *Themeda triandra* and four of each of 12 perennial forbs. Three months after planting, all *Austrodanthonia caespitosa* had established and one seedling of *Themeda triandra* had died. The survival of the transplanted forb species ranged between 47% (*Pycnosorus chrysanthes*) and 100% (*Arthropodium strictum*, *Calocephalus citreus*, *Linum marginale*).

Austrodanthonia caespitosa was the dominant grass in all plots during the first growing season. Across all treatments, the plants flowered and seeded heavily and very large numbers of seedlings emerged in the following autumn (1999). Although individual grass plant numbers were not recorded after the initial count in September 1998, biomass harvests and field observations indicated that *Austrodanthonia caespitosa* individuals were relatively short-lived (one to three years) and that there were large numbers of suppressed recruited seedlings beneath the expanding *Themeda triandra* canopy. *Austrodanthonia caespitosa* plants were much more productive in the fertilised, rather than unfertilised plots, until they senesced or were out-competed by *Themeda triandra*.

Themeda triandra plants established well but were slower growing than *Austrodanthonia caespitosa*. Individual plants were long-lived and eventually became very large relative to all other species. Some individual plants flowered in the first summer and seed production was heavy from the second (2000) summer. However, recruited seedlings remained small and contributed little, if at all, to the *Themeda triandra* biomass harvested during the course of the project.

The above ground presence of the individual planted forbs varied between species and with season, depending on their life form. Plant counts fluctuated because the above ground growth of several of the species died back seasonally to ground level or underground dormant buds. The survival results presented here are from counts in September of each year, when most living plants had resumed above ground growth. *Bulbine bulbosa* was the only forb whose initial seedlings persisted in all treatments for the four years of the project. In a further nine species (*Arthropodium strictum*, *Calocephalus citreus*, *Chrysocephalum apiculatum*, *Craspedia variabilis*, *Helichrysum scorpioides*, *Podolepis jaceoides*, *Pycnosorus chrysanthes*, *Velleia paradoxa*, *Wahlenbergia stricta*) some individuals from the initial planting persisted in at least one treatment, most commonly on unfertilised, annually harvested plots. For the other two species (*Leucochrysum albicans*, *Linum marginale*) all of the original transplants died, although *Linum marginale* seedlings recruited readily and were widely distributed within the experimental area.

The least persistent forb was the relatively short-lived perennial daisy *Leucochrysum albicans*. Most of the original transplants of this species failed to persist in fertilised plots after the second summer, particularly when the plot was not harvested until the second year. On unfertilised plots that were harvested annually, a few individuals persisted until the third summer (Fig. 8). No individuals survived to the end of the fourth year and seedling recruitment was not observed for this species.

A similar pattern was recorded for *Helichrysum scorpioides*, although the number of individuals persisting into the third year was higher. One individual, in an unfertilised, annually–harvested plot, survived to the end of the fourth year.

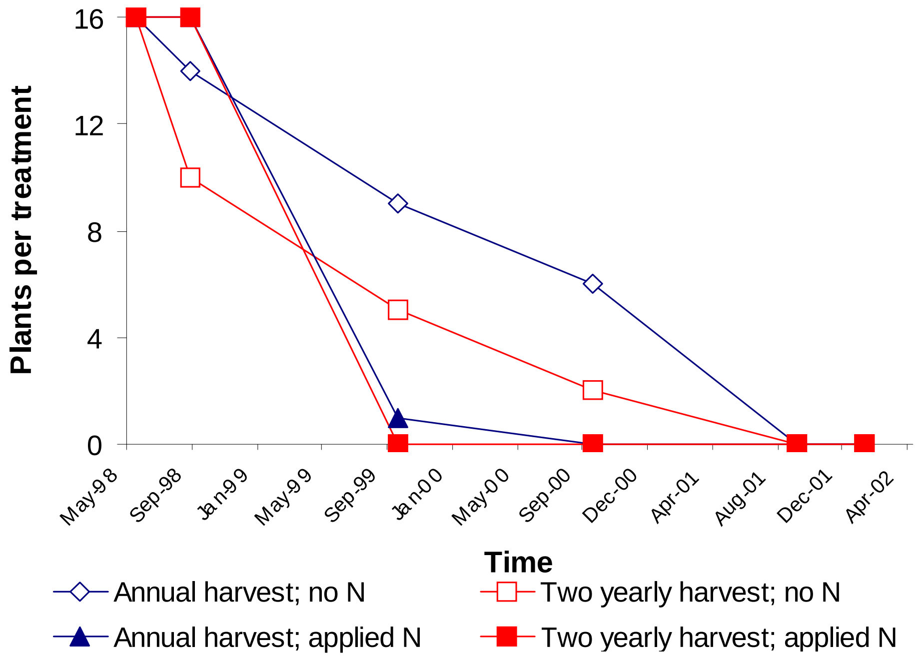

Figure 8 Persistence of seedlings of *Leucochrysum albicans* var. *tricolor* in a planted grassland grown on sub-soil with and without the application of nitrogen and cut annually 100 mm above soil level or every two years, in late summer.

