Developing Ecologically-Adapted Plants for Farming Systems in Southern Australia: Perennials for the Medium to Low Rainfall Zone

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Key points : Rising watertables and increasing soil salinity have led to the realisation that current farming practises in southern Australia are unsustainable . Lucerne was the only perennial legume available for the medium-to low-rainfall region , although it is not adapted to low soil pH , waterlogged conditions or soil salinity and requires some summer rain . However , it possesses the key characteristics required for perennials in the medium-rainfall region , namely , a deep-rooting system and some summer activity to utilise out-of-season summer rain . These characteristics were used in the search for other perennials to increase the diversity of species available . Species identified as having high potential for the medium-rainfall region include chicory , phalaris and sulla . For the low-rainfall region increased summer dormancy is required to survive the summer drought . Species showing potential for this region include birdsfoot trefoil , plantain and cocksfoot . The use of genetic resources is essential in the development of ecologically-adapted pasture species .

Key words : perennials , genetic resources , ecogeography , deep-rooting system , summer dormancy

Introduction

The ecological adaptation of pasture plants for the farming systems of southern Australia is essential for their persistence and production , plus decreases the time spent developing new cultivars . The qualities required for ecological adaptation include ecogeographic factors and agronomic characteristics to fit into current farming systems . Ecogeographic factors include soil type , soil pH and climate (annual rainfall , rainfall pattern across the year , minimum and maximum temperatures , frost days etc .) . The required agronomic factors depend on the farming system for which the species is being developed , but typically include factors such as ease of establishment , tolerance to grazing , persistence , quality of feed and presentation of seed for ease of harvesting . Other factors that must also be considered are the presence of anti-nutritional compounds (Revell & Revell , 2007) and potential weediness (Bennett & Virtue , 2004 , Stone *et al* . ,2008) .

Table 1 *Agro-climatic classification of areas of southern Australia targeted for perennial pasture plant improvement , along with current dominant landuse and options for including perennials in the farming-system (adapted from Ewing , 2004 , Hutchinson et al . , 2005) .*

Climatic description (code reference from Hutchinson *et al* . , 2005)	Geographic occurrence	Current dominant land uses	Perennial options
Temperate , cool season , wet , high rainfall (D5)	Tasmanian lowlands , southern Victoria and NSW tablelands	Forestry , sown permanent pastures and horticulture	Options available : white clover and temperate grasses
Classic mediterranean climate with cool , wet winters and warm to hot , dry summers (E1)	South-west WA and southern SA	Winter cropping and sown pastures (animal dominant) , forestry and horticulture	Limited options : Lucerne plus new options emerging
Mediterranean climate with drier , cooler winters than E1 (E2)	Inland of E1 in south-west WA , southern SA , north-west Victoria and southern NSW	Winter cropping , improved pastures (cropping dominant)	No options . New thinking required . See text for emerging ideas .
Temperate , sub-humid (E3)	NSW western slopes	Winter & summer cropping , sown and native pastures , horticulture	Limited options : cocksfoot and tall fescue plus new options emerging

The agricultural region of southern Australia is generally described as having a semi-arid mediterranean-type climate with mild , wet winters and dry , warm to hot summers with rain falling almost exclusively in the winter months (Bennett *et al* . , 1998) . Other areas in the world with a similar climate include the Mediterranean Basin , South Africa , California and Chile (Dallman , 1998) . A more detailed agro-climatic description is given by Hutchinson *et al* . (2005) that links light , temperature and moisture data to plant growth . The agro-climatic zones in southern Australia are given in Table 1 , along with the dominant land use in each zone . Soil types in southern Australia range from relatively sandy soils in south-western WA and parts of south-east

SA , through to heavier textured clay and duplex soils in much of south-eastern Australia . , Soil pH varies from highly alkaline to highly acid . Southern Australia can therefore be broken down into a number of different ecological niches for which species requirements differ .

