New annual pasture legumes for southern Australia - 15 years of revolution

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Abstract

Fifteen years ago subterranean clover and annual medics dominated annual pasture legume sowings in southern Australia. Since then a number of sustainability and economic challenges to existing farming systems have emerged, exposing shortcomings in these species and the lack of legume biodiversity. Public breeding institutions have responded to these challenges by developing new annual pasture legumes with adaptation to both existing and new farming systems. This has involved commercialisation of new species and overcoming deficiencies in traditional species. Traits incorporated include deeper root systems, protection from false breaks, a range of hardseed levels, acid-tolerant root nodule symbioses, tolerance to pests and diseases and provision of cheap seed, through ease of seed harvesting and processing. Ten new species (French serradella, biserrula, sulla, gland, arrowleaf, and crimson clovers and sphere, button and hybrid disc medics) have been commercialised, while improved cultivars have been developed of subterranean, balansa, rose, Persian and purple clovers, burr, strand and barrel medics and yellow serradella. Further species and cultivars are likely to be released soon. The contributions of genetic resources, rhizobiology, seed ecology, plant pathology and entomology have been paramount to this success. A farmer survey has shown widespread adoption of the new pasture legumes, particularly in Western Australia, and this trend is likely to increase due to the increasing cost of inorganic nitrogen, the need to combat herbicide-resistant crop weeds and improved livestock prices. Mixtures of these legumes allows for more robust pastures buffered against variable seasons, soils, pests, diseases and management decisions. This paper discusses development of the new pasture legumes, their potential use and deficiencies in the current suite.

Key Words

Pasture legumes, plant breeding, cultivars, crop rotations, ley farming, phase farming, nitrogen fixation

Introduction

The constraints posed by the mediterranean-type climate and the inherently low soil fertility of southern Australia have resulted in development of farming systems incorporating annual pasture legumes native to the Mediterranean basin (Howieson *et al.* 2000). In combination with the use of superphosphate, pasture legumes have led to improved soil fertility, increased crop yields in both mediterranean (Puckridge and French 1983) and cool temperate (Zhang and Evans 2004) climatic areas and to greater animal production (Doyle *et al.* 1993). Howieson *et al.* (2000) list a range of benefits for incorporating pasture legumes into farming systems. These include their ability to fix atmospheric nitrogen (with benefits for both companion pasture species and subsequent crops), ability to increase soil fertility and structure, and capacity to break disease and pest life cycles of crops when grown in rotation. More recent research has demonstrated the use of specialist pasture legumes for weed control in crop rotations (Loi *et al.* 1995a; 1995b).

Ley farming has been the traditional crop rotation system in Western Australia (Underwood and Gladstones 1979) and South Australia (Puckridge and French 1983), whereby the pasture phase is reliant on self-regeneration of annual legumes from hardseeds which remain dormant during a cropping phase of one or two years. Since the 1970s grain legumes have been increasingly incorporated into many of these cropping rotations in place of pasture legumes. In the cropping areas of south-eastern Australia phase farming has been the most common crop rotation system, whereby 3-6 successive crops are followed by a period of legume-dominated pasture (Reeves and Ewing 1993). In this system farmers must re-sow the pasture after each cropping sequence. In higher rainfall and irrigated areas pastures tend to be permanent or semi-permanent, supporting meat, wool and dairy production. Annual legumes form the basis of most of these pastures, but perennials are often included in the most favoured rainfall or irrigated environments. More recent studies have, however, demonstrated the feasibility of a ley cropping system in the high rainfall areas of south-eastern Australia (Zhang and Evans 2004).

Annual pasture legumes prior to the 1990s

Annual pasture legume options in southern Australia were largely confined to subterranean clover (*Trifolium subterraneum*) and annual medics (*Medicago* spp.) prior to 1990. Subterranean clover is estimated to have been sown over 20 million hectares in Australia (Donald 1970) and consists of three subspecies[1]: ssp. *subterraneum* (adapted to well-drained, acid soils); ssp. *yanninicum* (adapted to waterlogged, acid soils); and ssp. *brachycalycinum* (adapted to neutral-alkaline cracking or stony soils). The two keys to its widespread use are its tolerance of heavy grazing and a suite of cultivars differing in flowering time, enabling it to be grown in environments with a wide range of growing season lengths. Annual medics have been widely sown on neutral-alkaline soils in low-medium rainfall areas. Their high levels of hardseededness makes them well adapted to ley farming systems. The main species sown have been *Medicago truncatula*, *M. littoralis* and *M. polymorpha* var. *brevispina*, with limited sowing of *M. scutellata*, *M. rugosa*, and *M. tornata*. The acid-tolerant *M. murex* was also commercialised in the mid 1980s (Oram 1990). Other commercially available species with cultivars registered in Australia were yellow serradella (*Ornithopus compressus*), balansa clover (*T. michelianum*), Persian clover (*T. resupinatum*), rose clover (*T. hirtum*), cupped clover (*T. cherleri*) and slender serradella (*O. pinnatus*) (Oram 1990). A purple clover (*T. purpureum*) cultivar was released in 1971 (Oram 1990), but failed commercially due to its extreme susceptibility to clover scorch (*Kabatiella caulivora*) disease.

