Annual pasture legumes for farming systems in cool-temperate areas with summer soil moisture deficits

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Abstract

Seed softening rates of subterranean clover (*Trifolium subterraneum*) are lower in cool-temperate environments than in typical Mediterranean areas, allowing the accumulation of large seed banks. These large seed banks should enable a pasture to self-regenerate following a year of cropping in which the pasture has been removed. To test this hypothesis, a 1:1 pasture/crop rotation system was established at three sites in southern Victoria, Australia, with subterranean, balansa (*T. michelianum*), Persian (*T. resupinatum*) and arrowleaf (*T. vesiculosum*) clovers. At Hamilton, pure subterranean clover herbage yields of up to 10 t DM/ha were obtained under grazing. This was followed by wheat grain yields averaging 7 t/ha with 12.7% grain protein over three seasons. After a year of dryland cropping, the pastures self-regenerated with more than 3 000 clover seedlings/m^2. At Gnarwarre and Streatham, all four clover species were well adapted to the pasture/crop rotation in terms of their seed-seedling dynamics, with the highest regeneration after cropping at 8 000 seedlings/m^2 in balansa clover and the highest seasonal herbage production of 12.8 t DM/ha in arrowleaf clover. No nitrogen fertiliser was applied in the system.

Key words: annual legumes, cool-temperate climate, crops, seed softening rates

Introduction

Southern Australia contains about 20 million ha of sown subterranean clover (*Trifolium subterraneum*), which is well adapted to summer drought. The species is used in permanent pastures in the high (500$^+$ mm) rainfall zone (HRZ) of southern Victoria and Tasmania, where summer soil water deficits make white clover unreliable. However, there are situations and ecological niches in which subterranean clover performs poorly. Pasture legumes for newly developed agricultural systems, and ecological niches where subterranean clover fails, are being developed. New annual species, such as balansa clover (*Trifolium michelianum* Savi. var. *michelianum*), Persian clover (*T. resupinatum* L. var. *resupinatum* Gib. and Belli) and arrowleaf clover (*T. vesiculosum* Savi.) are increasingly being incorporated into pasture/crop rotation systems in the HRZ where the pasture self-regenerates after each cropping year (ley farming system).

In cool-temperate environments, subterranean clover seed softens at a much slower rate than in lower latitudes with a typical Mediterranean climate (Evans & Smith 1999). This suggests that a 1:1 pasture/crop (PC) rotation in which all regenerating pasture is killed with herbicide in the crop year should be successful in terms of: a) the high proportion of seeds in the seed bank not germinating b) the opportunity for additional hard seed breakdown during the cropping phase to promote regeneration in the following pasture year, and c) high crop yields, because of the nitrogen (N) fixed by the legume in pasture years. Gradual changes in ley farming from the "classical" system described by Puckridge & French (1983) have introduced more flexibility by including grain legumes, N fertilisers, direct drilling and stubble retention. However, it is now generally regarded that the ley system is in decline due to poor legume regeneration (Howieson *et al*. 2000). This is because in typical Mediterranean climates, seed softening rates of pasture legumes are very high. For example, more than half the seeds of a subterranean clover seed bank will soften over the first summer, and less than 20% of the initial seed population persists beyond the third summer (Taylor *et al.* 1984; Taylor & Ewing 1992). A factor affecting the viability of ley systems in southern Australia has been a decline in the legume content of pastures (Carter 1982, Carter 1992) over and above that expected by seasonal fluctuation and reduced legume component as fertility increases (Rossiter 1966). This was attributed to a decline in the quantity of legume seed in the soil (Carter 1982). In cool–temperate areas, this need not be the case, as after six years, more than 20% of subterranean clover seed, initially set, still remained in the ground in Tasmania (Evans & Hall 1995). The introduction of cropping in the HRZ may prevent the decline in legume content, as the crop will use resources, such as N, that would otherwise benefit weeds in the pasture phase.

In this paper, we examine the hypothesis that under a cool-temperate regime, a 1:1 P:C rotation is sustainable, both in terms of high crop yields and the accumulation of large banks of annual clover seed, leading to a dense, self-regenerating pasture after the cropping phase.