Wahlenbergia stricta failed to persist after its second flowering season in spring 1999 on fertilised plots and on unfertilised plots that were harvested every second year (Fig. 9). On annually harvested, unfertilised plots two of the initial sixteen plants were present four years after planting. No new seedlings were observed.

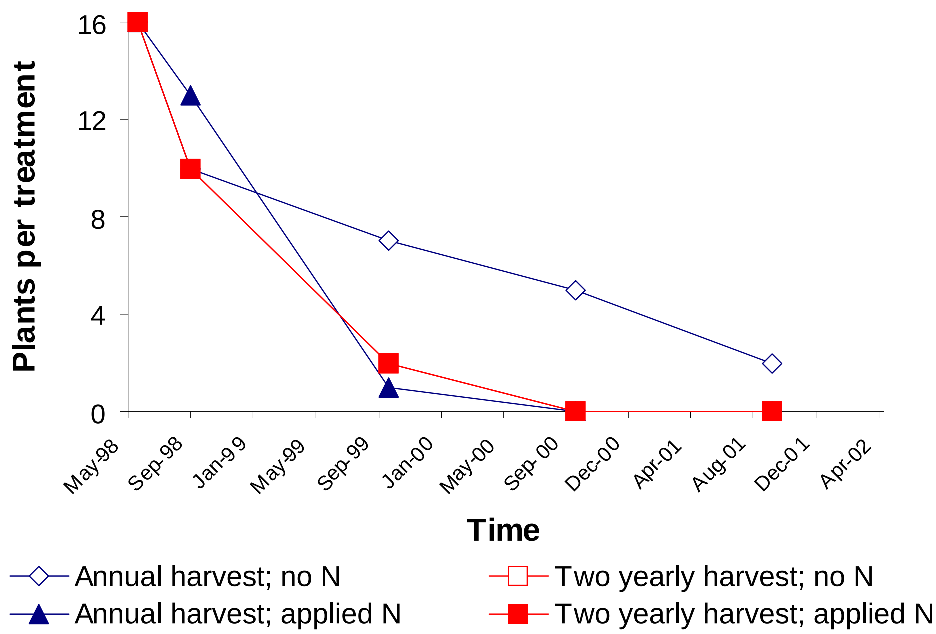

Figure 9 Persistence of seedlings of *Wahlenbergia stricta* in a planted grassland grown on sub-soil with and without the application of nitrogen and cut 100 mm above soil level annually or every two years, in late summer.

The above ground tissues of the geophytes, *Arthropodium strictum* and, to a lesser extent, *Bulbine bulbosa* died back to below-ground dormant buds during the summer and early autumn (Fig. 10). Therefore, their counts declined during these seasons even though a number of the original plants survived for the duration of the project. Other species that displayed a similar seasonal pattern, in at least some treatments, were *Helichrysum scorpioides*, *Craspedia variabilis*, *Podolepis jaceoides*, *Velleia paradoxa* and *Wahlenbergia stricta*.