Annual pasture legume improvement programs and the drivers for change

National breeding and selection programs were established for subterranean clover in 1983 and for annual medics in 1987. Breeding and early generation selection of subterranean clover was conducted by the Department of Agriculture and Food Western Australia (DAFWA) and of annual medics by the South Australian Research and Development Institute (SARDI). Additional field evaluation of advanced lines was conducted by New South Wales Department of Primary Industries (NSWDPI), Department of Primary Industries Victoria (DPIV), Department of Primary Industries and Fisheries, Queensland (QDPIF) and the

Tasmanian Institute of Agricultural Research (TIAR)/Tasmanian Department of Primary Industries, Water and Environment (TDPIWE).

Since the early 1990s a number of sustainability and economic challenges to existing farming systems have emerged, exposing shortcomings in the traditional species and a lack of legume biodiversity. Ewing (1989) first highlighted the need for a new emphasis on annual pasture legume breeding and selection to solve particular farming system problems, rather than continuing the breeding of subterranean clover and annual medics alone. The main drivers influencing breeding and selection directions are discussed in detail by Cocks and Bennett (1999), Ewing (1999), Howieson *et al.* (2000), Dear (2003) and Loi *et al.* (2005a) and include: 1) poor adaptation of subterranean clover and annual medics to difficult soils, particularly deep, acid sands and soils subject to waterlogging or salinity; 2) poor adaptation of subterranean clover to false breaks; 3) sustainability challenges for the ley farming system, notably herbicide-resistant weeds, seed bank depletion of soft-seeded pasture legumes from increased cropping frequencies, and residual deleterious effects on legume growth from crop herbicides; 4) environmental concerns from soil erosion caused by vacuum harvesting subterranean clover and annual medic seeds; 5) the need for cheap seed for re-sowing pastures, particularly for short-term phase pastures; 6) the need for specialist fodder legumes; 7) the need for longer-season plants to maximise productivity in long-growing season areas; 8) the need for deeper-rooted plants to reduce groundwater recharge and the potential for dryland salinity; 9) the need for greater annual legume diversity within paddocks to stabilise productivity; and 10) the need to overcome deficiencies in existing subterranean clover and annual medic cultivars, particularly susceptibility to clover scorch and root rot diseases in midseason and late flowering subterranean clovers, soft-seededness in subterranean clovers for cropping rotations and aphid susceptibility in annual medics. The most significant farming system change was advocated for medium and low rainfall cropping areas, in which ley crop rotations would be replaced by phase rotations with long crop and pasture phases (Reeves and Ewing 1993).

These new challenges demanded an expansion in the range of pasture legume options with traits to meet the needs of current and prospective farming systems. The Cooperative Research Centre for Legumes in Mediterranean Agriculture (CLIMA), based at the University of Western Australia, was formed in 1992 and initiated much of the development of alternative annual legume species (Loi *et al.* 2005a). In 1997, the National Annual Pasture Legumes Improvement Program (NAPLIP) was formed as a partnership of the organisations involved in the existing national subterranean clover and annual medic programs with CSIRO Tropical Crops and Pastures, the Grains Research and Development Corporation and Australian Wool Innovation. Breeding and selection for acid soils was largely conducted by DAFWA and CLIMA, for alkaline soils by SARDI, for high rainfall environments by DPIV and for tropical legumes by CSIRO, with each of the collaborating States undertaking field evaluation of advanced breeding lines as appropriate. The formation of NAPLIP heralded the shift in emphasis towards developing plants to solve pasture production problems and to provide new farming system opportunities (Ewing 1999). Other pasture improvement projects have also been conducted by individual organisations in parallel to NAPLIP.

New cultivars

Forty nine annual pasture legume cultivars and three of the short-lived perennial species, *Hedysarum coronarium* (sulla), have been developed by public institutions since 1991 (Table 1). Sulla has been included in the list, as it was developed as part of evaluation programs to select plants for phase farming systems. New cultivars have been developed in 25 species, including 14 new species that have either been commercialised or are candidates for release, subject to final testing. Twenty five cultivars have been bred and selected by DAFWA and CLIMA, 17 by SARDI, four by DPIV, and one each by QDPIF, NSWDPI and TIAR/TDPIWE, with 36 having been developed through national collaboration as part of the NAPLIP and fore-runner programs. Evaluation is also underway for two new species, *Lotus ornithopodioides* and *Melilotus siculus*, which may be commercialised in the near future. Access to germplasm from the Australian Trifolium and Annual Medicago Genetic Resource Centres, coupled with major inputs from the disciplines of rhizobiology, pasture ecology and physiology, plant pathology, entomology and plant chemistry, have been the cornerstones of cultivar development.