Materials and Methods

Hamilton

The experiment was conducted at the Pastoral and Veterinary Institute, Hamilton, in southwestern Victoria, Australia (37°49’ S, 142°04’ E), which receives an average annual rainfall of 690 mm. Monthly rainfall during the 2001 season, together with long term averages and soil moisture contents, are shown in Figure 1. A grazing experiment comparing cultivars of subterranean clover in mixtures with perennial ryegrass, sown in 1990, was put into a 1:1 P:C rotation at Hamilton in autumn 1997. The pasture treatments sown in 1990 were the subterranean clover cultivars ‘Leura’, ‘Trikkala’ and ‘Enfield’ and a mixture containing ‘Enfield’, ‘Larisa’, ‘Trikkala’ and ‘Karridale’. Subterranean clovers were sown with 5 kg/ha of ‘Ellett’ perennial ryegrass. Total sowing rate for the subterranean clovers was 10 kg/ha and plots were 0.2 ha. The experiment was arranged as a split plot design with 2 replicates, with the four base treatments of subterranean clover as the main plots and crop cultivars as subplots replicated four times. Single superphosphate (9% P; 11% S) and muriate of potash (48% K) were applied annually at 250 and 150 kg/ha, respectively, to maintain fertility. Nitrogen fertiliser was not applied. Summer and winter seed banks of subterranean clover were determined by taking 30 soil cores (50 mm diameter) from each replicate to a depth of 50 mm, followed by washing off the soil in sieves, threshing and aspirating the samples and finally hand-sorting the seed. Clover regeneration was determined each autumn by counting seedlings in 50 cores of 80 mm diameter from each replicate. Clover dry matter production was determined by cutting $0.1m^2$ quadrats inside each of eight cages per replicate. These were used in the pasture years, as the area was set stocked with sheep. The cages were moved after each cut. The grass was killed with 375 µl/ha of select (a.i. 240 g/L clethodim) in the spring of 1996. In 1997, wheat was direct-drilled, after killing the pasture with glyphosate (2 L/ha, a.i. 360 g/L) and dicamba (1 L/ha, a.i. 200 g/L). The pasture was allowed to regenerate in 1998. Again in 1999, wheat ‘Silverstar’ was sown over the whole area in May, following the chemical removal of the pasture. In 2000, the pastures were allowed to regenerate, then removed in 2001 when plots were split and sown to wheat and canola in May. Crops were harvested using plot harvesters. Plots were then grazed to ground level by sheep to reduce the amount of stubble. In summer of 1998, the residual stubbles were burnt.

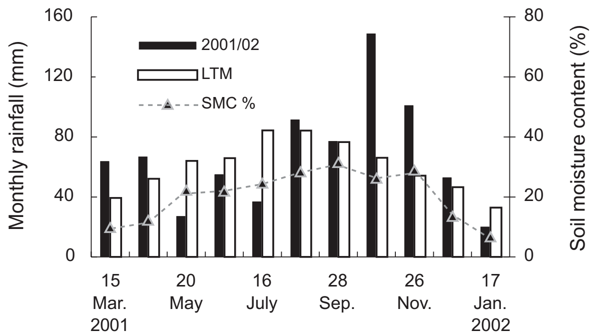

Figure 1 Monthly rainfall (mm) during mid-March 2001 and mid-January 2002, long term mean (LTM) and measured soil water content (SMC %) to 100 mm depth at Hamilton.

Streatham and Gnarwarre

The experiments were conducted during 1997-2001 in southern Victoria at Gnarwarre (38°10’ S, 144°15’ E) and Streatham (37°41’ S, 143°04’ E). The long-term average annual rainfalls at Gnarwarre and Streatham are 520 and 600 mm, respectively.

At both sites, a 1:1 P:C rotation was evaluated. A randomised complete block design with four replicates was used with four pasture legumes as treatments, including ‘Leura’ subterranean clover, ‘Bolta’ balansa clover, ‘Nitro Plus’ Persian clover and ‘Arrotas’ arrowleaf clover. Each plot measured 9 x 4.5 m, with 2 m buffer strips between replicate blocks and 1 m between plots.

The two crops (1998 canola and 2000 wheat) were direct drilled after counting seedling regeneration of the pasture and applying glyphosate and dicamba at the same rates as used at Hamilton. Sowing rates, weed control, fertiliser applications, seed preparation and DM production assessments of the pastures were described by Evans *et al.* (2002).

The density of legume seedlings was determined from quadrat counts in the first year of the experiment, 6 weeks after sowing. Starting from the second year, including the two crop phases (1998 and 2000), the density of legume seedlings from self-regeneration was determined following the autumn break prior to herbicide application. If densities were high (more than 1000 seedlings/m^2), 10 soil cores (5 cm in diameter by 5 cm deep) were taken from each plot and broken up to count seedlings; otherwise, they were counted from three 0.1 m^2 quadrats per plot.