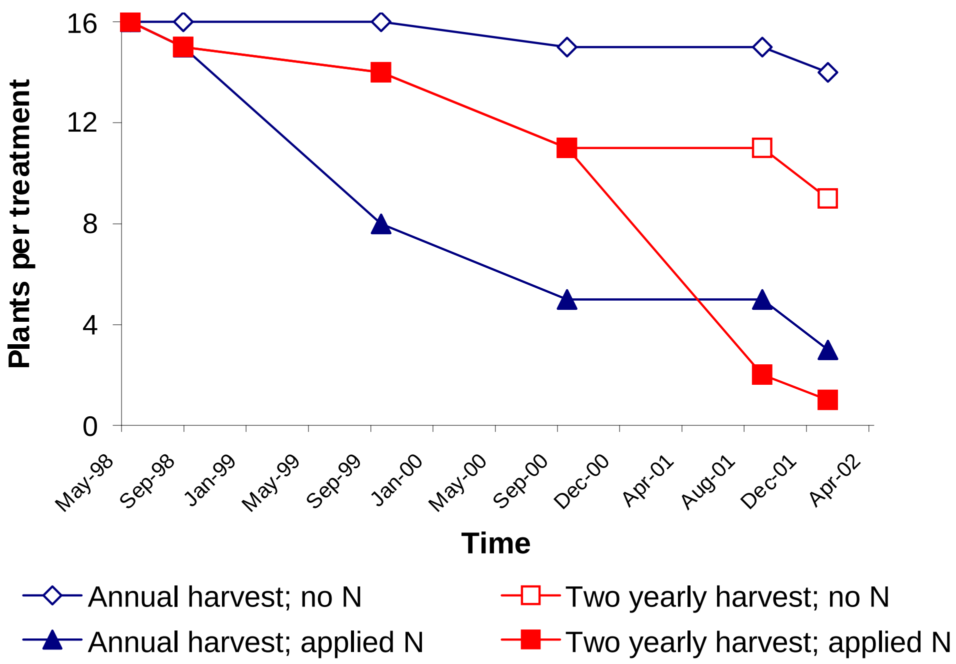

Figure 10 Persistence of seedlings of *Bulbine bulbosa* in a planted grassland grown on sub-soil with and without the application of nitrogen and cut 100 mm above soil level annually or every two years, in late summer.

Reproductive phenology

Austrodanthonia caespitosa is a C3 (cool season) species that flowered in spring and shed its seed during late spring and very early summer. *Themeda triandra* is a C4 (warm season) species. Once mature, it flowered in late spring and summer, with seed fall concentrated in middle to late summer. Both species had shed most of their seed by the time of the late summer harvests.

The forbs were predominantly spring flowering except for *Calocephalus citreus*, which reached peak flowering in December and January (Fig. 11). This species holds its seeds in compact heads for periods of up to several months before dispersal. In harvested plots, the entire seed crop was removed. *Pycnosorus chrysanthes* also holds its seeds in dense heads. Although this species flowers earlier than *Calocephalus citreus*, dispersal was not complete by late summer and some seed was removed during harvest. Although predominantly spring flowering, *Linum marginale* and *Wahlenbergia stricta* flowered continuously throughout the spring and summer, and some seed was removed during harvests. Where flowering occurred on plots that were not due to be harvested, seed maturation and dispersal was completed. Several other species (*Arthropodium strictum*, *Bulbine bulbosa*, *Chrysocephalum apiculatum*, *Helichrysum scorpioides*, *Podolepis jaceoides*, *Velleia paradoxa*) were still holding some seed at the time of the annual harvest but most of their seeds had already dispersed (Fig. 8). Following harvest, none of the forb species re-initiated flowering in the autumn.