Maturity ratings (Table 1) give some indication of which rainfall zones these cultivars are best adapted to. In broad terms, ratings of 1-2 indicate suitability for low rainfall zones with short growing seasons. In much of southern Australia, this represents the low rainfall wheatbelt, which has a high emphasis on cropping. Ratings of 3-4 indicate suitability for medium rainfall zones, which are predominantly mixed farming, while ratings of 5-7 indicate suitability for long growing season areas, much of which are permanent or semi-permanent pastures. Of the cultivars released, 10 are best suited to low rainfall areas, 22 to the medium rainfall zone and 20 to the high rainfall zone. Cultivar development for the low rainfall zone has been more difficult, due to limited availability of early flowering germplasm. Table 2 lists adaptive features and optimum farming system suitability of the species for which cultivars have been developed or are undergoing advanced evaluation.

While at first glance, it appears that a large number of cultivars and species have been developed, it is important to note the large number of potential agro-ecological niches that need to be filled across southern Australia. Consideration needs to be given to the multi-dimensional matrix of soil type (texture, pH, and fertility), environmental considerations (waterlogging, salinity), length of growing season and farming system. To illustrate this, the simple scenario of 3 growing season lengths, (short, medium and long), 2 soil pH reactions (acidic and alkaline), 3 soil texture types (sands, loams and clays) and 4 farming systems (ley, phase, permanent pastures and fodder production) gives a total of 72 possible combinations and excludes specific niches such as deep infertile sands, waterlogging and salinity. The need to increase biodiversity within paddocks through the use of mixtures further accentuates the need for a large suite of cultivars.

Table 1. Publicly-bred annual pasture legume cultivars developed in Australia since 1991, their origin, relative maturity and year of initial release to seed growers. The short-lived perennial, sulla, is also included.

Species	Cultivar	Origin	Maturity[$]	Release year	Breeding institute[%]
New species commercialised in Australia					
Biserrula pelecinus	Casbah	Morocco	3	1997	CLIMA
?	Mauro	Sardinia	4	2002	DAFWA[N]
Hedysarum coronarium	Wilpena	Synthetic	7	2005	SARDI[N]
?	Moonbi	Synthetic	6	2005	SARDI[N]
?	Flamenco	Tunisia	6	2006	CLIMA
M. orbicularis	Bindaroo	Libya	2	2007	QDPIF[N]
M. sphaerocarpos	Orion	Sicily	3	1993	DAFWA
M. tornata x *M. littoralis*	Toreador	Crossbred	2	2001	SARDI[N]

Melilotus albus	Jota	Mass selection	7	2006	DPIV [N]
Ornthopus sativus	Cadiz	South Africa	3	1996	CLIMA
?	Erica	Mass selection	3	2003	DAFWA[N]
?	Margurita	Mass selection	3	2003	DAFWA[N]
Trifolium dasyurum	95GCN39[#]	Greece	3	2007	DAFWA[N]
T. glanduliferum	Prima	Israel	3	2001	DAFWA[N]
T. incarnatum	Caprera	Sardinia	5	1998	CLIMA
T. isthmocarpum	H14216[#]	Mass selection	6	2008	DPIV[N]
T. spumosum	CFD27[#]	Cyprus	3	2008	DAFWA[N]
T. vesiculosum	Arrotas	Italy	7	1997	TIAR/TDPIWE
?	Cefalu	Mass selection	5	1998	CLIMA
Trigonella balansae	SA5045[#]	Unknown*	3	2008	DAFWA[N]
New cultivars of species previously registered in Australia					
Medicago littoralis	Herald	Crossbred	2	1996	SARDI[N]
?	Angel	Mutation	2	2005	SARDI
M. polymorpha	Cavalier	Crossbred	2	2003	SARDI[N]
?	Scimitar	Crossbred	2	2003	SARDI[N]
M. truncatula	Caliph	Crossbred	2	1993	SARDI[N]
?	Mogul	Crossbred	3	1992	SARDI[N]