This paper concentrates on the search for perennial plants for the medium (650-400 mm/yr) to low (<400 mm/yr) annual rainfall agricultural regions of southern Australia with a mediterranean climate (E1 and E2 in Hutchinson *et al* . , 2005) . This is an area of southern Australia for which there are currently few perennial options , yet it is also subject to the same sustainability issues as other regions of southern Australia , particularly rising watertables and increasing soil salinity . Forecasts of climate change predict a reduction in annual rainfall , along with increased unreliability . It is also a region where the economic margins are low and therefore there is a requirement for the adoption of any new pasture species to be profitable compared to current systems . Within this paper a background is provided on the farming systems currently practised in Australia , the drive to move away from an annual-based farming system to a more sustainable perennial-based system is described , with a focus on the importance of genetic resources to identify the ecological characteristics required for the medium-to low-rainfall regions of southern Australia .

Background to pasture species for the mediterranean zone of Australia

In the mediterranean zones of Western Australia (WA) and South Australia (SA) subterranean clover (*Trifolium subterranean* L .) and medics (*Medicago* sp .) have been the traditional annual legume pasture options for the ley-farming crop rotation systems . Ley-farming relies on the regeneration of the annual legumes from hard-seed after one to two years cropping (Taylor *et al* . , 1991) . Subterranean clover has been sown predominantly in the acid soils of WA (Underwood & Gladstones , 1979) , whereas annual medics are better suited to the more alkaline soils of SA (Puckridge & French , 1983) . A more flexible , adaptive form of ley-farming evolved during the 1980s , now called phase-farming , in which longer periods of cropping are rotated with a longer pasture phase (Reeves & Ewing , 1993) .

In the last 15 years there has been a drive to increase the suite of species available for the farming systems of southern Australia in light of the lack of legume diversity and arising sustainability options . These include ; a) the lack of adaptation of subterranean clover and annual medics to difficult soils , including deep , acid sands and soils subject to salinity and waterlogging ; b) poor adaptation of subterranean clover to a variable climate , particularly false breaks ; c) increase of herbicide-resistant weeds ; d) need for longer-season legumes to increase productivity in longer growing-season areas and for legumes which are drought-tolerant to survive in areas with unreliable rains ; e) soil erosion concerns from vacuum harvesters used to harvest subterranean clover seed ; f) increase legume diversity to protect against variation in productivity between and within seasons ; and g) to increase protection and susceptibility to disease and insects . These issues are discussed in detail by Nichols et al . (2007) and Cocks and Bennett (1999) . Cultivars of species have subsequently been released from a number of different annual legume species including yellow serradella (*Ornithopus compressus* L .) , bisserula (*Bisserula pelecinus* L .) , Persian clover (*T . resupinatum* L .) , balansa clover (*T . michelianum* Savi) and bladder clover (*T . spumosum* L .) (Nichols *et al* . , 2007) . Cultivars of these species have all been bred from accessions collected in the Mediterranean Basin as the winter rainfall-dominant growing season mimics that required for the agricultural zone of southern Australia . A detailed understanding of the ecology of annual legumes has led to the success in developing a suite of species that provide legume options for the range of different soil types , climates and farming systems of southern Australia (Rossiter , 1966 , Cocks , 1997 , Bennett , 1999) .

Other farming systems practised in southern Australia include ; permanent pasture systems , which are typically found in the high-rainfall region where cropping is not possible , and alley-farming , where shrub species such as tagastaste (*Chamaecytisus proliferus* Link .) and saltbush (*Atriplex* sp .) are sown in alleys with annual pasture or crops sown between the rows or alleys . The phase-farming and alley-farming are found in the medium-to low-rainfall regions with alley farming usually practised in the low-rainfall region where soil salinity or wind-erosion limits cropping (Dear & Ewing , 2008) .