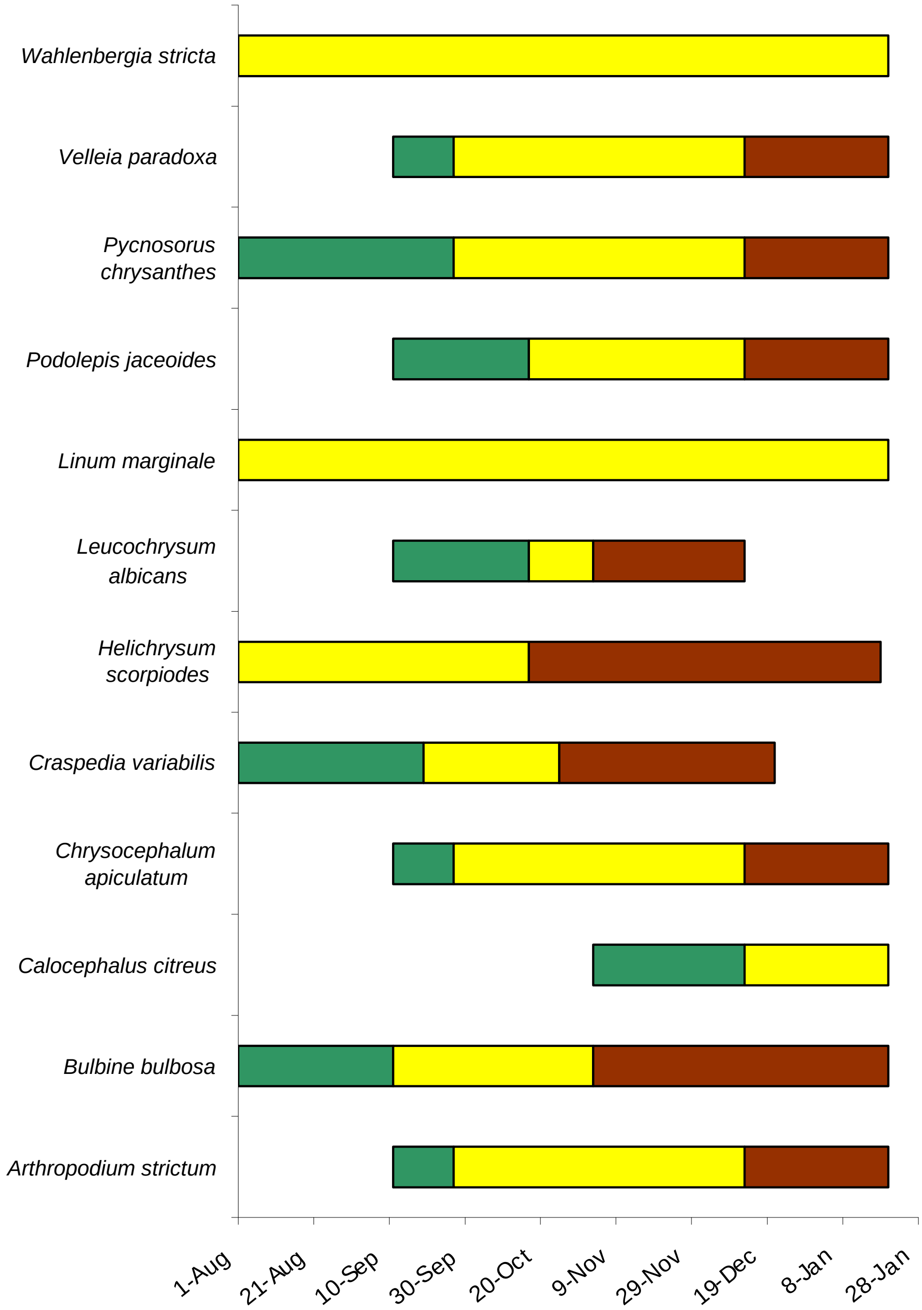

Figure 11 Reproductive phenology of 12 grassland forbs in their second flowering season. The forbs were grown in a densely planted native grass matrix. ■ visible buds; ■ flowers; ■ seed dispersal. All experimental plots were harvested in late January, removing reproductive material. *Linum marginale* and *Wahlenbergia stricta* carried buds, flowers and dispersing fruit throughout the period represented here. *Helichrysum scorpiodes* was already in flower at the start of the period. *Calocephalus citreus* had not started to disperse seed at the time of harvest.

Discussion

Temperate native grasslands are critically endangered in south-eastern Australia and have been the subject of intensive research and conservation efforts in recent decades. A further means by which these communities, and their component species, may be conserved is by replanting for urban parks and other public spaces, and for domestic and commercial landscapes (Hitchmough 1994). Such plantings have the potential to provide well-adapted plantings that evoke a strong sense of place and have low nutrient and mowing requirements. However, in the face of modified soil conditions and competition from exotic plants, invertebrates and soil micro-organisms, the success and benefits of such plantings are not assured.

This project investigated the persistence and reproductive phenology of a range of perennial grassland forbs under combinations of nitrogen nutrition and biomass management in a densely planted grass matrix. From a common starting point, the structure and composition of the plant communities changed over four years in response to four experimental treatments that combined two levels of nitrogen nutrition with two frequencies of biomass reduction. The main features of these changes were differences in the rate at which *Themeda triandra* replaced *Austrodanthonia caespitosa* as the dominant grass species and the differing rates at which most of the planted forbs were excluded. The responses of individual forb species to both applied nutrition and cutting interval were also interesting and variable.

Responses to canopy management

Perhaps the most critical factor determining the fate of the various forb species was the extent and duration of the canopy formed by the two grass species, *Austrodanthonia caespitosa* and particularly *Themeda triandra*. This species was planted and survived at high densities. Under increased nitrogen nutrition it eventually formed a more-or-less continuous leaf canopy above the surface of the experimental plots, until it was reduced in late summer every one or two years (Fig. 12).

Only the taller growing forbs, particularly *Bulbine bulbosa* and *Linum marginale*, were able to emerge through this canopy and effectively compete for light. The lower growing forbs were further disadvantaged in those treatments in which the grass canopy was reduced only every second year.

