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Perennial pastures for recharge control in temperate drought-prone environments.
1. Productivity, persistence and herbage quality of key species

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Abstract. Perennial-based pasture swards potentially offer land managers the capacity for recharge control in temperate cropping zone environments to satisfy the dual role of fostering increased agricultural productivity and reduced deep drainage. This study evaluated the productivity, persistence and herbage quality of lucerne (\textit{Medicago sativa} L.), phalaris (\textit{Phalaris aquatica} L.), chicory (\textit{Cichorium intybus} L.), perennial veldt grass (\textit{Ehrhata calcycina} Sm.), grazing brome (\textit{Bromus stamineus} E. Desv.), plantain (\textit{Plantago lanceolata} L.), Rhodes grass (\textit{Chloris gayana} Kunth), tall fescue (\textit{Festuca arundinacea} syn. \textit{Lolium arundinaceum} Schreb. syn. \textit{Schedonorus phoenix} (Scop.) Holub.) and cocksfoot (\textit{Dactylis glomerata} L.) in 2 contrasting environments in the cropping zone of southern New South Wales (NSW), Australia. Performance of 2 cultivars with contrasting levels of summer activity of each of the latter 2 species was also assessed. Lucerne was the most productive species evaluated, producing 54-85\% more herbage than phalaris, the next most productive species. Lucerne was also the most persistent species with a higher basal frequency than all other species during the experimental period and, averaged across samplings, had the highest crude protein (22.3\%) in the leaf and stem of any species. Chicory herbage had the highest dry matter digestibility (76.7\%) and ash content (15.1\%) and lowest neutral (35.4\%) and acid detergent fibre content (21.8\%) compared with other species. The more summer dormant cultivars of cocksfoot (cv. Kasbah) and tall fescue (cv. Fraydo) were both found to be more persistent than their semi-summer active counterparts (cvv. Currie and Demeter, respectively), demonstrating the importance of summer dormancy for the persistence of both species in these environments. Tall fescue cv. Fraydo was equally persistent yet produced only 42-51\% of the cumulative biomass of phalaris over 5 years, indicating that tall fescue is not a viable species in these drought-prone environments, nor were plantain and grazing brome due to their inferior productivity and persistence. The study highlighted the lack of viable perennial
pasture options currently available in cropping zone environments of southern NSW other than lucerne, phalaris and the summer dormant cultivar of cocksfoot, Kasbah. Chicory and perennial veldt grass, with further breeding and selection under Australian environmental conditions, could have potential to be viable perennial pasture options for the cropping zone of southern NSW.

**Additional keywords:** Competition, digestibility, metabolisable energy, ash content, crude protein, subterranean clover, summer dormancy, orchardgrass, alfalfa,

**Introduction**

The proposition that perennial pasture species can mitigate the risk of environmental degradation attributable to deep drainage across agricultural landscapes is broadly quoted in contemporary scientific literature. There is little doubt that perennial pasture species have demonstrated a greater capacity to create a larger ‘dry soil buffer’ compared to annual crop and pasture species in a range of seasons and environments (Angus, et al. 2001; Bell, et al. 2006; Brown, et al. 2005; Heng, et al. 2001; Latta, et al. 2001; Lolicato 2000; Ridley, et al. 1997; Sandral, et al. 2006; Ward, et al. 2006).

The success of perennial pastures to substantially reduce deep drainage across the landscape is dependent upon perennial species being abundant across the landscape (Black, et al. 1981; Roberts, et al. 2009). Perennial pasture species therefore need to be broadly adopted on-farm to have a significant impact on deep drainage control in temperate Australia. There are a complex range of factors impacting upon the decision of individual farmers to adopt (or not to adopt) changed practices on-farm (Pannell, et al. 2006), such as the replacement of traditional annual-based pastures with perennial-based pastures. However, regardless of the complexities associated with the decision making process, it seems clear that economic benefit remains a key priority for land managers in considering the adoption of a new technology (Bathgate and Pannell 2002; Pannell, et al. 2006). In this context, the broader adoption of perennial pastures across the agricultural landscape will not be possible without demonstrating some level of economic benefit associated with perennial species. In order to develop more environmentally sustainable farming systems it is therefore important not only to quantify the soil drying characteristics of individual species, but also to quantify their productive attributes to help inform the decision making process and validate the economic merits of perennial species.
Lucerne (*Medicago sativa* L.) is known to contribute a number of desirable attributes to production agriculture. It is a legume that commonly fixes about 20-25 kg/ha of nitrogen for every tonne of above-ground biomass produced (Peoples, et al. 1998), reducing the need for nitrogen fertiliser inputs in both the pasture and crop phases. It is a versatile high quality forage that is suited to fodder conservation or rotational grazing by livestock (Griffiths and Burns 2004; Lodge 1991; Machado, et al. 2007). Although some cultivars vary in winter activity (Humphries and Hughes 2006), lucerne is generally summer active, producing high quality out-of-season feed for livestock in environments that typically rely on winter-spring rainfall for forage production (FitzGerald 1979; Wolfe, et al. 1980). It has the capacity to persist in the medium rainfall cropping belt of south-eastern Australia for in excess of 20 years, although stands of lucerne lasting 3-7 years are more common (Lodge 1991).