Perennials for the farming systems of southern Australia

Rising watertables , increasing levels of soil salinity and increasing soil acidification has led to awareness over the last 10 years that current farming systems based on rotations of annual legumes and crops are not sustainable (Dear *et al* . , 2003 , Ewing & Dolling , 2003) . It has been suggested that for watertables to return to pre-land clearing levels then perennial agricultural systems are required which mimic the water use by native vegetation (Hatton & Nulsen , 1999) . A decade ago , lucerne (*M . sativa* L .) was the main perennial legume option available for most of the medium to low rainfall regions of southern Australia . Lucerne has its limitations as it is intolerant of acid soils , waterlogging and soil salinity and requires some summer rain . However , it is known that lucerne is capable of lowering watertables due to its deep-rooting system (Ward *et al* . , 2001) . A search for perennial legumes with similar deep-rooting systems would provide further options for the agro-ecological zones where lucerne is not successful . Ideally a suite of perennial options is required that would fit the ecologically niches currently filled by annual legumes . White clover (*Trifolium repens* L .) is the only other perennial legume sown extensively in southern Australia , although its use is restricted to permanent grazing regions receiving more than 700 mm annual rainfall , as it does not persist in lower rainfall regions due to a lack of tolerance to drought conditions (Dear & Ewing , 2008) .

More perennial grass options are available including the temperate C3 grasses such as perennial ryegrass (*Lolium perenne* L.), tall festuce (*Festuca arundinacea* Schreb.), phalaris (*Phalaris aquatica* L.) and cocksfoot (*Dactylis glomerata* L.), the sub-tropical C4 grasses such as kikuyu (*Pennesetum clandestinum* Hochst. Ex Chiov.) and Rhodes grass (*Chloris gayana* Kunth), and the halophytic grasses tall wheatgrass (*Thinopyrum ponticum* Podp.) and puccinellia (*Puccinellia ciliata* Bor.) which are suited to saltland pasture areas of southern Australia. The temperate grasses are all restricted to the medium-to high-rainfall regions of southern Australia and, other than temperate types of tall fescue, are shallow-rooted, therefore contributing little to lowering the watertables (Sanford, 2006). The sub-tropical grasses have more summer activity, therefore contributing more to water use during out of season rains. Other than kikuyu and Rhodes grass their use has generally been restricted to the summer-dominant rainfall zones of Australia, although research is currently underway on expanding their use into winter-dominant rainfall zones with some summer rain or with a shallow or perched non-saline watertable (Moore, 2006).

Table 2 *Status and breeding priority of perennial legumes, grasses and herbs for the medium to low rainfall agricultural regions of southern Australia, identified in CRC Salinity evaluation trials (adapted from Dear et al., 2008).*

Plant species & priority rating	*Target landscape aar (average annual rainfall)*	*Agroecological niche*
Birdsfoot trefoil (Lotus corniculatus) [1 2 3]	*D5, E1, E3 (breeding for E2)*	*More tolerant of acid soils than lucerne, and can tolerate some waterlogging. Breeding in progress for increased drought tolerance.*
Chicory (Chichorum intybus) [1 3]	*D5, E1, E3. Recharge environments*	*High livestock feeding value and antihelminthic properties. Superior acid soil tolerance compared to lucerne.*
Cocksfoot (Dactylis glomerata) [1 2 3]	*Summer dormant cultivars D5, E1, E3*	*Summer dormant cultivars highly productive in autumn-winter. Breeding programme in progress to extend to E2.*
Lucerne (Medicago sativa) [1 2 3]	*D5, E1. Freely draining environments*	*Superior drought tolerance and persistence to other perennial legumes. Potential to increase tolerance to aluminium and waterlogging.*
Phalaris (Phalaris aquatica) [1 3]	*D5, E3 (breeding for E1)*	*One of most productive and persistence grasses. Summer dormancy increases persistence in lower rainfall regions. Some waterlogging tolerance. Potential to increase salt tolerance.*
Puccinellia (Puccinellia ciliata) [1 3]	*E1-E2. Highly saline, waterlogged environment*	*Appears to require significant waterlogging to ensure persistence.*
Rhodes grass (Chloris gayana) [1 4]	*E3. Requires significant proportion summer rain*	*Poor persistence where cold, wet winters. Moderate salt tolerance. Breeding to extend to E1.*
Strawberry clover (Trifolium fragiferum) [1 4]	*D5, E1. Poorly drained environment*	*Best performance on poorly drained and heavy clay soils low in landscape. Best performance on soils which moist in summer.*
Sulla (Hedysarum coronarium) [1 4]	*D5, E1, E3. Well-drained soils*	*Short-lived perennial. Thought to possess moderate salt tolerance, but lacks waterlogging tolerance.*
Tall fescue (Festuca arundinacea) [1 2 3]	*Summer dormant cultivars E1, E3.*	*Summer dormant cultivars showing improved persistence. Breeding programme in progress.*
Tall wheat grass (Thinopyrum ponticum) [1 4]	*E1-E2*	*Highly persistence across diverse range of sites. Salt and waterlogging tolerant, but not as tolerant of waterlogging as puccinellia.*
Wallaby grass (Austrodanthonia caespitosa) [1 2 3]	*E1-E2. Low input pasture*	*Good persistence. New cultivars being developed.*