The most persistent forb was *Bulbine bulbosa*, with at least one of the initial 16 plants surviving for four years in all four treatments. In the annually harvested plots with no added fertiliser, fourteen of the original *Bulbine bulbosa* transplants survived to the end of the project, although none of these plants flowered during the final spring and summer. *Bulbine bulbosa* recruited abundantly from seed and its tall inflorescences remained a showy presence during the spring and summer.

Other species to persist well were *Calocephalus citreus*, *Pycnosorus chrysanthes* and *Arthropodium strictum*, but almost exclusively in the low nutrient plots. All transplants of *Calocephalus citreus* survived in these plots, while only two survived when exposed to competition from the grass canopy on the fertilised plots. Interestingly, this taller growing, shrub-like forb persisted longer under biennial cutting than when reduced annually (along with its grass competitors). This seems somewhat at odds with our field observation that this species can persist well within more frequently mown remnants along roadsides and within cemeteries etc. This suggests that the interactions between the frequency and timing of biomass removal and the survival of particular species are complex and warrant further research. *Pycnosorus chrysanthes* is also a spreading, shrub-like forb, which under the onditions of this experiment, tended to remain growing and flowering throughout the year. After heavy losses in the months following planting, a number of the surviving plants proved to be very competitive and showy when not overshadowed by *Themeda triandra*.

Figure 12 More-or-less continuous canopy cover formed by planted grasses in plots with added nitrogen. Harvested plots in the background reveal the gaps that persist under the canopy.

Arthropodium strictum is a fine leafed, tuberous species that dies back to dormant, underground buds during summer. In spite of its slight above-ground structure, this species persisted very well under severe competition for light. Of the species included in this experiment, *Arthropodium strictum* appeared to be one of the most adaptable to its available resources. It shared this characteristic with *Bulbine bulbosa*, another, more robust, geophyte. This adaptability is best illustrated through the plant's reproductive effort. In the first spring after planting, individuals within each treatment produced buds and flowers. However, as the various treatments took effect, only those plants receiving nutrients and/or experiencing reduced canopy competition produced buds annually. Plants growing on low nutrient, biennially harvested plots persisted in high numbers but remained small and rarely flowered.

Linum marginale initially appeared to compete well within the dominant grass canopy. It produced tall, leafy, persistent stems during the growing season and, under the conditions of this experiment, tended to retain these stems from season to season, rather than die back to basal buds. This species grows vigorously under high nutrition and, when cut, it branches heavily. It flowers and seeds profusely throughout the late spring and summer and it may be self-compatible, as is its domesticated relative, flax (*Linum usitatissimum*). Although the original seedlings did not persist for the full period of the experiment, the species retained a conspicuous presence through the very large numbers of seedlings that recruited and reached reproductive maturity.

The rest of the species, *Chrysocephalum apiculatum*, *Craspedia variabilis*, *Helichrysum scorpioides*, *Leucochrysum albicans*, *Podolepis jaceoides*, *Velleia paradoxa* and *Wahlenbergia stricta* struggled to compete and persist. In nature, all re-grow seasonally from perennial basal buds and they are either rosette forming (*Craspedia variabilis*, *Leucochrysum albicans*, *Podolepis jaceoides*, *Velleia paradoxa*) or produce horizontal or lax vegetative stems (*Chrysocephalum apiculatum*, *Helichrysum scorpioides* and *Wahlenbergia stricta*). In these densely planted communities, most established and grew well for one or two seasons but few individuals were alive at the completion of the project.

Responses to nutrient level

The forb species' responses to enhanced nitrogen levels were of interest for two reasons. Firstly, many modified rural and urban soils contain elevated plant nutrient levels due to fertiliser applications for agriculture and horticulture. This is usually considered a constraint on the successful establishment of native herbaceous species and communities because these species are thought to be at a competitive disadvantage relative to exotic ruderal weeds. Therefore, the forbs' response to enhanced nutrition in the absence of weeds was of interest. Secondly, in a weed-free soil (as used here), the more rapid canopy cover achieved with the use of additional nitrogen may reduce the capacity of migrating weedy species to become established, thus reducing competition from this source.