However, it is important that alternative pasture species be found to replace or compliment lucerne in production systems. First, from a biosecurity perspective, invasions from pests and diseases will inevitably occur from time to time and a farming system that is totally reliant upon only one species is increasingly vulnerable (Cocks 2001). A series of invasions from pests and diseases has already been experienced in Australia as recently as the 1970’s which exposed the vulnerability of the lucerne industry to diseases such as phytophthora root rot and anthracnose, and to 2 pests which had not previously been reported in Australia, spotted alfalfa aphid (*Theroaphis trifolii*) and blue-green aphid (*Acyrthosiphon kondoi*) (Irwin, et al. 2001). The lack of tolerant cultivars and the subsequent reduction in area under lucerne (Auricht 1999) serves as a reminder of the risks involved in relying on only one species. If perennial pastures are to be used as a key tool to reduce the risk of soil degradation attributable to deep drainage, it is critically important that farming systems be robust and mitigate the risk of annihilation from pests and diseases.

Secondly, there is a need to increase the options available to growers to optimise the production of their enterprise. Despite lucerne being a robust and broadly adapted species under Australian field conditions, it has some substantial agronomic limitations: (i) a lack of tolerance of acid (Bouton 1996) or (ii) waterlogged soils (Christian 1977), (iii) poor persistence under uncontrolled grazing (Humphries, et al. 2006; Lodge 1991), (iv) a highly competitive habit that reduces the regeneration of annual pasture species (Dear, et al. 2000; Dear, et al. 1998) leading to a high proportion of bare ground in lucerne stands, and (v) the risks to livestock health associated with bloat and red-gut (!!! INVALID CITATION !!!).

Thirdly, a constraint commonly exists within farming enterprises which places an upper limit on the land area on-farm that can be sown to any one pasture species without a reduction
in whole farm profit regardless of how broadly adapted and productive that species is (Robertson 2006). There may be a range of reasons contributing to this upper limit, such as the need to vary seasonal biomass production to maintain continuity of feed supply or to vary the diet of grazing livestock to avoid animal health disorders. Computer-based modelling supports this justification with the area on-farm under perennial-based pastures increasing and farm profitability being maintained when kikuyu (*Pennisetum clandestinum* Hochst. ex Chiov.) was included on a simulated farming enterprise in Western Australia in addition to lucerne (A. Bathgate unpublished data). The combination of this factor and the constraints mentioned above may in part explain why lucerne only occupies 1-4% of the land area to which it is theoretically suited in Australia, based on soil and climate information (Irwin, et al. 2001; Robertson 2006).

We propose that the above limitations of lucerne can be at least partially overcome with the incorporation of alternative perennial species which collectively possess a broader range of agronomic characteristics. This study examined the productivity, persistence and herbage quality of phalaris (*Phalaris aquatica* L.), chicory (*Cichorium intybus* L.), perennial veldt grass (*Ehrhata caledyina* Sm.), grazing brome (*Bromus stamineus* E. Desv.), plantain (*Plantago lanceolata* L.), Rhodes grass (*Chloris gayana* Kunth), tall fescue (*Festuca arundinacea* syn. *Lolium arundinaceum* Schreb. syn. *Schedonorus phoenix* (Scop.) Holub.) and cocksfoot (*Dactylis glomerata* L.) in two environments in the cropping zone of temperate Australia compared to lucerne. The soil drying capacity of these species is reported in the subsequent paper (Hayes et al. 2010).