[1] Cultivars available for immediate use; [2] Breeding in progress; [3] Further breeding a high priority; [4] Further investigation warranted

Initial searches for perennial legumes were made in the Mediterranean Basin, as this region was known to be climatically similar to large areas of the agricultural region of southern Australia. Three collections were made in Italy, followed by ecogeographic surveys (Russi *et al.*, 2003) and initial agronomic evaluation (Pagnotta *et al.*, 2003) to determine which species might fit into the southern Australian farming systems and to identify key ecological characteristics which enable perennials to persist in semi-arid environments. Subsequent plant collection missions have extended to other areas of the world with a mediterranean climate including central Asia, south-east Asia, and the Macronesian Islands, plus material has been accessed from plant germplasm collections around the world of perennial legume, grass and herb species with potential in southern Australia (Hughes *et al.*, 2008). A number of plant collections were also undertaken across southern Australia to collect native perennial legume, grass and herb species which could be included in national evaluations (Hughes *et al*., 2008). The contribution of genetic resources to plant breeding programmes when expanding into new agricultural systems is enormous. The collection of plant material, along with associated ecogeographic information provides a solid base from which to develop an understanding of the climatic and geographic requirements of each species being evaluated. Species can then be targeted to specific niches within agro-climatic zones, e.g. acid soils or waterlogged conditions. In the past, collections in areas with a mediterranean climate have been for annual pasture species; perennial pasture species are now required for these regions.

Complimentary to plant collections, scoping studies (a review plus future priority identification) were undertaken to determine the full suite of herbaceous perennial species that may have potential for the agricultural regions of southern Australia (Bennett *et al*., 2002, Dear *et al*., 2003, Rogers *et al*., 2005), along with priority agro-ecological areas. From preliminary evaluation of material from the collection missions, genetic resource centre introductions, and material identified in the scoping documents, a priority list of species for further evaluation was determined comprising 11 species and three leguminous genera (Hughes *et al*., 2008). Priority species targeted for the medium-to low-rainfall regions were those that were deep-rooted with the potential to lower watertables. Species adapted to waterlogged and saline soils were also targeted. These species have been the subject of a nationally coordinated evaluation program across southern Australia through the CRC for Plant-Based Management of Dryland Salinity (CRC Salinity) (Dear *et al*., 2008). A number of new species are at an advanced stage of evaluation with each species showing adaptation to particular ecological niches within the farming system. Identified priority species with potential for immediate application are shown in Table 2. During the evaluation program it was found that the perennial species evaluated were not well adapted to current farming systems in southern Australia, and that new farming systems were required. The majority of the perennial legume and herb species evaluated do not persist under set-stocking. Longevity of the pasture, production and the quality of the feed is improved by rotational grazing of perennial pastures. Also few species were found to be adapted to the low rainfall regions (less than 450 mm annual rainfall or E2 (Table 1) as they did not persist over summer.

Ecological-adaptation of plants for the low-rainfall zone of southern Australia

There is a current drive to identify perennial species that are adapted to the low-rainfall region (E2). Key characteristics that have been identified as important for their persistence include deep-rooting ability to utilize moisture stored in the soil profile and to help lower watertables, increased winter activity and increased summer dormancy to protect against summer drought. Species that are currently under evaluation and showing promise in the development of cultivars adapted to the low rainfall regions of southern Australia include;