Crops were harvested in the same way as at the Hamilton site. Legume seed reserves were determined in January each year. For subterranean clover, 15 soil cores (50 mm diameter by 50 mm deep) were taken per plot, and for the other clovers, seed reserves were determined by taking 3 quadrat cuts of 0.1 m^2 each per plot.

Data were analysed by analysis of variance (ANOVA) using Genstat 5 (Genstat 5 Committee 1997). A 2-way analysis in randomised blocks was used for all individual characters, involving 2 sites. When an F-test indicated significant differences ($P < 0.05$) between treatments, multiple comparisons were made; least significant differences (lsd) were calculated at $\alpha = 0.05$.

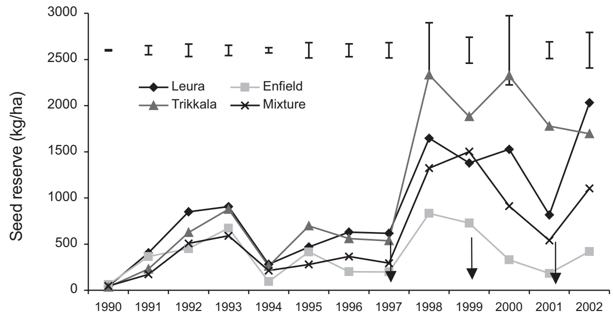

Figure 2 Seed banks of four subterranean clover cultivars in a permanent mixture with ryegrass at Hamilton (until 1996) and in a 1:1 pasture:crop rotation with wheat (1997, 1999) or canola (2001) (indicated by arrows). Vertical bars denote the values of *least significant differences (lsd)* at α = 0.05 for comparisons between the clovers.

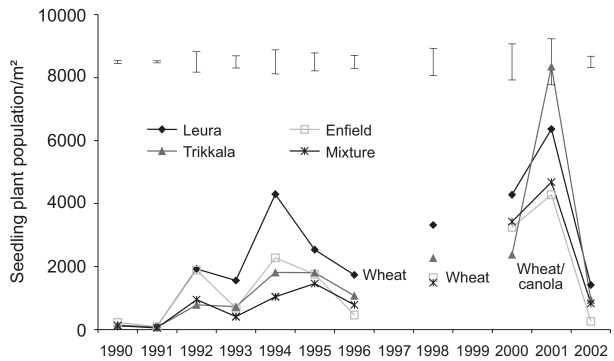

Figure 3 Autumn seedling regeneration of four subterranean clover cultivars in a permanent mixture with ryegrass at Hamilton (until 1996) and in a 1:1 pasture:crop rotation with wheat or canola (1997, 1999, 2001). Vertical bars denote the values of *lsd* at α = 0.05 for comparisons between the clovers.

Results

Hamilton

Subterranean clover seed banks exceeded 1 000 kg/ha, except for 'Enfield', and seedling numbers in the autumn following cropping averaged 3000 seedlings/m^2 (Figures 2 and 3). Clover DM production during 2000 averaged 10 t/ha for 'Leura' and 'Trikkala' under grazing, while 'Enfield' and the mixture averaged 7 and 8.7 t/ha, respectively. The average wheat yield over three seasons (1997, 1999, 2001) was 7 ± s.e. 0.23 t/ha with mean 12.7 ± s.e. 0.06 % grain protein content. In 2001, mean canola grain yields were 4 ± s.e. 0.26 t/ha.

Streatham and Gnarwarre

Average seedling population following sowing were 2200 plants/m^2 for the four pasture legumes at Gnarwarre but only 330 plants/m^2 at Streatham in 1997. At both sites, the smaller-seeded balansa and Persian clovers had populations over 2 000 plants/ m^2 whereas arrowleaf clover had populations of only 470 plants/ m^2 and subterranean clover 150 plants/ m^2 (Figure 4).

Plant populations were higher at Gnarwarre than at Streatham in 1999, but were lower at Gnarwarre than at Streatham in 2000 and 2001, with balansa clover and Persian clover regenerating at exceptionally high populations at both sites (5 530 and 2 450 plants/m^2, respectively).

In 1998, average plant populations of the four clovers from self-regeneration (prior to the application of the knockdown herbicide) were 4 120 and 5 100 plants/m^2 at Gnarwarre and Streatham, respectively. Balansa clover and Persian clover had higher populations (7 780 and 7 610 plants/m^2, respectively) than subterranean and arrowleaf clovers (Figure 4).