**Materials and methods**

**Sites and treatments**

Two field experiments were established in 2004 in the medium rainfall cropping zone of south-eastern Australia. Experiment 1 was located south of Cootamundra, New South Wales (NSW), on a Yellow Dermosol (Isbell 1996). The soil surface (0-0.1 m) at this site was acidic with pH$_{Ca}$ (1:5 soil/0.01M CaCl$_2$) 4.5 and aluminium comprising 19% of the effective cation exchange capacity. The experiment was sown to monocultures of 10 perennial pasture treatments arranged in a randomised complete block design with 4 replicates. Plot size was 6 × 4 m and pasture species and sowing rates were: lucerne cv. Aurora (6 kg/ha), chicory cv. Grasslands Puna (5kg/ha), grazing brome cv. Gala (25 kg/ha), phalaris cv. Landmaster (4 kg/ha), cocksfoot cv. Currie (4 kg/ha), perennial veldt grass cv. Mission (8.5 kg/ha), plantain cv. Tonic (4 kg/ha), Rhodes grass cv. Pioneer (6 kg/ha), and two tall fescue treatments cvv.
Demeter and Fraydo (12.5 kg/ha each). Seed was sown into a cultivated seed bed using a cone seeder prior to the beginning of spring (26 August) in 2004. Lucerne seed was inoculated with commercial rhizobia and lime pelleted prior to sowing.

Experiment 2 was located at the Wagga Wagga Agricultural Institute, NSW. The soil was a Red Kandosol (Isbell 1996) with pH_{Ca} 4.4 and 6% exchangeable aluminium. Treatments sown at Experiment 2 included: lucerne cv. Aurora (6 kg/ha), chicory cv. Grasslands Puna (4 kg/ha), phalaris cv. Landmaster (4 kg/ha), cocksfoot cvv. Currie and Kasbah (4 kg/ha each), and tall fescue, cvv. Demeter and Fraydo (12.5 kg/ha each). Cultivars Kasbah and Fraydo were less summer-active than Currie and Demeter, respectively. Plot size was 6 × 4 m and seed was sown into a cultivated seedbed using a cone seeder. The experiment was sown on 21 May 2004 and all treatments were sown with subterranean clover (*Trifolium subterraneum* L.) cv. Seaton Park LF (4 kg/ha). Subterranean clover and lucerne seeds were inoculated with appropriate commercial rhizobia and lime pelleted prior to sowing.

**Agronomic management**

Both experiments received an application of 180 kg/ha starter fertiliser (14.9% N, 13% P, 10.5% S) at sowing. In subsequent years both experiments were top-dressed with an application of 160 kg/ha of superphosphate (8.8%P, 11%S) in autumn annually. Nitrogen fertiliser (granulated urea, 46% N) was applied at 100 kg/ha annually at Experiment 1 only. Applications of pesticides to both experiments were confined to years 1 and 2 of the experimental period with the first application of insecticide occurring within 1 week of sowing as a preventative measure against insect damage. Herbicides were applied to both experiments as required to control specific weeds. Neither experiment was grazed in the establishment year. In subsequent years grazing would typically occur immediately following an assessment of herbage yield, at which time the sites would be heavily grazed with a high stocking rate of adult sheep. The experiments would then be mowed to ensure herbage in all treatments was defoliated to a uniform height if required. A residual of 500-800 kg/ha of above-ground biomass remained on the plots following defoliation.

**Plant density and herbage yield**

Initial seedling density of perennial species was assessed in both experiments approximately 9 weeks after sowing using a 1 m² quadrat, replicated twice per plot. Plant density was measured at fixed locations in the second year in July. From year 3 onwards, basal frequency
was measured to estimate relative plant density of the perennial species as many established plants were too large to reliably distinguish individuals. This was done by placing a 1 m² quadrat, divided into squares 0.1 x 0.1 m, over the sampling area and counting the percentage of squares occupied or partially occupied by the base of a sown perennial plant.

Herbage yield of Experiments 1 and 2 was assessed on 14 and 12 occasions, respectively, during the experimental period and usually coinciding with the end of a season. A visual technique was used for the assessment of total biomass which involved splitting each plot into 6 cells to account for within-plot variability and giving each a score between 1 and 10. Scores of each cell were averaged to give a mean plot score. Scores were calibrated at each assessment by taking 10-12 representative cuts using a 0.1 m² quadrat. The coefficient of determination of the herbage yield calibrations (R²) at both experiments ranged from 0.77 – 0.99 (data not shown).

The proportion of sown perennial species, annual legumes and weeds was assessed at the same time as herbage yield using the dry weight rank technique (Jones and Hargreaves 1979; 't Mannetje and Haydock 1963) replicated 10 times within each plot. Botanical composition data were used to determine the herbage yields of the respective components of each sward.