- Accessions of chicory (*Chichorum intybus* L.) that have been collected from relatively low rainfall regions of the Caucasus offer significant potential to increase the drought tolerance and persistence of this species (Dear *et al*., 2008). Currently available cultivars will fit into current pasture crop rotations providing a short-term perennial forage, particularly on acid soils, with good summer and autumn growth. However, increased summer dormancy is required for persistence in low-rainfall regions.
- Winter-active cultivars of plantain (*Plantago lanceolata* L.). Cultivars of plantain included in the CRC Salinity evaluation programme were summer-active. These showed good growth in summer and autumn (Reed *et al*., 2008). However, for the species to persist in low-rainfall environments increased winter activity and increased summer dormancy is required.
- Cultivars of phalaris with increased drought tolerance. Germplasm from north Africa has been exploited with increased levels of summer dormancy which has already led to the release of one semi-summer dormant cultivar, Atlas PG (Culvenor & Boschma, 2005) for use in the 450-500mm annual rainfall zone. Further lines with higher levels of summer dormancy and earlier flowering should result in the release of cultivars of phalaris adapted to lower rainfall regions (<500 mm annual rainfall).
- Summer dormant cultivars of cocksfoot. These cultivars which were derived from accessions collected in Morocco were highly persistent over the four years of the CRC Salinity evaluations programme at sites with less than 350 mm annual rainfall.
- Birdsfoot trefoil (*Lotus corniculatus* L.). Focussed breeding work on developing cultivars adapted to lower rainfall areas is in progress in WA (G. Sandral and D. Real pers. comm.).
- The Australian native, wallaby grass (*Austrodanthonia caespitosa* (Gaudich.) H.P.Linder), which is well adapted to the 300 to 400 mm rainfall zone. It shows good persistence and is very responsive to summer rain and is thought to have a role in low input systems or those being retired from cropping in marginal environments (Dear *et al*., 2008).
- The Australian native perennial legume *Cullen australasicum* (Schltdl.) J.W.Grimes is a further species that may have potential in the low rainfall zone of southern Australia, although further investigation is required before a confident assessment can be made (Dear *et al*., 2008). It showed good persistence in the CRC Salinity evaluation programme and possesses extreme drought tolerance. However, little is known about the management of this species or how it would fit into the farming system. Other native perennials may also have potential and are being investigated (M. Ryan, Pers. Comm.)

The requirement for species adapted to low rainfall regions has led to plant collecting missions away from the Mediterranean Basin to areas with lower annual rainfall and increased summer drought such as north Africa and the Middle East. Recent collections have been made to low-rainfall regions of South Africa (B. Dear, J. Howieson and R. Yates, Pers. Comm.), Azerbaijan for drought and grazing tolerant wild relatives of lucerne (A. Humphries, Pers. Comm.), the United States for perennial *Trifolium* species (D. Real, Pers. Comm.) and the Canary Islands for perennial *Lotus* species (G. Sandral, Pers. Comm.). Material from earlier collections of perennial grasses in North Africa is being exploited for accessions with increased levels of summer dormancy in the temperate grasses (S. Clark, Pers Comm.). This collection of material offers real opportunities to extend the mixed farming systems of southern Australia into lower rainfall regions, offering farmers in these regions productive and persistent perennial options.

Concluding comments

Current problems facing farming systems in southern Australia and the drivers for change from a reliance on annual legumes and grasses towards perennial legumes, grasses and herbs have been outlined in this paper. A suite of species are currently available which fit into the high rainfall regions of southern Australia, with a limited but growing number available for medium-rainfall regions. However, there are very few options so far available for the low rainfall region and still many environmental niches within the medium-and high-rainfall regions for which there are no perennial options. To find species or new cultivars that will fit into areas where there are currently gaps, germplasm acquisition and research partnerships have been initiated in areas that have similar ecogeographic conditions. The practical importance of genetic resources in finding material that is ecologically-adapted to the target regions and farming systems has been highlighted.

References

Bennett, S J. (1999) Using collections to describe ecological relationships. In Bennett, S J. & Cocks, P S. (Eds.) *Genetic Resources of Pasture and Forage Legumes*. 41-52. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Bennett, S J., Ayres, J., Dear, B S., Ewing, M A., Harris, C A., Hughes, S J., Mitchell, M., Moore, G A., Nie, Z., Reed, K F M., Sandral, G A., Slattery, J. & Snowball, R. (2002) Perennial pastures for the recharge areas of southern Australia. Scoping Docment No. 1. Crawley, Western Australia: CRC for Plant-Based Management of Dryland Salinity.