?	JesterⓅ	Crossbred	3	2001	SARDI[N]
Ornithopus compressus	SantoriniⓅ	Greece	3	1995	CLIMA
?	YelbiniⓅ	Greece	2	2002	DAFWA[N]
?	King	Greece	3	2001	NSW DPI[N]
?	CharanoⓅ	Greece	2	1997	CLIMA
Trifolium hirtum	SARDI Rose	Spain	5	?2005	SARDI
T. michelianum	BoltaⓅ	Turkey	5	1997	SARDI[N]
?	FrontierⓅ	Mass selection	3	1999	SARDI[N]
?	KRC-2[#]	Mass selection	4	2007	SARDI[N]
T. purpureum	ELECTRA™	Turkey	7	2006	CLIMA
T. resupinatum	Persian Prolific	Turkey	3	1998	CLIMA
?	Nitro PlusⓅ	Syria	3	1998	CLIMA
?	SARDI Persian™	Mass selection	3	2005	SARDI[N]
?	LusaⓅ	Mass selection	7	?2007	DPIV[N]
?	Morbulk	Afganistan	7	1999	DPIV
T. subterraneum (ssp. *brachycalycinum*)	MintaroⓅ	Crossbred	5	2005	SARDI[N]
T. subterraneum	DenmarkⓅ	Sardinia	6	1992	DAFWA[N]
(ssp. *subterraneum*)	GoulburnⓅ	Sardinia	6	1992	DAFWA[N]
?	LeuraⓅ	Sardinia	6	1992	DAFWA[N]

?	York(PBR)	Sardinia	4	1995	DAFWA[N]
?	Urana(PBR)	Crossbred	3	2001	DAFWA[N]
?	Coolamon(PBR)	Crossbred	5	2003	DAFWA[N]
?	Izmir(PBR)	Turkey	1	2003	DAFWA[N]?
T. subterraneum	Gosse(PBR)	Crossbred	5	1992	SARDI[N]
(ssp. *yanninicum)*	Riverina(PBR)	Crossbred	4	1995	DAFWA[N]
?	Napier(PBR)	Crossbred	6	2002	DAFWA[N]?

(PBR)Plant Breeder's Protection granted or pending in Australia; ™Trademarked variety name; [#]Candidate for release, subject to satisfactory final testing; * Obtained from the University of Uppsala, Sweden; [$]1-7 ratings based on days to first flowering in Perth from an early May sowing (1 = < 80 days, 2 = 80-94, 3 = 95-109, 4 = 110-124, 5 = 125-139, 6 = 140-154, 7 = >154 days); [%]See text for acronyms; [N]Developed as part of the NAPLIP and fore-runner programs.

Table 2. Preferred soil type, optimum farming system and agronomic traits of annual pasture legume species for which cultivars have been developed since 1991.

Species	Preferred soil properties		Optimum farming system				Agronomic traits					
	Texture[a]	pH ($CaCl_2$)	Ley	Short-term[b] phase	Long-term phase[c] and permanent	Fodder	Deep roots	Header harvestable	Hard-seeded	Delayed seed softening	Water-logging tolerant	Salinity tolerant
Biserrula pelecinus	2-4	4.5-7.5	√				√	√	√	√		
Hedysarum coronarium	3-6	5.5-8.5		√		√	√	√ (pods)				
Lotus ornithopodioides[d]	4-5	5.0-8.5	√				√	√	√	√		

Medicago littoralis	2-4	5.8-9.0	√						√			
M. orbicularis[d]	4-5	5.8-9.0	√		√				√			
M. polymorpha	4-6	5.2-8.5	√		√				√	√		√
M. sphaerocarpos	3-4	4.8-8.0	√						√			
M. tornata x *M. littoralis*	2-4	5.8-9.0	√						√			
M. truncatula	4-5	5.8-9.0	√						√			
Melilotus albus[d]	4-6	6.0-8.5			√	√						√
Melilotus siculus[d]	3-6	5.5-8.5			√				√	√	√	√
Ornithopus compressus	1-4	3.5-6.5	√		√		√	√ (pods)	√	√		
O. sativus (cv. Cadiz)	1-4	3.5-6.5		√		√	√	√ (pods)				
O. sativus (cvv. Margurita, Erica)	1-4	3.5-6.5	√	√		√	√	√ (pods)				
Trifolium dasyurum[d]	3-5	5.0-8.0	√	√		√		√		√		
T. glanduliferum	3-5	4.5-8.0	√	√				√		√		

T. hirtum	2-4	4.5-7.5		√				√			
T. incarnatum	2-4	4.2-7.0		√		√	√	√			
T. isthmocarpum[d]	3-6	4.5-8.0			√	√		√			√
T. michelianum	3-6	4.5-8.0		√	√	√		√			√
T. purpureum	3-5	4.8-8.5		√		√	√	√			
T. spumosum	3-6	5.2-8.5	√	√	√			√	√	√	
T. subterraneum (ssp. *subterraneum)*	3-5	4.2-7.0	√		√						
T. subterraneum (ssp. *yanninicum)*	3-5	4.2-7.0			√						√
T. subterraneum (ssp. *brachycalycinum)*	4-6	6.5-8.5	√		√						
T. vesiculosum	2-4	4.5-7.5	√	√		√	√	√			
T. resupinatum	4-6	5.0-8.0		√	√	√		√			√