Herbage quality analysis
Herbage quality samples were taken from Experiment 1 only. During 2005-06, samples of sown perennial plants were taken from each plot on 7 occasions within a 12 month period, namely early spring (12 September), mid spring (13 October), late spring (9 November) and early summer (9 December) in 2005 and early autumn (23 March), early winter (8 June) and late winter (22 August) in 2006. Due to the late break of season samples on 8 June 2006 actually were taken prior to the first substantial rains of the growing season. Regardless, all perennial species except grazing brome were active and had produced adequate herbage for sampling at this time. At each sampling time, perennial plants were selected at random in each plot and cut at a height of around 2 cm above the soil surface. Care was taken to ensure samples were not contaminated with herbage from other species. Some treatments could not be sampled on all occasions due to insufficient quantities of herbage available. Sampling of the Rhodes grass treatment was restricted to a small number of individual plants. All samples were stored in a cooled insulated container immediately after sampling for transporting back to the laboratory where they were dried for approximately 48 hours at 60ºC before being ground through a 1 mm laboratory mill.
Samples were analysed for ash content (method 1.10R), acid detergent fibre (1.8A[a]), neutral detergent fibre (1.9A[a]) and crude protein (1.5R) as described by AFIA (2006). Estimates of dry matter digestibility (DMD) and dry organic matter digestibility (DOMD) were obtained using near infra-red (NIR) with calibrations based on the rumen fluid technique (Tilley and Terry 1963). However, the NIR method relies upon pre-determined calibrations which are not always accurate for the less common species. Therefore values obtained using the Pepsin-cellulase method (method 1.7R; AFIA 2006) have been tabulated for comparison in Appendix 1. Most of the discussion throughout the paper refers to values obtained using NIR method. Metabolisable energy (ME) was calculated according to method 2.2R (AFIA 2006) from DOMD values using the following formula:

\[
ME = 0.203 \times \text{DOMD} - 3.001
\]

**Seasonal conditions**

The experimental period coincided with an extended period of drought widespread across much of south-eastern Australia. Total annual rainfall received during the experimental period at Cootamundra, approximately 10 km north of the Experiment 1 site, was 472 mm (2004), 637 mm (2005), 243 (2006), 566 mm (2007) and 445 mm (2008), compared to the long-term median annual rainfall of 617 mm (BOM 2009).

Total annual rainfall received at Experiment 2 was consistently below the long-term average 530 mm (402, 476, 272, 382 and 414 mm in 2004-08, respectively). The rainfall in 2001-03, 3 years preceding the experiment, was also below average (data not shown). It was the 4th driest year in 108 years of records in 2006 (year 3 of the experiment) at the Wagga Wagga Agricultural Institute and was found to be a severe drought in terms of plant survival and growth across the region. Irrigation was applied to the entire experiment during year 3 only using a series of dripper lines laid on the soil surface approximately 0.3 m apart with 2.0 L/hr pressure compensating nozzles placed at 0.3 m. They were connected in a sealed system that covered one replicate (18 × 12 m) and a flow meter was installed on the supply line to measure the quantity of water being delivered to each replicate. Total moisture (rainfall + irrigation water) received in 2006 was 622 mm.

**Statistical analysis**

Variables measured at the plot level were analysed by a one-way analysis of variance using Genstat Release 11.1 (Gilmour, et al. 2006; Lawes Agricultural Trust 2008) with ‘perennial species’ as treatment. A repeated measure analysis of variance which fitted ‘time’ as an additional factor was applied to the herbage yield and botanical composition data only. Where
appropriate, a linear mixed model was fitted using the method of restricted maximum likelihood (REML) to take account of spatial variability which included ‘perennial species’ as fixed terms. Random terms included ‘replicate’ and ‘replicate × plot’. Row and column effects were fitted as required.

**Results**

*Plant density and basal frequency*

*Experiment 1.* All perennial species except Rhodes grass established successfully with densities of up to 148 perennial plants/m² 9 weeks after sowing. By July in year 2, the perennial plant density of all lines declined to below 40 plants/m² (Table 1). Plantain and grazing brome failed to persist at adequate densities beyond year 2, registering basal frequencies of less than 10% in June 2006. There was a decline in perennial plant basal frequency in all treatments from years 3 to 5 (Table 2). Lucerne and chicory maintained the highest basal frequency in year 5.

