Australian experience with cool season annual legumes - the challenge to develop environmentally sustainable farming systems

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Abstract

Australian farming systems have traditionally relied on annual legumes such as subterranean clover (*Trifolium subterraneum*) and annual medics (*Medicago* spp.) in either short-term pastures in rotation with crops or permanent pastures to provide low cost biologically fixed N and a high quality forage for livestock. The role of legumes in farming systems is now being reassessed because of the recognition that their extensive use is associated with widespread soil acidification, loss of species diversity in native pastures and increasing dryland salinity. In the future, annual legumes are more likely to be sown in mixtures

with deep-rooted perennial pasture species, both in permanent pastures and in rotation with crops, to improve hydrological balance in the landscape. As a result, there is a change of direction in annual legume selection and breeding programs within Australia with a greater focus on the ability of legumes to coexist with perennial species, as well as on characteristics such as an extended growing season and deeper rooting habit to exploit subsoil water. There is also a trend towards increasing the diversity of annual legume species sown in pasture mixes to better exploit paddock variation and variable seasonal conditions.

Selection for ease of seed harvestability is becoming

Figure 1 The agroecological zones where annual legumes are currently sown in southern Australia, subdivided on the basis of soil type and rainfall distribution.

increasingly important to lower seed costs and reduce environmental damage associated with seed harvesting. The economic pressure to increase the intensity of cropping has led to an increased use of high density legume (HDL) forages grown as a one year disease break and N source, and the sowing of oat–legume mixtures for high quality forage or silage.

New annual legume species and cultivars recently released or under development include *Trifolium glanduliferum*, *T. michelianum*, *T. resupinatum*, *T. isthmocapum*, *T. purpureum*, *T. hirsutum*, *T. formosum*, *T. diffusum*, *Biserrula pelecinus*, *Ornithopus sativus*, and *Melilotus albus*.

Key words: annual legumes, balansa clover, biserrula, dryland salinity, gland clover, Moroccan clover, Persian clover, purple clover, serradella, subterranean clover

Introduction

Annual temperate pasture legumes such as subterranean clover (*Trifolium subterraneum*) or annual medics introduced from the Mediterranean region have been the main source of N in farming systems of southern Australia for over 60 years. The area sown in these legumes is estimated to exceed 17 million ha. Their dual role as a high quality feed for livestock, combined with their ability to restore soil N for both grazing and cropping industries, has ensured their central role in pastures across southern Australia. In extensive areas of non-arable hill country and tableland regions, the combination of subterranean clover and superphosphate has resulted in large increases in pasture productivity and stocking rates on native pastures. The area sown to annual legumes in Australia is shown in Figure 1. The area is subdivided based on soil type, pH and rainfall and these form the target zones for breeding new annual legume cultivars by the National Annual Pasture Legume Improvement Program (NAPLIP). NAPLIP is a consortium of State Departments of Agriculture, Universities and CSIRO, and is financially supported by producers through the Grains Research and Development Corporation and Australian Wool Innovation.

Subterranean clover is also sown in mixtures with cocksfoot (*Dactylis glomerata*), phalaris (*Phalaris aquatica*), perennial ryegrass (*Lolium perenne*) or tall fescue (*Festuca arundinacea*) in permanent pastures, but difficulty in readily establishing perennial grasses in rotation with crops has limited

their use in cropping systems. Lucerne (*Medicago sativa*) is grown on about 3 million ha, mainly on better soils in the cropping zone, its further adoption being limited by lack of tolerance to waterlogging, soil acidity and inappropriate grazing practices.

A new environmental perspective

Farming systems incorporating annual legumes initially proved highly productive, however the increased supply of nitrogen and the inefficient use of rainfall by shallow rooted annual species led to extensive soil acidification (Helyar & Porter 1989, Ridley *et al.* 2001), loss of species diversity in native pastures and the emergence of dryland salinity on a continental scale. The National Land and Water Resource Salinity Audit (NLWRA 2001), for example, recently estimated that 5.7 million ha are at risk or affected by dryland salinity in Australia in 2001, and the area is predicted to increase to 17 million ha in the next 50 years (Table 1). The present financial cost is estimated to be \$230 million p.a. in lost production and damage to infrastructure.