Trigonella balansae[d]	3-5	6.0-8.5	√		√

[a]1 = deep infertile sand, 2 = sand, 3 = sandy loam, 4 = loam, 5 = clay loam, 6 = clay; [b]1-3 years, [c] >3 years; [d]Promising species undergoing evaluation

Plants for difficult soils

From Table 2, it can be seen that only two species, yellow serradella and French serradella (*Ornithopus sativus*) are suited to deep, infertile acid sands. Although well adapted to these soils (Bolland and Gladstones 1987), adoption of the original yellow serradella cultivars was constrained by high seed costs due to the need for suction harvesting and difficulty in dehulling seed from the pods. This constraint was tackled in two ways. Firstly, Yelbini, Charano and Santorini yellow serradellas were selected for low and medium rainfall areas in Western Australia for the combination of pod retention and straight (non-segmenting pods), which allowed direct heading and reduced seed processing difficulties (Loi *et al.* 2005a). Their high hardseededness (Loi *et al.* 2005a) provides a very persistent option for these soils, either in rotation with crops or as permanent pastures. A fourth cultivar, King, was selected for its high productivity and persistence in northern New South Wales. Secondly, the related species, French serradella, was recognised as having adaptation to similar soils, but with much better harvesting and pod characteristics. The cultivar Cadiz was released to provide a new cheap alternative for these soils. Its combination of aerial seeding and retentive pods (allowing direct header harvesting), which readily break up into segments, and fully soft seeds (allowing direct seeding of pod segments without the need for any seed processing) represented a major breakthrough in productive options for these soils (Nutt and Loi 1999). Its soft-seededness, however, meant that it could not be used in cropping rotations without re-sowing after each crop. The more recent release of the moderately hardseeded cultivars Margurita and Erica has largely addressed this problem.

The success of Paradana balansa clover on waterlogged, predominantly acid soils in medium to high rainfall areas led to development of cultivars Bolta (Craig 1998) and Frontier (Craig *et al.* 2000) for higher and lower rainfall areas, respectively. This has led to a significant expansion of the species range. More recently, KRC-2 has been selected as a more productive and root rot-resistant candidate for release to replace Paradana. Similarly, the ssp. *resupinatum* Persian clover cultivars, Persian Prolific and Nitro Plus, were developed to extend the species into medium rainfall waterlogged environments (Snowball and Evans 1998, Evans and Snowball 1998). Later flowering ssp. *majus* types were also developed to overcome deficiencies in the unregistered, but commonly sown, completely soft-seeded Maral variety. Morbulk was developed as a more productive and earlier flowering cultivar than Maral (Lee *at al.* 1999), while the partially hardseeded cultivar Lusa has recently been developed for greater persistence. Moroccan clover (*T. isthmocarpum*) has been identified as another species adapted to waterlogged soils (Dear *et al.* 2003). Preliminary studies in Western Australia indicate most genotypes have higher hardseed levels and slower rates of seed softening than balansa and Persian clovers. A new cultivar, H14216, is a candidate for release to complement the softer seeded species.

The selection of annual legumes for saline soils is a more recent activity. While balansa clover and Persian clover have been widely touted as having salinity tolerance, recent evidence has shown their tolerance to be low (Nichols *et al.* 2006, Rogers *et al.* 2006). The burr medic cultivars, Scimitar and Cavalier, have greater salinity tolerance and offer good prospects on saline land in low rainfall areas with only transient waterlogging. *Melilotus albus* cv. Jota was selected for its excellent performance on raised beds on saline soils in high rainfall, alkaline environments (Evans and Kearney 2003) and is likely to be released commercially. *Melilotus siculus* (syn. *messanensis*) offers the best prospects to date to combine high tolerance to both salinity and waterlogging (Rogers *et al.* 2006) and a cohort of the most promising genotypes is currently undergoing evaluation.

Plants for phase farming

The development of plants specifically adapted to phase farming is the major innovation in pasture legume improvement over the past 15 years. Eight new annual legume species have been or are likely to be soon commercialised for use in this farming system, comprising French serradella, gland clover (*Trifolium glanduliferum*), crimson clover (*T. incarnatum*), purple clover (*T. purpureum*), arrowleaf clover (*T. vesiculosum*), bladder clover (*T. spumosum*) eastern star clover (*T. dasyurum*) and *Trigonella balansae*. A new cultivar of rose clover (*T. hirtum*), SARDI Rose, has also been released, while other more hardseeded genotypes with better seed harvestability are undergoing evaluation. Each of these species has been selected for ease of seed harvesting and processing to provide seed cheaply for the re-sowing that is required after extended cropping phases. Common attributes are an upright growth habit and aerial seeding, enabling seed harvesting by conventional cereal harvesters, ease of extraction from the pod and high seed production capacity. They also tend to be softer seeded than legumes specifically adapted to ley farming systems. The short-lived perennial, sulla, was also selected for use in phase farming systems. Cultivars Wilpena and Moonbi were selected predominantly for high herbage production, while cv. Flamenco was selected specifically for its ease of harvest and seed production capacity (Yates *et al.* 2006).