*Experiment 2.* Perennial plant establishment ranged from 53 plants/m² in lucerne to 370 plants/m² in tall fescue cv. Fraydo. Within 12 months perennial plant density of all species had declined, ranging from 4 plants/m² in tall fescue cv. Demeter to 38 plants/m² in chicory (Table 1). Perennial plant basal frequency also declined in all treatments from years 3 to 5 with lucerne again registering the highest basal frequency in the final year of experimentation at the second location (Table 2).

(Insert Tables 1 & 2 near here)

Annual legumes at Experiment 2 initially established at densities between 32-56 plants/m². Regeneration of annual legumes in year 2 was between 724-2989 plants/m² with densities greater in the lucerne and chicory swards that received a selective grass herbicide (Table 3). Annual grass regeneration in year 2 was found to be significantly less in the Demeter tall fescue sward (476 plants/m²) compared with the remaining perennial grass treatments (mean 1289 plants/m²; Table 3).

(Insert Table 2 near here)

*Herbage yield*

*Experiment 1.* Total cumulative available herbage during the 5 year experimental period ranged from 24 t DM/ha in the perennial veldt grass and grazing brome swards to 40 t/ha in the lucerne swards (Table 4). Volunteer grasses, mainly annual ryegrass (*Lolium rigidum* Gaudin), barley grass (*Hodeum leporinum* Link) and silver grass (*Vulpia* spp.), and legumes, mainly subterranean clover, contributed in excess of 53% to total available biomass in all
swards, except the lucerne sward where volunteer species only contributed 35% of available biomass. Lucerne yielded 85% more cumulative biomass than the next most productive sown perennial species, phalaris, but there was no significant difference in cumulative herbage production of phalaris and chicory (Table 4). Chicory and lucerne were clearly the most summer active species tested, contributing appreciable amounts to sward production during the summer periods (Table 5). Perennial veldt grass consistently demonstrated the highest level of summer activity of all the temperate grass species tested, as evidenced by the relatively high contribution to total sward biomass production made by this species at the harvests taken during or shortly after summer.

**Experiment 2.** Lucerne yielded 54% more cumulative biomass than the next most productive species, phalaris, but again there was no significant difference in cumulative herbage production of phalaris and chicory (Table 4). However, this did not translate into a significant difference in total cumulative sward production between perennial pasture treatments with each treatment producing 29-31 t/ha from 2004-08. Annual legumes, mainly subterranean clover, contributed 38-44% of total cumulative available herbage in the perennial grass swards and 48-55% in the lucerne and chicory swards, respectively. Volunteer annual grasses, mainly annual ryegrass, barley grass and silver grass, contributed 28-34% of cumulative biomass in the perennial grass swards and 14-15% in the lucerne and chicory swards, respectively (Table 4).

(Insert Tables 4 and 5 near here)

**Herbage quality (Experiment 1)**

The crude protein, DMD, ME, neutral detergent fibre, acid detergent fibre and ash content of the herbage differed with perennial species and varied between sampling times. Excluding Rhodes grass, the DMD and ME of all species tended to be at their highest during winter (June-August) and lowest in summer (Table 6). Chicory was the exception, registering its highest reading for both parameters in mid-spring (October). Crude protein was highest in all species during winter and early spring. Lucerne had the highest mean crude protein levels averaged over the whole growing season although at certain times such as late spring and in March protein levels in chicory were equivalent to lucerne. Herbage quality in terms of DMD, ME and crude protein was lowest for all species in early summer (Table 6). Averaged across all sampling times, chicory had the lowest neutral and acid detergent fibre values, and the highest DMD and ash content.

(Insert Table 6 near here)
Discussion

Persistence

Lucerne was the most persistent species evaluated in these drought-prone environments, justifying its current dominant role in mixed farming systems (Dear, et al. 2010). Lucerne had the highest basal frequency in years 3-5 in both experiments (Table 2). Phalaris, chicory, Kasbah cocksfoot and Fraydo tall fescue had lower basal frequencies than lucerne but may still be adequately persistent in these environments, particularly in a series of years with more favourable climatic conditions. Currie cocksfoot and perennial veldt grass persisted adequately until year 3 of the experiment so may be suitable species for short-phased rotations. The least persistent species in these environments were plantain, grazing brome and Demeter tall fescue. The grazing regime imposed on the experiments was very lenient with pastures typically receiving a high intensity grazing followed by a 10-12 week period of recovery. This is far more lenient than a typical grazing regime in the region, particularly in times of drought, so it is the view of the authors that if species were unable to persist in this study they are going to be even less likely to persist in a farm situation.