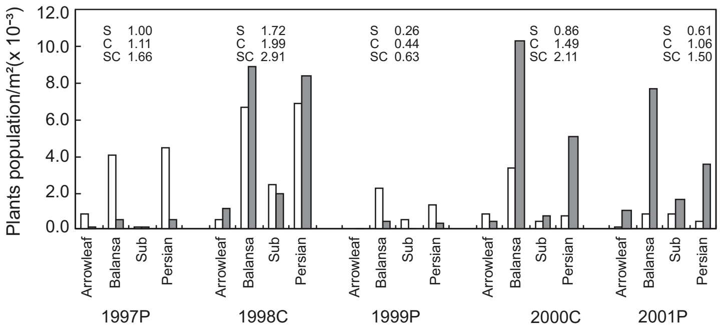

Figure 4 Plant populations from sowing (in 1997) or seedling regeneration (1998-2001) of four annual clovers in Gnarwarre (%) and Streatham (%). P denotes pasture year and C crop year, with pasture seedling numbers counted prior to being killed by herbicides before crop was sown in the cropping year. Values of *lsd* at α = 0.05 given for the five individual crop or pasture years are for comparisons between sites (S), clovers (C) and interactions of site by clover (SC).

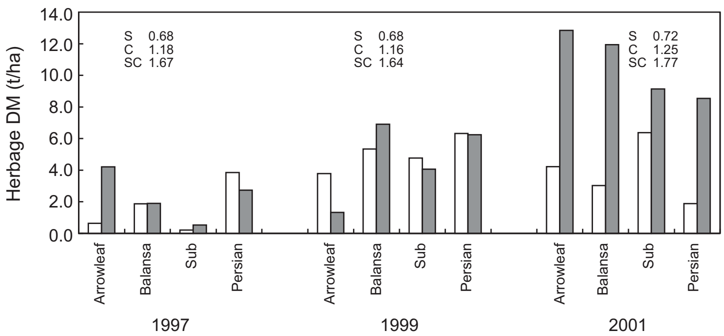

Figure 5 Seasonal pasture dry matter production (t/ha) of four annual clovers in three pasture years (1997, 1999 and 2001) at Gnarwarre (%) and Streatham (%). Values of *lsd* at α = 0.05 given for each individual pasture year are for comparisons between sites (S), clovers (C) and interactions of site by clover (SC).

In 1999, average clover populations from self-regeneration were 1 030 and 215 plants/m^2 at Gnarwarre and Streatham, respectively. Balansa clover had the highest population (2 230 plants/m^2) at Gnarwarre, whilst arrowleaf clover had the lowest population at both sites.

In 2000, the average population of the four clovers was 4 170 plants/m^2 at Streatham, compared with 1 350 plants/m^2 at Gnarwarre. Balansa had the highest average population (6 810 plants/m^2) over the two sites.

In 2001 after the 2000 crop phase, the clovers maintained 3 440 plants/m^2 at Streatham and 610 plants/m^{2}at Gnarwarre. Over the two sites, balansa clover had the highest population of 4 250 plants/m^2 (Figure 4).

The four clovers produced similar herbage DM yields at both sites in 1997 and 1999, but differed ($P < 0.01$) in 2001. In 1997, the average annual herbage production at Streatham was 2.24 t DM/ha, slightly higher than at Gnarwarre (1.82 t DM/ha). Arrowleaf clover produced the highest yield (4.2 t DM/ha) at Streatham (Figure 5).

In 1999, the average annual herbage production by the four clovers was 5.0 t DM/ha at Gnarwarre and 4.6 t DM/ha at Streatham. Persian and balansa clover produced the highest yields (6.3 and 6.1 t DM/ha, respectively).

In 2001, very high herbage production was recorded for all four clovers at Streatham, with an average of 10.6 t DM/ha, which was higher than at Gnarwarre at 3.86 t DM/ha (Figure 5). Arrowleaf clover produced the highest total production at Streatham of 12.84 t/ha.

In 1997, the average seed yields of the four clovers were 190 kg/ha at Gnarwarre, which was lower than at Streatham (550 kg/ha). Balansa clover produced the highest seed yields at both sites (410 and 922 kg/ha, respectively).

In 1999 the average seed yields of the four clovers were 1 040 kg/ha and 1 070 kg/ha at Gnarwarre and Streatham. Subterranean clover produced higher seed yields (1 530 kg/ha) than balansa clover (1 010 kg/ha) or arrowleaf clover (950 kg/ha).

Seed yields of the 4 clovers in 2001 were comparable to those in 1997 at both sites. Balansa clover at Streatham again produced the highest seed yields (1 345 kg/ha).