The new suite of legumes suit different production systems and environments. Of the legumes selected for medium rainfall areas, the French serradellas are the only ones suited to deep, infertile acid sands, CFD27 bladder clover is suited to fine textured acid soils (Loi *et al.* 2003), SA5045 *Trigonella balansae* is suited to alkaline soils (Howie *et al.* 2001), while Prima gland clover is suited to moderately acid soils that may or may not have transient waterlogging (Dear *et al.* 2003, Nutt *et al*. 2006). Prima also has the particular advantage of resistance to redlegged earthmite and aphids (Nutt *et al*. 2006). Crimson, arrowleaf and rose clovers are dual purpose grazing and fodder species well suited to moderately acid soils. Crimson clover is soft-seeded and has larger seeds than arrowleaf clover. It provides higher early season grazing potential, while arrowleaf clover is likely to be more persistent. The sole crimson clover cultivar, Caprera, is suited to high rainfall areas, while the two arrowleaf clover cultivars, Cefalu and Arrotas, have been selected for medium to high and very high rainfall areas, respectively. The rose clover SARDI Rose has also been selected for medium-high rainfall areas, but earlier flowering types for lower rainfall areas are being evaluated. ELECTRA™ purple clover is a further dual purpose grazing and fodder species with broad soil adaptation in high to very high rainfall areas.

95GCN39 eastern star clover is a particularly interesting development. It germinates very late in the season compared to traditional pasture legumes and weeds (Loi *et al.* 2005b). This characteristic is related to its marked delay in seed softening, in combination with delayed imbibition. Seed softening occurs only after the seed has been exposed to high temperature (60? C in summer), followed by low diurnal fluctuating temperatures (20 to 5? C in autumn) and a long period of wet conditions (several weeks after the break of the season) (Loi and Taylor unpublished data). Not only does it provide strong protection from false breaks, it also offers the opportunity to control crop weeds during the pasture phase, particularly those resistant to selective herbicides. In the year after establishment non-selective herbicides or intensive grazing can be used 4-6 weeks after the opening of the season prior to 95GCN39 germination. This can be followed up by a hay cut to obtain almost complete weed control. Seeds can also be harvested with conventional header harvesters.

Plants for ley farming

Traditional species

The development of new medic cultivars is described in Nair *et al.* (2002). Three cultivars of barrel medic (*Medicago truncatula*), Caliph, Mogul and Jester, were developed through back-crossing as aphid-resistant replacements for the susceptible cultivars Cyprus, Borung and Jemalong, respectively. The *M. littoralis* cv. Herald was also developed through backcrossing as an aphid resistant replacement for the susceptible cultivar Harbinger, while cv. Toreador was developed as an aphid resistant hybrid of *M. tornata* and *M. littoralis*. The incorporation of resistance has been highly successful. Field trials demonstrated the new cultivars supported substantially less blue green aphid colonisation than their susceptible parent cultivars (Berlandier *et al.*1999). This has been supported by glasshouse trials, which also demonstrated good tolerance to spotted alfalfa aphids (Nair *et al.* 2003). New cultivars of *M.*

polymorpha, Scimitar and Cavalier, were also developed as more productive replacements for cvv. Santiago and Circle Valley, respectively.

The new *M. littoralis* cultivar, Angel, is very innovative. It is an induced mutant of cv. Herald with tolerance to chlorsulfuron and other Group B herbicides (Howie *et al.* 2002) and offers the opportunity to overcome the deleterious effects of residues from these herbicides on legume growth following their use in-crop.

Eleven new subterranean clovers have been released since 1992. They represent a new generation of cultivars, with cv. Dalkeith being the only older cultivar still widely recommended. Seven have application in cropping rotations. Cultivars Izmir and Urana were primarily selected for their increased hardseededness over Nungarin and Daliak, respectively (Nichols *et al.* 2006a; 2006d), while cv. York was selected as a more hardseeded replacement for cv. Seaton Park (Nichols *et al.* 1995). Cultivars Goulburn and Coolamon were selected for high rainfall mixed farming areas, where cropping is sometimes practiced. They are more hardseeded replacements for Woogenellup and Junee with resistance to both races of clover scorch and to

some of the major races of *Phytophthora clandestina* (Nichols and Nicholas 1992, Nichols *et al.* 2006c). On soils prone to waterlogging, the ssp. *yanninicum* cv. Riverina was selected as a more hardseeded replacement for cv. Trikkala with improved resistance to both races of clover scorch and to some of the major races of *Phytophthora clandestina* (Dear *et al.* 1996). The ssp. *brachycalycinum* cv. Mintaro has recently been released as a more productive and persistent replacement for cv. Rosedale for cracking or stony neutral-alkaline soils. A range of ssp. *subterraneum* breeding lines with cotyledon resistance to redlegged earth mite are currently undergoing evaluation in the field.