The comparison between the 2 contrasting cultivars of these species clearly showed that the cultivars of both species with higher levels of activity over summer, Demeter tall fescue and Currie cocksfoot, were less persistent than their more dormant counterparts, highlighting the importance of summer dormancy for the persistence of tall fescue and cocksfoot in these cropping zone environments. This finding is consistent with previous research from North America and Europe (!!! INVALID CITATION !!!). However, increased persistence was not always shown to be of benefit in terms of production. The comparison between the 2 tall fescue cultivars at Experiment 2 showed the more summer active cultivar, Demeter, failed to persist beyond year 1 in contrast to cv. Fraydo which persisted to at least year 3. Yet, the cumulative herbage production during the entire experimental period of cv. Demeter was 59% greater than that of cv. Fraydo (Table 4) although this difference was not significant ($P > 0.05$). It therefore appears that the increased persistence in summer dormant tall fescue came at a substantial cost to total production. Comparing the different cultivars of cocksfoot and tall fescue with similar levels of summer activity, our study indicated that tall fescue was generally less persistent in these environments than cocksfoot. Therefore, whilst it is true to say that a more summer dormant cultivar of tall fescue may increase the persistence of that species in drier environments (Malinowski, et al. 2005; Norton, et al. 2006b), perennial
grass persistence would likely be increased even further if a suitable cultivar of cocksfoot, such as Kasbah, were chosen instead.

This argument can be extended to include the other temperate perennial grass species, phalaris and perennial veldt grass, even though our study did not include contrasting cultivars of these species. The phalaris cultivar included in the current study, Landmaster, was chosen for its adaptability to acid soil environments and could be considered to be moderately summer active (Oram, et al. 2009). This cultivar, which is perhaps not the most persistent phalaris cultivar under drought, still proved to have equal or greater persistence than any other grass species evaluated. Considering Fraydo tall fescue only yielded 51% and 42% of cumulative phalaris herbage mass at Experiments 1 and 2, respectively (Table 3), it could be concluded that even a semi-summer active cultivar of phalaris is a more appropriate option for this environment than a Mediterranean cultivar of tall fescue. There is little evidence to suggest that other commercially available Mediterranean-type cultivars of tall fescue offer substantial production advantages over cv. Fraydo (Reed, et al. 2008a).

Rhodes grass, the only subtropical species tested in our study, failed to establish in this experiment. The unreliable establishment is a common constraint to the broader adoption of these otherwise drought-hardy species being more widely utilised in temperate environments (Reed, et al. 2008b). The lack of summer rain during the experimental period most likely restricted its ability to thrive and colonise. Rhodes grass is a common component of roadside vegetation in this region where increased runoff and a lack of grazing contributes to its competitiveness. The Rhodes grass treatment in Experiment 1 provided useful herbage quality data for that species, which was otherwise a ‘naturalised’ pasture stand. The low productivity of this stand compared with lucerne highlights the importance of successful pasture establishment in production enterprises.

Productivity
Lucerne was the most productive species evaluated, producing 54-85% more cumulative biomass than phalaris, the next most productive species. The superior productivity of lucerne observed in our study is in part attributable to its superior persistence. First, by definition a species that is more persistent has more opportunity to add to cumulative production although as previously mentioned, increased persistence did not translate into increased production in the case of tall fescue at Experiment 2. Second, its superior persistence made it possible for lucerne to opportunistically add to production by utilising out-of-season rainfall, when the plant density of most other species had declined to negligible levels (Table 5). For example,
lucerne was one of the few perennial species still present at the experimental sites when above average monthly rainfall was received at both sites in late 2007 and early 2008 (Hayes, et al. 2010). Much of the justification for including perennial-based pastures into crop and livestock production enterprises is to help stabilise annual herbage production through the greater utilisation of unseasonal rainfall (Oram and Hoen 1967). A perennial species that fails to persist in a given environment clearly has limited capacity to utilise unseasonal rainfall in the longer term.

Phalaris, chicory, perennial veldt grass and Kasbah cocksfoot were also found to be moderately productive in these environments. Chicory most closely emulated lucerne in its timing of biomass production with both species being most active in spring and summer (Table 5). However, the total productivity of chicory was inferior to that of lucerne, largely due to its inferior persistence relative to lucerne. Total productivity of phalaris was similar to that of chicory at both locations, but phalaris was more active during winter and spring compared to lucerne and chicory. Perennial veldt grass was very similar to Currie cocksfoot both in terms of persistence and timing of biomass production.