Bennett, S J., Saidi, N. & Enneking, D. (1998) Modelling climatic similarities in Mediterranean areas: A potential tool for plant genetic resources and breeding programmes. *Agriculture Ecosystems & Environment*, 70, 129-143.

Bennett, S J. & Virtue, J G. (2004) Salinity mitigation versus weed risks-can we resolve the conflicts of interest in introducing new plants? *Australian Journal of Experimental Agriculture*, 44, 1141-1156.

Cocks, P S. (1997) Seed production, seed bank dynamics and reproductive strategies of Mediterranean annual legumes. In Fernandez, D G A., Marlorell, D R. & Munoa, D P. (Eds.) *Improving forage crops for semi-arid areas*. 213-223. Mallorca, Spian, 2-4 October.

Cocks, P S. & Bennett, S J. (1999) Introduction: Role of pasture and forage legumes in mediterranean farming systems. In Bennett, S J. & Cocks, P S. (Eds.) *Genetic Resources of pasture and forage legumes*. 9-19. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Culvenor, R. & Boschma, S. (2005) Evaluation of phalaris (Phalaris aquatica L.) germplasm for persistence under grazing on the North-West Slopes, New South Wales. *Australian Journal of Agricultural Research*, 26, 731-741.

Dallman, P R. (1998) *Plant life in the world's mediterranean climates*, Berkeley and Los Angeles, California: California Native Plant Society, University of California Press.

Dear, B S. & Ewing, M A. (2008) The search for new pasture plants to achieve more sustainable production systems in southern Australia. *Australian Journal of Experimental Agriculture*, 48, 387-396.

Dear, B S., Moore, G A. & Hughes, S J. (2003) Adaptation and potential contribution of temperate perennial legumes to the southern Agricultural wheatbelt: a review. *Australian Journal of Experimental Agriculture*, 43, 1-18.

Dear, B S., Reed, K F M. & Craig, A D. (2008) Outcomes of the search for new perennial and salt tolerant pasture plants for southern Australia. *Australian Journal of Experimental Agriculture*, 48, 578-588.

Ewing, M A. (2004) New trees and pastures-when, where and likely role in farming system. In Ridley, A., Feikema, P., Bennett, S J., Rogers, M., Wilkinson, R. & Hirth, J. (Eds.) *Proceedings of the Conference Salinity Solutions: Working with Science and Society, 2-5 August 2004*. Bendigo, Victoria: CRC for Plant-Based Management of Dryland Salinity, Perth.

Ewing, M A. & Dolling, P J. (2003) Herbaceous perennial pasture legumes: Their role and development in southern Australian farming systems to enhance system stability and profitability. In Bennett, S J. (Ed.) *New perennial legumes for sustainable agriculture*. 3-14. Crawley, Western Australia: University of Western Australia.

Hatton, T J. & Nulsen, R A. (1999) Towards achieving functional ecosystem mimicry with respect to water cycling in southern Australian agriculture. *Agroforestry Systems*, 45, 203-214.

Hughes, S J., Snowball, R., Reed, K F M., Cohen, B., Gajda, K., Williams, A R. & Groeneweg, S L. (2008) The systematic collection and characterisation of herbaceous forage species for recharge and discharge environments in southern Australia. *Australian Journal of Experimental Agriculture*, 48, 397-408.

Hutchinson, M F., McIntyre, S., Hobbs, R J., Stein, J L., Garnett, S. & Kinloch, J. (2005) Integrating a global agro-climatic classification with bioregional boundaries in Australia. *Global Ecology and Biogeography*, 14, 197-212.

Moore, G.A. (2006) Introduction-why perennial pastures? In Moore, G.A., Sanford, P. & Wiley, T. (Eds.) *Perennial pastures for Western Australia*. Perth, Western Australia: Department of Agriculture and Food Western Australia.