Soil acidification and rapidly increasing dryland salinity have been attributed to the inability of current farming systems based on shallow rooted annual species to cope with the change in water use and N cycling resulting from the removal of deep-rooted native perennial grasses, shrubs and trees. Although annual legumes from the Mediterranean region have proven well adapted to the southern Australian environment, their short growing season and shallow rooting behaviour resulted in a significant increase in the movement of water into the subsoil. This leads to large increases in deep drainage, acidification of the soil profile, as a result of nitrate leaching, and the mobilising of ancient stores of salt (Ridley *et al.* 1990) (Figure 2). Once the salt is mobilised in the ground water it either drains into rivers through aquifers, or if subsurface flows are interrupted, comes to the surface, causing salt scalds in lower lying areas.

The unsustainability of current farming practices based on annual species requires a revolution in landuse. New farming systems that better mimic the water use and nutrient cycling of the original native vegetation (Stirzaker *et al.* 2000) are required. Current estimates suggest that at least 40% of the landscape in southern Australia will need to be covered by deep-rooted perennials, including lucerne, perennial grasses and herbs such as chicory (*Cichorium intybus*), if deep drainage to the ground water is to be reduced from current levels of 50–150 mm p.a. to

around 4–7 mm p.a. (Figure 2). This is the estimated deep drainage that occurred under the original vegetation prior to clearing and the level considered necessary to achieve hydrological stability. Growers require a new range of perennial pasture plants that can be readily established in crop rotations and are tolerant of soil acidity, salinity, waterlogging or heavy grazing that limit use of existing perennial species. Similarly, an array of annual legumes that can successfully coexist with these perennial plants to provide the necessary N input must be developed.

While the problems associated with the widespread use of annuals in the landscape became apparent, there was also the view that most of the natural genetic potential of subterranean clover and annual medics had been largely exploited. Selection programs have made significant progress in lowering oestrogen levels, increasing disease resistance and manipulating hard seed levels, either raising them as insurance against “false breaks” or lowering them to compensate for the slower rates of softening in cool temperate environments (Evans & Hall 1995). To make further progress towards the goals of increased species diversity and greater resilience to variable seasonal conditions, it was accepted that a new spectrum of annual legume species need to be domesticated to exploit a greater array of adaptive and reproductive mechanisms (Cocks & Bennet 1998). These new annual species will also need to coexist with perennials, which will form the basis of pastures in the future.

In this paper recent progress in understanding the stresses experienced by annuals coexisting with perennials, new uses of annual legumes and recent cultivar releases, are discussed.

New selection criteria for annual legumes

Selection of annual legumes to coexist with perennial grasses and lucerne

Experience suggests that maintaining a vigorous annual legume component in phalaris or lucerne stands can be difficult, particularly in lower rainfall environments (<600 mm) (Dear *et al.* 2001a). Typically, the annual legume component declines in mixtures with lucerne, leading to bare areas between plants and low winter sward productivity. Similarly, older phalaris and cocksfoot pastures often have a low annual legume component leading to N deficiency and a decline in feed quality and the vigour of the grasses.

Table 1 Areas (ha) with a high potential to develop dryland salinity in Australia.

State	1998/2000	2050
New South Wales	181 000	1 300 000
Victoria	670 000	3 110 000
Queensland	not assessed	3 100 000
South Australia	390 000	600 000
Western Australia	4 363 000	8 800 000
Tasmania	54 000	90 000
Total	5 658 000	17 000 000

Source: National Land and Water Resources Audit 2001.

Figure 2 Diagrammatic representation of the change in deep drainage in the southern Australian landscape as a result of: 1) the removal of native vegetation, and 2) adoption of pasture/crop farming systems based on shallow-rooted annual pastures and crops. Expected drainage under perennial-based pastures is also shown.