The yellow serradella cultivars Yelbini, Charano, Santorini and King are also well adapted to ley farming systems, particularly on very sandy soils. The improvements in harvestability and seed processing of Yelbini, Charano and Santorini make them a much cheaper pasture option to establish than previous cultivars.

New species

With the poor persistence of subterranean clover in many cropping rotations, other more hardseeded species adapted to acidic soils have been examined. *Medicago murex* (cv. Zodiac) and the sphere medic (*Medicago sphaerocarpos*) cv. Orion were released in 1988 and 1993, respectively, in response to this initiative (Gillespie 1994) and to exploit improved acid tolerance in their root nodule symbiosis (Howieson and Ewing 1989). However, in spite of high productivity in these species, large seeds and the ready accessibility of pods to grazing animals led to their poor persistence under grazing, resulting in limited adoption. Biserrula (*Biserrula pelecinus*) was researched because its symbiosis promised to be acid tolerant (Howieson *et al.* 1995). Biserrula is indeed proving to be a very successful alternative on acid soils where subterranean clover has historically been used. It is extremely hard seeded with a delayed seed softening pattern (Loi *et al.* 1999) and is deeper-rooted than most other annuals (Loi *et al.* 2005a). Sheep tend to avoid grazing biserrula for periods in spring, preferentially targeting other plants, including weeds. Thus the use of biserrula has considerable potential for herbicide-free weed management (Loi *et al.* 2005b). Moreover, biserrula seeds can be harvested with commercial headers (Loi *et al.* 2005a). One concern, however, has been sporadic outbreaks of photo-sensitisation in sheep grazing biserrula in spring. Two cultivars, Casbah and Mauro, have been released for medium and medium-high rainfall areas, respectively (Loi *et al.* 2001; 2006). The release of Margurita and Erica French serradellas also allows the species to be used in ley farming systems.

Four new species adapted to ley farming systems are currently being considered for commercialisation. CFD27 bladder clover (*Trifolium spumosum*) has been selected for fine-textured hard-setting soils, in which subterranean clovers are unable to bury their burrs (Loi *et al.* 2003). A group of *Lotus ornithopodioides* genotypes is also undergoing evaluation. It is adapted to a similar soil type to *T. spumosum*, but there are prospects of selecting earlier flowering genotypes. Both species are considerably more hardseeded than subterranean clovers, have a delayed seed softening pattern and their seeds can be harvested with commercial headers (Loi *et al.* 2005a). *L. ornithopodioides* has the additional advantages of deep-rootedness and resistance to redlegged earth mites and aphids (Loi *et al.* 2002). Bindaroo will be the first cultivar of button medic (*M. orbicularis*), having been selected for its higher seed production and persistence than barrel medics in dry and marginal environments of southern Queensland and South Australia. It is likely to be used in permanent pastures in southern Queensland.

Plants for high rainfall permanent pastures

The ssp. *subterraneum* cultivars, Denmark, Goulburn and Leura were released as clover scorch and Phytophthora root rot-resistant replacements for high rainfall permanent pastures where cvv. Mt Barker and Karridale had previously been sown (Nichols and Nicholas 1992, Nichols 1998). For waterlogged soils, the ssp. *yanninicum* cultivars Riverina, Gosse and Napier were selected as replacements for cvv. Trikkala, Larisa and Meteora, with greater resistance to clover scorch and Phytophthora root rot (Oram 1992, Dear *et al.* 1996, Nichols *et al.* 2006b). The late flowering cultivars of balansa, Persian, Moroccan, crimson and purple clovers are also suitable for high rainfall pastures.

Impact and adoption

Farmer interest in the new cultivars has been high, particularly in Western Australia. Loi *et al.* (2005a) estimated French and yellow serradellas, biserrula and aerial seeding clovers have already been adopted over 1.5 million hectares in the State. Results of a survey among Western Australian farmers conducted at a series of field days in spring 2005 support this high adoption rate. Farmers were asked to list their total farm area and the area and varieties sown to pasture in 2005. Of 127 respondents, with a combined total farming area of 460,000 ha and ranging from 250-650 mm average annual rainfall, 171,000 ha (37%) was in pasture during 2005. 31,000 ha (18%) of this pasture area was re-sown during the year. From Figure 1, it can be seen that only 31% of all species sown were the traditional subterranean clover and annual medics. French serradella comprised 25% of all new sowings, biserrula 17% and yellow serradella 10%. Adoption of the more recently released cultivars is likely to extend this trend as more seed becomes available.