Predictably, forbs receiving additional nitrogen responded with an increase in biomass in the first one to two years. However, both the numbers of individuals and total forb biomass fell rapidly thereafter. The rate at which individual forb species declined under the intense competition from the grasses seems to have been related to their inherent longevity, their growth habit (life form) and their capacity to regenerate from dormant buds when cut to 100 mm in late summer. The relatively short-lived daisy *Leucochrysum albicans* completed its life cycle more quickly under elevated nutrition. The taller growing species *Calocephalus citreus* and *Linum marginale* grew rapidly under the higher nutrient regime and together contributed 80% of the forb biomass harvested in the first year (1999). However, although 75% of *Calocephalus citreus* plants in the high nutrient treatment were still alive 12 months later, they had recovered very little biomass and none of these plants was alive at the time of the third annual harvest (2001). *Linum marginale*, under high nutrition, recovered well from the first annual harvest and contributed 90% of forb biomass harvested from this treatment in year 2. However, all *Linum marginale* plants grown under high nutrition, in both harvest treatments, died following this harvest. Initially, it seemed that their death was caused by a failure to regenerate from their basal buds, as the smaller plants in the low-nutrient, biennial-harvest treatment appeared to recover. However, these plants also failed to persist for a further 12 months. This suggests that the species can recover well after cutting but is relatively short-lived, at least under the conditions of this experiment. *Linum marginale* did, however, seed profusely and large numbers of seedlings recruited and reached reproductive maturity. *Linum marginale* was abundant on the plots for the duration of the project, even though none of the original transplants survived.

Concluding comments and recommendations

This project was a first attempt to observe and measure the responses of a range of grassland species when planted at high densities in weed-free conditions. The only factors that differed between the planted communities were their access to nitrogen and the frequency of biomass reduction. Both of these factors were tested at only two levels but both were shown to have a rapid and lasting impact on the structure of the planted communities. Under the conditions of this experiment, regular applications of nitrogen and annual biomass removal in late summer produced a vigorous and attractive mixed grass sward, with *Themeda triandra* the dominant species. Under high nutrient conditions, plots harvested every second year became overlain by senescing grass vegetation that lead to the rapid exclusion of most forb species and the death of grass tussocks, including *Themeda triandra*. The forbs were more persistent in the absence of applied nitrogen, and these plots produced attractive, diverse vegetation that resembled remnant communities. However, the response to mowing frequency varied between species. *Calocephalus citreus* was included as a later-flowering species. If subjected to routine annual harvests in late summer, it would never disperse mature seeds, unless its growth form modified to produce some inflorescences below the cutting height. However, it is a robust and long-lived species. An occasional modification to the mowing schedule may allow it to release seed and recruit seedlings from time to time.

Two of the selected forb species (*Bulbine bulbosa*, *Linum marginale*) recruited freely from seed and they remain a persistent and colourful component of the plant community eight years after the initial planting and four years after the cessation of regular biomass removal. None of the other species has been observed to recruit from seed in that time, although a number of the species still persisted in small numbers from the initial planting (*Arthropodium strictum, Bulbine bulbosa, Calocephalus citreus*, *Pycnosorus chrysanthes, Wahlenbergia stricta*).

Many factors may be implicated with the success or otherwise of such plantings and a better understanding of each may be needed before diverse, native temperate grassland communities can be planted and managed reliably. These factors include the initial species mix, planting densities (particularly of the dominant tussock grasses), soil nutrient levels, the role of mycorrhizal associations in the relative competitiveness of species and the deleterious effects of exotic organisms such as fungi and grazing molluscs. Overlaying these are practical issues such as the availability of seed and establishment techniques, and the level of management sophistication needed to maintain species diversity and public acceptance.

The one certainty is that there exist powerful examples where intact remnants continue to persist, surrounded by exotic vegetation, which demonstrate all of the aesthetic and practical characteristics that would be desirable in reconstructed, urban forms of these communities (Fig. 13).

This study used only one planting density and two mowing frequencies. This produced dense, mounded grassy vegetation within which only a few of the selected forb species persisted for more than two or three years. While the vegetation was attractive even when forb diversity was low, it would require more frequently mown pathways if pedestrian access was to be maintained year round.

It is recommended that priorities for future research on planted native grasslands include:

- varying the planting density;
- increasing the range of forb species;
- increasing the population size of individual forb species;
- increasing the range of native grasses;
- increasing mowing frequency to study its effect on –
    - vegetation cover
    - grass and forb species persistence
    - year round accessibility and floral interest for pedestrians.

Figure 13 A remnant *Themeda triandra* grassland, Rokewood Cemetery, Vic., in late December. This grassland conserves a large population of the nationally endangered daisy, *Rutidosis leptorrhynchoides*. The green surface is regrowth of *Themeda triandra*, mown to provide a walkable surface for car parking.

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