To understand why annual legumes decline in mixtures with perennials it is important to identify the stages of the lifecycle that are susceptible to competition. The size of the seed pool at the end of summer is highly correlated with the number of clover seedlings that emerge in the following autumn (Dear *et al.* 2000). Hence any negative effects of perennial components on seed set (B in Figure 3) will decrease the proportion of annual legume in the subsequent sward. Perennials have been thought to reduce seed set of annuals through increased competition for soil water in spring during flowering and seed set. However recent work has shown that although perennials such as lucerne and phalaris dry the profile

Figure 3 Subterranean clover life cycle stages that are susceptible to competition from perennial components of the sward. A=seedling survival, B=seed set.

below the annual root zone (Ridley *et al.* 1977), they have little effect on the rate of drying of that part of the soil profile (0–40 cm) exploited by annuals in spring (Dear *et al.* 2000).

There is good evidence, however, that shading of annual legumes in spring does suppress seed set, with the level of shading being a function of perennial density and biomass (Dear *et al.* 2000). Thus, minimising shading through grazing management is important to maximise clover seed set and long-term legume content.

Figure 4 The percentage of clover seedlings that survived following an early autumn (late February) start to the season in mixed swards containing lucerne or perennial grass compared to clover monocultures. Source: Dear & Cocks 1997.

Note: Additional seedlings emerged in annual plots after initial germination.

Annuals also appear particularly vulnerable to competition from perennials during seedling establishment in autumn (A in Figure 3). Competition from perennials during clover seedling emergence reduces the availability of mineral N, light and water, and as a result severely restricts subterranean clover seedling growth rates and survival (Table 2) (Dear & Cocks 1997; Dear *et al.* 1998). Significantly lower levels of available soil N in grass swards (Table 2) can restrain the growth of clover seedlings that have yet to effectively nodulate and rely heavily on mineral N for early growth.

The availability of soil water in perennial swards during autumn germination and emergence of annual

Table 2 The effect of lucerne and phalaris (relative to pure clover swards) on weight and turgor of subterranean clover seedlings following an early start to the growing season and differences in available soil N at cotyledon stage.

Pasture type	Seedling wt (mg/plant)	Seedling relative water content (%)	Available soil N ($\mu\text{g N/g soil}$)
	15 March		11 March
Subterranean clover only	2.02	74.5	32.7
Phalaris/subterranean clover	0.99	33.8	12.6
Lucerne/subterranean clover	0.56	29.3	12.6
Least significant difference ($\alpha=0.05$)	0.32	0.22	-

Source: Dear & Cocks 1997

Figure 5 Effect of perennial grasses and lucerne on clover seed reserves and clover populations in winter in 4-year-old mixed swards compared with annual swards in a 600 mm rainfall environment. Source: Dear *et al.* 2001a.

legumes also influences their successful establishment. Lucerne and cocksfoot respond rapidly to late summer – early autumn rain when temperatures are still relatively high and can rapidly dry out the soil surface when subterranean clover is germinating, decreasing seedling turgor, size and survival (Table 2). Later in autumn, when prevailing temperatures are lower, phalaris is less restricted by high temperature dormancy and responds more rapidly, whereas lucerne is less responsive to these conditions. The rapid drying of the top 100 mm of soil by perennials can be an advantage if it prevents premature germination in late summer, but a disadvantage following autumn rainfall, where it increases the probability of “false breaks” (Dear & Cocks 1997). The significant decrease in clover seedling survival in swards with perennials compared with pure annual swards following an early autumn rain is apparent in Figure 4. In annual swards, clover seedlings can continue to germinate and emerge over

an extended period of time following rain, but the more rapid drying of the surface soil in perennial swards narrows the window for germination.

Once the “true” break of season occurred, clover seedling numbers in perennial swards were still significantly lower than in pure annual swards. The close relationship between seedling density and summer seed reserves reinforces the importance of maximising seed set in the previous summer (Figure 5).