In general, chicory was found to have the highest herbage quality of all species, registering the highest average dry matter digestibility and the lowest levels of acid detergent fibre and neutral detergent fibre. The ash content of chicory herbage was found to be 31% and 51% higher than lucerne and phalaris, respectively, which is perhaps explained by the high herbage mineral content of chicory relative to these species (Hayes, et al. 2008). However, given the relatively high metabolisable energy values in the chicory herbage (Table 6), in addition to many previous reports of the benefits of chicory to ruminant nutrition (Li and Kemp 2005), it is unlikely that the high ash content reported in our study would have any adverse implications to livestock productivity. Lucerne, the only legume species evaluated, registered the highest average crude protein undoubtedly due to increased nitrogen supply to this species through biological N₂ fixation.

The herbage quality of cocksfoot was generally found to be similar or higher relative to the other temperate grass species. The crude protein levels in cocksfoot (16.2%) were on average higher ($P < 0.05$) than Fraydo tall fescue (13.5%), phalaris (14.6%) and Demeter tall fescue (14.7%), but similar to perennial veldt grass (17.1%). Cocksfoot also had a high average dry matter digestibility relative to those grass species. This observation would appear to dispel the common perception amongst producers that cocksfoot has a lower nutritive value than alternative perennial grass options. Perennial veldt grass was the grass species with the highest acid and neutral detergent fibre contents while Fraydo tall fescue and phalaris tended
to be the lowest for these attributes. More work is required to determine whether the relatively low ash content observed in Fraydo tall fescue is related to a low mineral composition of this species.

**Competition with annual weeds**

One of the interesting findings of this study was the marked ability of Demeter tall fescue to suppress annual grass weeds. Annual grass weed regeneration at Experiment 2 in the Demeter tall fescue sward was 63% lower compared with the remaining temperate perennial grass swards in year 2, and 61% less than in the Fraydo tall fescue sward (Table 3). As annual grasses were not sown in this experiment, their emergence was reliant upon background seed populations which was relatively even in all other grass treatments (1215-1375 plants/m²). The suppressive effect of cv. Demeter on grass weeds was likely to be due to its strong competition in spring resulting in a reduction in annual grass seed set as Demeter tall fescue was by far the most productive perennial species in year 1 producing 4.4 t/ha of above-ground biomass accounting for 86% of total sward production (Table 5). Demeter tall fescue did not persist itself in adequate densities to have a suppressive effect on annual grass weed regeneration in autumn of year 2 when new seedlings were emerging.

The ideal perennial species for mixed farming systems would be highly competitive against weeds in the establishment year, and be sufficiently persistent to survive in swards lasting 3-5 years. The apparent competitive advantage of Demeter tall fescue in the first year highlights a significant challenge for the future incorporation of perennial grasses into cropping environments. Demeter tall fescue is one of the least likely of all the perennial grasses evaluated in this study to be utilised in the cropping zone due to its inferior persistence. However, the other perennial grass species that were more persistent were shown to be far less competitive with grass weeds in the establishment year. One of the major reasons for utilising perennial grasses in cropping environments is to provide an opportunity to control weeds in cropping rotations (Oram and Hoen 1967). However, given many of the problem weeds in crop rotations are annual grass weeds and given that there are few selective herbicide options available for controlling annual grass weeds in establishing perennial grass pastures (Dear, et al. 2006), incorporating perennial grass species that are not competitive with annual grass weeds may prove problematic for many growers. A challenge for future research will therefore be to find a balance between perennial grasses that are highly competitive in the establishment year but are sufficiently persistent to remain in the sward in a 3-5 year pasture phase. A mixture of species that includes highly vigorous and competitive
species in year 1 alongside less vigorous but more persistent species has not been found to provide an effective solution to this conundrum (Virgona and Hildebrand 2007).

It was interesting to note that there was little difference in the regeneration of annual legumes between the 5 temperate perennial grass swards. It appears that Demeter tall fescue was in less direct competition for resources with the annual legumes than it was with the annual grasses. The reason for this is not immediately clear. Dear et al. (2007) found that in mixtures with lucerne, phalaris and Wallaby grass (Austrodanthonia richardsonii Kunth), subterranean clover seed yield was inversely related to perennial herbage yield suggesting that in our study, assuming the same principle applied to Demeter tall fescue, subterranean clover seed yield should have been suppressed in the same way annual grass seed set was. However, the same study also found that regeneration of subterranean clover was negatively related to perennial plant density in autumn. This may suggest that in our study, a possible reduction in subterranean clover seed yield could have been partially offset by increased clover seedling survival due to lower Demeter tall fescue densities in autumn of year 2. More work is required to understand the population dynamics of these species more fully.