Nichols, P.G.H., Loi, A., Nutt, B.J., Evans, P.M., Craig, A.D., Pengelly, B.C., Dear, B.S., Lloyd, D.L., Revell, C.K., Nair, R.M., Ewing, M.A., Howieson, J.G., Auricht, G.A., Howie, J.H., Sandral, G.A., Carr, S.J., de Konning, C.T., Hackney, B.F., Crocker, G.J., Snowball, R., Hughes, S.J., Hall, E.J., Foster, K.J., Skinner, P.W., Barbetti, M.J. & You, M.P. (2007) New annual and short-lived perennial pasture legumes for Australian agriculture-15 years of revolution. *Field Crops Research*, 104, 10-23.

Pagnotta, M.A., Bennett, S.J., Cocks, P.S., Ewing, M.A., Howieson, J.G., Moore, G.A., Norman, H.C., Nutt, B.J., Porqueddu, C., Russi, L. & Snowball, R. (2003) Evaluation of perennial legumes collected in Italy: First year data. In Bennett, S.J. (Ed.) *New perennial legumes for sustainable agriculture*. Crawley, Western Australia: University of Western Australia Press.

Puckridge, D.W. & French, R.J. (1983) The annual legume pasture in cereal-ley farming systems of southern Australia: A review. *Agriculture Ecosystems & Environment*, 9, 229-267.

Reed, K.F.M., Nie, Z.N., Miller, S., Hackney, B.F., Boschma, S., Mitchell, M., Albertsen, T.O., Moore, G.A., Clark, S.G., Craig, A.D., Kearney, G.A., Li, G.D. & Dear, B.S. (2008) Field evaluation of perennial grasses and herbs in southern Australia. I. Establishement and herbage production. *Australian Journal of Experimental Agriculture*, 48, 409-423.

Reeves, T.G. & Ewing, M.A. (1993) Is ley farming just a passing phase? *Proceedings of the XVII International Grassland Congress*. 2169-2177.

Revell, C. & Revell, D. (2007) Meeting 'duty of care' obligations when developing new pasture species. *Field Crops Research*, 104, 95-102.

Rogers, M.E., Craig, A.D., Munns, R., Colmer, T.D., Nichols, P.G.H., Malcolm, C.V., Barrett-Lennard, E.G., Brown, A.J., Semple, W.S., Evans, P.M., Cowley, K., Hughes, S.J., Snowball, R., Bennett, S.J., Sweeney, G.C., Dear, B.S. & Ewing, M.A. (2005) The potential for developing fodder plants for the salt-affected areas of southern and eastern Australia: an overview. *Australian Journal of Experimental Agriculture*, 45, 301-329.

Rossiter, R.C. (1966) Ecology of the Mediterranean annual-type pasture. *Advances in Agronomy*, 18, 1-56.

Russi, L., Bennett, S.J., Pagnotta, M.A., Norman, H.C., Nutt, B.J., Porqueddu, C., Cagiotti, M.R., Snowball, R. & Moore, G.A. (2003) Ecogeography of perennial legumes collecting missings in Italy. In Bennett, S.J. (Ed.) *New perennial legumes for sustainable agriculture*. 161-176. Crawley, Western Australia: University of Western Australia Press.

Sanford, P. (2006) Temperate perennial grasses. In Moore, G.A., Sanford, P. & Wiley, T. (Eds.) *Perennial pastures for Western Australia*. Perth, Western Australia: Department of Agriculture and Food Western Australia.

Stone, L.M., Byrne, M. & Virtue, J.G. (2008) An environmental weed risk assessment model for Australian forage improvement programs. *Australian Journal of Experimental Agriculture*, 48, 568-574.

Taylor, G.B., Maller, R.A. & Rossiter, R.C. (1991) A model describing the influence of hard seededness on the persistence of an annual forage legume, in a ley farming system, in a Mediterranean-type environment. *Agriculture Ecosystems & Environment*, 37, 275-301.

Underwood, E.J. & Gladstones, J.S. (1979) Subterranean clover and other legumes. In Burvill, G.H. (Ed.) *Agriculture in Western Australia 1829-1979*. 139-156. Crawley, Western Australia: University of Western Australia Press.

Ward, P.R., Dunin, F.X. & Micin, S.F. (2001) Water balance of annual and perennial pastures on a duplex soil in a Mediterranean environment. *Australian Journal of Agricultural Research*, 52, 203-209.