Most Australian studies of annual and perennial mixtures have used subterranean clover as the annual component. There is some work, however, that suggests some annual legume species, such as *T. hirtum*, *T. cherleri* and *T. pauciflorum*, are better able to coexist with lucerne than subterranean clover (G. Sandral pers. comm.). These findings are supported by a study by Dear *et al.* (2003a), who found the proportion of balansa clover (*Trifolium michelianum*) and annual medics increased significantly and the proportion of subterranean clover declined when lucerne was present in a sward. Future research should focus on identifying the attributes that allow some annual species to better coexist with perennials.

Increasing water use by annual legumes

Increasing the proportion of perennials in the sward is only one option for increasing water use. Alternative strategies include growing new annual legume species, such as biserrula (*Biserrula pelecinus*) and serradella, which may be better able to exploit deep subsoil water. Another approach is to grow later maturing species, such as purple clover (*T. purpureum*), with a longer growing season and the capacity to use water in late spring. A third strategy is to utilise alley farming techniques or wide row spacing, where annual legumes are combined with deep-rooting perennial grasses, perennial legumes or trees and shrubs, but where spatial arrangement is used to minimise interspecies competition while still achieving the desired hydrological outcomes (Stirzaker *et al.* 2002). In response to these needs, the newly formed Cooperative Research Centre for Plant-based Management of Dryland Salinity (PBMDS) is directing in excess of \$2.5 million/p.a. towards the selection of a range of new deep-rooted perennial legumes and grasses and the development of appropriate high water use farming systems.

Increased species diversity

The great diversity of annual legumes found growing in close association in natural Mediterranean landscapes is in stark contrast to the monocultures or binary mixtures sown in Australian farming systems. More agronomists should seek to mimic this natural diversity in sown pastures to increase their adaptability to variations in aspect, soil type and drainage within a paddock, as well as to increase their resilience to seasonal variability. For example, by sowing three or more different legume species, such as balansa clover, subterranean clover and gland clover, in a mixture with perennial pasture legumes or grasses to provide more resilient and adaptable swards.

Selection of salt and waterlogging tolerant species

The increasing incidence of dryland salinity and rising water tables has increased the focus on selection of annual species with increased salt and waterlogging tolerance. These include selection for a greater range of maturities within balansa and Moroccan clovers (*T. isthmocarpum*), because both species exhibit superior tolerance to salinity and waterlogging. Selection of a low coumarin cultivar of sweet clover (*Melilotus albus* Medik.), 'Jota', is also well-advanced and targeted at saline and waterlogged soils (Evans & Kearney 2003).

Balansa clover has been one of the most successful of these new waterlogging and saline tolerant species developed, with the area sown in southern Australia estimated to be over 1.5 m ha (Craig & Ballard 2000). The release of the early flowering balansa clover cultivar, 'Frontier', (Craig *et al.* 2000) has extended its range into lower rainfall areas (350–500 mm) of the wheatbelt. The later maturing cultivar 'Bolta' is adapted to higher rainfall regions (>600 mm). Balansa clover has proven persistent in mixtures with lucerne on heavy clay soils prone to waterlogging (Dear *et al.* 2003a) and is becoming an important species for saline discharge areas.

Another new waterlogging tolerant legume close to release is 'Napier' subterranean clover. A member of the yannicum subspecies, it has been selected for improved winter and spring productivity and is expected to replace 'Meteora' and 'Larisa'.

Selection for ease of seed harvest

Seed costs are a major factor restricting the adoption and use of new annual legumes. There is also public concern about the dust caused by harvesting subterranean clover burr. Thus researchers are intent on developing aerial seeding legume species that can be more easily harvested by farmers (Nutt *et al.* 1999). Small areas of pasture legumes within a paddock can be fenced off and allowed to flower and the seed harvested for use on-farm. Newly released annual species such as gland clover (*T. glanduliferum*), French serradella (*Ornithopus sativus*), and biserrula, are readily harvested by conventional machinery and offer significant potential for low cost seed production (Nutt *et al.* 1999).