Crop grain yields

Wheat averaged 5 t/ha at Streatham and 2.5 t/ha at Gnarwarre. Generally the best yielding crops followed the highest yielding pasture the previous year, regardless of pasture species used (Figure 6).

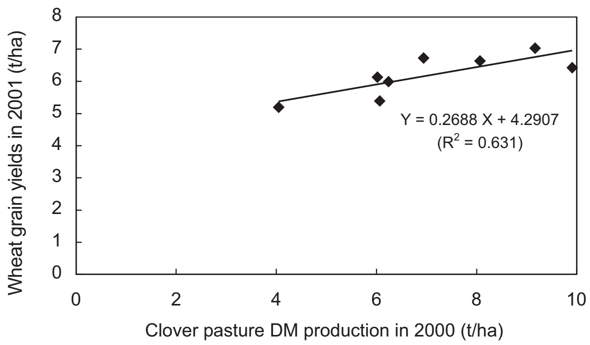

Figure 6 Relationship between grain yields of 'Silverstar' wheat in 2001 (t/ha) and herbage dry matter (DM) production in 2000 (t/ha) using the pooled data from Gnarwarre and Streatham.

Discussion

In terms of pasture persistence, under a 1:1 P:C regime in this study, the 4 clovers performed well at all sites as demonstrated by their seed yield and regeneration. The data also showed that as long as the seedling population reached acceptable levels (150 plants/m^2), there were no significant associations between plant population and total annual herbage DM produced. The very high populations achieved by Persian and balansa clovers are a function of their small seed size (1 mg against 7 mg for subterranean clover). These high populations would have given these species an advantage in winter DM production (Evans *et al.* 2002) but not in spring. This is because 'Leura' subterranean clover (and especially 'Arrotas' clover) has a longer growing season than the Persian and balansa clovers used in this experiment. The seedling populations were higher at Gnarwarre than Streatham in the first year. However, because seasons are shorter at Gnarwarre due to its lower rainfall, populations were greater at Streatham over time. At Hamilton, the poor performance of 'Enfield' was probably because it flowers approximately one month earlier than cultivars such as 'Leura' and consequently does not use the growing season completely. 'Enfield' is also extremely soft-seeded (Evans & Smith 1999), and this trait would put it at a disadvantage in a pasture/crop rotation system.

Pasture and crop yields appear to be higher under this system, compared with continuous crop or pasture (Karlen *et al.* 1994), most likely due to higher soil fertility and improved weed and disease control. It is estimated that for every tonne of legume DM produced, 25 kg of N is fixed (Peoples *et al*. 1998). Pastures in our experiment, therefore, could have fixed up to 300 kg N/ha/year. In a 1:1 P:C rotation system, the crop uses the nitrogen fixed by the pasture, instead of promoting the dominance of weeds, as can be the case in a continuous pasture situation. Subterranean clover seed yields can be around 30% higher in the absence of ryegrass (Evans & Hall 1995). Keeping the pasture in a pure state is critical in this system. Interestingly, under permanent pasture until 1996, seedling regeneration in autumn and summer seed banks had values around half those observed under the P:C rotation system at Hamilton (Figures 2 and 3).

A cropping rotation can increase clover content in the pasture; a decline is more likely to occur under continuous pasture rather than in a P:C rotation. For the system to succeed, a knockdown spray must be applied before sowing, and crops must always be direct-drilled. This prevents burying the pasture seed too deeply. Crop residues must be reduced as much as possible by grazing and if necessary, burning, because mulch on the soil surface can severely reduce annual legume seedling establishment.

At all sites in this study, there was a positive association between clover herbage yields and subsequent crop yields (r^2=0.63). Persian and balansa clovers are well adapted to winter waterlogged soils. Persian clover performs particularly well in alkaline soils while balansa clover has a wide range of adaptation. Arrowleaf clover has the capacity to grow well into the summer and can extend the growing season by approximately 2 months over and beyond late-maturing subterranean clover, particularly in wet years like 2001. This clover should play a major role in filling feed gaps in summer and autumn.

Conclusion

The introduction of a 1:1 pasture crop rotation provides the opportunity for increased hard seed breakdown to promote the regeneration of annual legumes, compared with long term pastures where the rate of hardseed breakdown may be too slow, particularly in cooler environments. An advantage of the 1:1 rotation appears to be the effective use of N fixed by the preceding pasture as high crop yield, and protein levels were achieved without the addition of N fertiliser. Such a system has the potential to provide economic benefits to farmers as well as to increase management options.

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