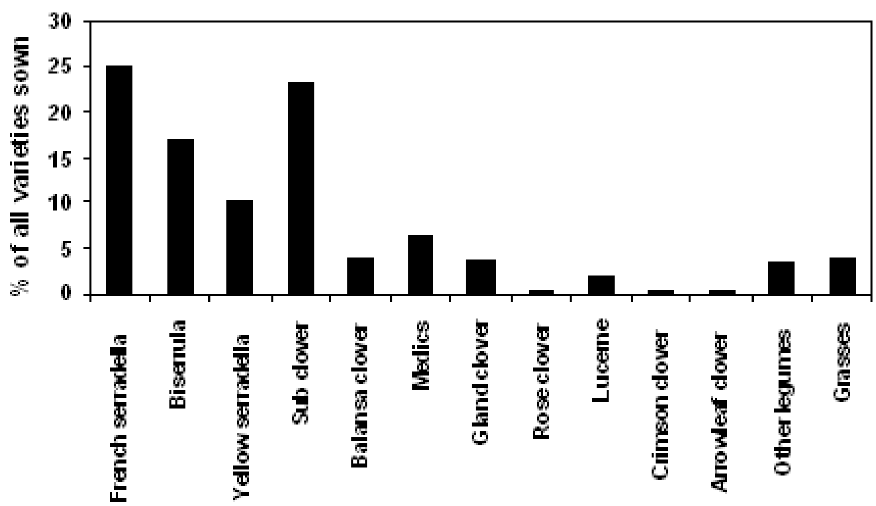

Figure 1. Proportions of pasture species sown (by area) in 2005 across Western Australia from a farmer survey of 127 respondents.

Future directions

Farming systems research for newly released cultivars

There is a need to develop extension packages for farmers and agribusiness to maximise potential benefits from using the new cultivars and best manage them on a whole farm basis. Management of individual species to maximise their productivity and persistence in most cases needs further work, as does determining compatibility of species and cultivars for pasture mixtures. The economic advantages for crop and animal production and effects on the environment through use of new cultivars also need better quantification. Such information will lead to greater confidence among producers in their use and to higher adoption in the long term.

Need for new cultivars

While a large number of cultivars and species have been developed, there are still important agro-ecological gaps that need to be filled across southern Australia. Most emphasis has been on the medium and high rainfall areas, for which there is a wider genetic resource from which to breed and select. Examination of Table 1 shows the low rainfall zone, particularly the very low rainfall zone (maturity rating 1), has the least options. While this area has traditionally had the least investment in pastures, the issues of herbicide-resistant crop weeds and the rising cost of inorganic nitrogen will increasingly draw farmers towards the need to increase legume content in their pastures. An appropriate array of pasture legume options will be needed to satisfy this demand. Recent collection missions to dry areas of the Mediterranean basin have expanded the range of available short-season germplasm and are likely to yield promising material for this zone.

The continuing need to increase pasture biodiversity within paddocks dictates that further cultivars should be developed, particularly for agro-ecological niches with few existing options. For most of the new species, only one or two cultivars have been or are about to be released. The range can be expanded by selecting cultivars in different maturity groups of these species, with much of the agronomic management recommendations still being relevant. With the increased focus on perennial-based pastures, attention needs to be given to selecting annual legumes able to co-exist. Dear *et al.* (2001) showed differential performance of subterranean clover varieties in co-existence with lucerne and temperate perennial grasses, and indicated the importance of appropriate seed softening attributes. The traits for co-existence of winter-active annual legumes with summer-active sub-tropical grasses also need elucidation.

Specific environmental concerns need to be addressed through pasture legume breeding and selection. Selection of plants for saline areas has had little attention to date. The review by Rogers *et al.* (2005) indicates a wide range of potential material with reputed salinity tolerance, including annual legumes. Recent results suggest a range in tolerance within *Medicago polymorpha* and several *Melilotus* species that could be exploited for breeding. Climate change is another environmental concern. Given the predicted onset of climate change is gradual, incremental plant breeding and technological changes will be needed to lessen the effects on agriculture (Kingwell and Pannell 2005).

Conclusions

Public breeding and selection programs have revolutionized the use of annual pasture legumes through major improvements in traditional species and commercialisation of several new species adapted to new and important niches and evolving farming systems. Plant genetic resource collections and the disciplines of rhizobiology, pasture ecology and physiology, plant pathology, entomology and plant chemistry have been essential to this development. However, as Kingwell and Pannell (2005) note, the continuing decline in terms of trade for agricultural commodities creates an imperative for continuing productivity improvements and that a healthy R & D sector remains crucial for this to occur. Pasture plant breeding will continue to increase productivity and present new opportunities. While the private sector is likely to become increasingly involved in developing varieties of mainstream species, the higher risk but more innovative breakthroughs will continue to come from the public sector, provided the skills base and funding of plant breeders and related disciplines are maintained.

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