The release of 'Cadiz' French serradella (Anon 1997) has been a major advance for sandy and loam soils where it has proven more able to exploit soil water deeper in the profile. The ability to readily harvest seed on farm with conventional crop harvesters has also assisted in its rapid adoption in the Western Australia and South Australia wheatbelts. The lack of hard seed in 'Cadiz' is a limitation in areas where summer rain causes premature germination and depletes seed reserves. Two new cultivars ('Margurita' and 'Erica') have been developed with increased levels of hard seed to overcome this problem (Dear *et al.* 2003b).

Biserrula is another new small-seeded annual species, with a deep-rooting habit that grows longer into spring than subterranean clover (Carr *et al.* 1999; Loi *et al.* 1999; 2000; 2001). It is being used successfully to control herbicide resistant ryegrass, as due to differences in palatability, sheep only graze the biserrula after consuming any ryegrass present.

The first cultivar of gland clover, 'Prima', was released in 2002 following a selection program by Brad Nutt at CLIMA (Dear *et al.* 2001b). It is unique for its very high level of resistance to blue-green aphids and red-legged earth mites (Wang *et al.* 1999), both serious pests of pastures in Australia.

Use of legumes as short term forages

High density legumes (HDLs)

The need for a high-yielding, high N fixing, one-year legume crop, which can also act as a disease break, has increased the sowing of legume combinations called high density legumes (HDLs). Typically three long season annual legume species are combined in a mix that conveys increased flexibility. It allows the

Table 3 Herbage yield (t DM/ha) and invitro digestibility (%) in parenthesis of legume or ryegrass monocultures and legume–oat mixtures at 3 cutting times.

Forage	Time of cut					
	Early season		Mid-season		Late season	
	Yield (t/ha)	Digest (%)	Yield (t/ha)	Digest (%)	Yield (t/ha)	Digest (%)
<i>Pure legumes</i>						
Berseem clover	4.2	(76)	7.1	(60)	6.2	(50)
Subterranean clover	4.8	(76)	5.6	(73)	6.0	(70)
Arrowleaf clover	4.6	(80)	7.2	(74)	7.1	(67)
Purple vetch	6.2	(74)	9.8	(68)	9.2	(63)
Field peas	6.9	(72)	11.7	(74)	13.2	(74)
Ryegrass	7.7	(75)	11.2	(60)	8.5	(50)
<i>Mixtures</i>						
Berseem clover + oats	6.5	(68)	11.0	(61)	13.3	(57)
Subterranean clover + oats	7.7	(72)	12.0	(65)	10.8	(60)
Arrowleaf clover + oats	7.3	(70)	10.2	(63)	9.8	(59)
Purple vetch + oats	8.3	(71)	14.8	(65)	11.1	(56)
Field peas + oats	9.5	(74)	14.8	(68)	12.8	(60)
Ryegrass + berseem	5.4	(75)	8.5	(65)	8.4	(57)

Source: Dear *et al.* (1991)

legumes to be grazed in autumn–winter, closed up for hay or silage production, and depending on the season, the late regrowth can be grazed in November–December. Typical mixes and sowing rates include a combination of 3 kg/ha arrowleaf (*T. vesiculosum*), 3 kg/ha Persian (*T. resupinatum*) and 6 kg/ha berseem clover (*T. alexandrinum*).

Oat–legume mixtures

An alternative to these legume mixes, is the sowing of annual legumes with oats where maximising forage yield is a priority. Annual legumes such as berseem, arrowleaf or Persian clovers, vetches or field peas are grown with oats. Our research has shown that including oats significantly increases total biomass production but at the expense of forage quality (Table 3) (Dear *et al.* 1991).

Conclusions

Annual legumes will continue to play an important role in Australian farming systems, but the composition of pastures is expected to progressively change to address the sustainability issues associated with annual pastures. A greater diversity of annual legume species will be sown, often in

mixtures with deep-rooted perennial grasses and legumes, to improve water use, reduce nitrate leaching and increase the resilience of pastures to environmental stresses. Greater emphasis will need to be given to maintaining annual legumes in mixtures with perennials to ensure the proportion of annual legume remains within desired limits. This will require a greater understanding of factors influencing competition between annuals and perennials in mixed swards and population dynamics in complex species mixtures.

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