Opportunities for further development
This study highlighted a number of instances where further development could increase the perennial pasture options available to farmers in low rainfall environments.

Chicory. Aside from lucerne, chicory was amongst the best performing species in this study despite the very dry seasonal conditions experienced at both locations and the cultivar used was selected in Palmerston North, New Zealand (Rumball 1986) where seasonal conditions are typically more favourable for plant growth. However, two main agronomic limitations remain with chicory in low-rainfall cropping environments. Firstly, chicory was found to have inferior persistence compared with lucerne and some of the grass species. This problem is likely to be exacerbated in situations where grazing is less well controlled due to the high palatability of this species (Li and Kemp 2005). As discussed previously, increased persistence is important for maximising productivity but is also important in maximising the utilisation of soil water (Hayes, et al. 2010) and for maximising the economic viability of pasture improvement programs on farm (Scott, et al. 2000). There are no chicory cultivars currently available that have been developed under Australian conditions, suggesting there may be an opportunity to select for more persistent chicory ecotypes for low rainfall environments.
Secondly, chicory production during winter was found to be inferior to that of lucerne and low winter production is a common criticism of lucerne swards. Lucerne at Experiment 1 was shown to out-yield chicory by 4-fold in August of year 3 when basal frequency of the two species was similar. A 3-fold difference was also observed in the herbage availability of the 2 species in early spring of year 5 also in Experiment 1, and lucerne had doubled the chicory herbage mass measured in early September in year 2 at Experiment 2 (Table 5). Chicory is known to be sensitive to cold growing conditions (Li, et al. 1997), so it is therefore reasonable to expect that the feed deficit experienced in chicory pastures would be even more severe in wetter and colder years than were experienced in our study. Low winter production is therefore likely to be a key constraint to the broader adoption of chicory. Further work is required to develop strategies to overcome this limitation, such as the inclusion of chicory cultivars with higher levels of winter activity than cv. Grasslands Puna (Hayes, et al. 2006) or the incorporation of vigorous winter active companion legumes.

*Kasbah cocksfoot.* Kasbah cocksfoot was the second most persistent species at Experiment 2 behind lucerne. This cultivar is known for its strong summer dormancy enabling it to persist in environments that experience very long and dry summers (Norton, et al. 2006a). In Experiment 2 Kasbah cocksfoot was the highest yielding species on 5 out of the 12 occasions on which an assessment of biomass was made compared to phalaris, which at no time registered the highest yield on any given date (Table 5). However, cumulative herbage of Kasbah cocksfoot at this location (5.5 t/ha) was less than phalaris (7.0 t/ha). This can largely be explained by differences in herbage production between the two species in the spring of the establishment year. Kasbah cocksfoot was the lowest yielding of all sown perennial species in year 1 at Experiment 2, producing only 15% of the biomass produced by phalaris at that time. Given the importance of initial seedling vigour in terms of weed suppression (see previous section) as well as for productivity, it seems clear that the adaptation of Kasbah cocksfoot to these environments would be improved if selections could be made from within the existing population for increased seedling vigour.

*Perennial veldt grass.* Cultivar Mission is effectively the only commercially available cultivar of this species. Results from Experiment 1 demonstrated that it had similar plant persistence to Currie cocksfoot. However, perennial veldt grass ranked 4th in production behind lucerne, phalaris and chicory, although differences in cumulative production between perennial veldt grass, phalaris, chicory, Currie cocksfoot and Fraydo tall fescue were not significant ($P < 0.05$, Table 4). Perennial veldt grass offered the additional benefit of producing significantly more forage than the other temperate perennial grass species in
autumn (particularly March and June year 3) prior to the breaking autumn rains (Table 5). Perennial veldt grass is a species that has the distinction of being identified in at least 4 previous agronomic evaluations in Australia as ‘warranting further investigation’ (INVALID CITATION !!!!) and Flower (1993) cited in Reed et al. (2008b), but has never been promoted in front of phalaris, cocksfoot and tall fescue in plant development programs. Our study concludes that a species that has undergone comparatively little breeding and selection over the last 50 years but was still the 4th most productive species under unfavourable seasonal conditions certainly warrants additional investigation to explore the full potential of this species for drier environments.

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