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Improvement of pasture and forage legumes and grasses for Mediterranean climate zones

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Abstract. Mediterranean climate zone pastures produce valuable animal products and sustain crop production. Well-managed natural grasslands in the Mediterranean basin contain a diversity of species that are adapted to survive the extremes of hot, dry summers and intermittent droughts. Many of these plants have also been introduced to other regions with similar climates, such as southern Australia. Extensive breeding and selection of pasture and forage species in Australia has led to a flourishing seed industry and the resulting cultivars have been sown world-wide in Mediterranean climates. Among the annual legumes, subterranean clover (*T. subterraneum*) and annual medics (*Medicago* spp.) have been widely utilised, while several other species have been released recently. Lucerne (*M. sativa*) is the most important perennial legume in Mediterranean climates, while early flowering, free-seeding white clover (*T. repens*) types are suited to higher rainfall parts of the zone. The temperate grasses, *Lolium perenne*, *Dactylis glomerata*, *Festuca arundinacea* and *Phalaris aquatica*, are important in higher rainfall areas of the Mediterranean zone, but require summer dormancy for persistence in drier parts. The summer-active perennial grasses, *Megathyrsus maximus*, *Chloris gayana* and *Pennisetum clandestinum*, have also been sown in parts of southern Australia with milder winter temperatures. Future cultivar improvement will make additional productivity and sustainability gains, particularly utilising local germplasm, but faces the issues of drier and more variable seasons, soil constraints, and greater profitability of cropping. Strong cooperation between scientists in Mediterranean climates and greater vertical integration between basic and applied science will provide the best solutions to farmers, in the face of declining research and development funds.

Keywords. Annual legumes – Perennial legumes – Perennial grasses – Cultivars – Australia.

Amélioration des légumineuses et graminées des pâturages et cultures fourragères dans les zones à climat méditerranéen

Résumé. *Les pâturages des zones à climat méditerranéen donnent des produits animaux intéressants et permettent la production de cultures. Les prairies naturelles bien gérées du bassin méditerranéen contiennent une diversité d'espèces qui sont adaptées pour survivre à des étés extrêmement chauds et secs et à des sécheresses intermittentes. Plusieurs de ces plantes ont aussi été introduites dans d'autres régions à climat semblable, comme le sud de l'Australie. L'amélioration et la sélection extensives des espèces pastorales et fourraggères en Australie ont crée une industrie des semences florissante et les cultivars résultants ont été semés dans le monde entier en climats méditerranéens. Parmi les légumineuses annuelles, le trèfle souterrain (*T. subterraneum*) et les medics annuelles (*Medicago *spp.) ont été largement utilisés, tandis que de nombreuses autres espèces ont été récemment commercialisées. La luzerne (*M. sativa*) est la légumineuse vivace la plus importante en climats méditerranéens, tandis que les types de trèfle blanc à floraison précoce, à ré-ensemencement (*T. repens*) sont adaptés aux parties plus pluvieuses de la zone. Les graminées tempérées,* Lolium perenne, Dactylis glomerata, Festuca arundinacea *et* Phalaris aquatica, *sont importantes dans les zones à plus forte pluviométrie de la région méditerranéenne, mais nécessitent une dormance d'été pour la persistance dans les zones plus sèches. Les graminées vivaces actives en été,* Megathyrsus maximus, Chloris gayana *et* Pennisetum clandestinum, *ont aussi été semées dans des zones du sud de l'Australie ayant des températures hivernales plus douces. L'amélioration future de cultivars permettra une productivité additionnelle et des gains en durabilité, en particulier en utilisant le germoplasme local, mais elle doit affronter les défis de saisons plus variables et plus sèches, de contraintes du sol, et d'une meilleure rentabilité des cultures. Une forte coopération entre scientifiques des climats méditerranéens et une plus grande intégration verticale entre science fondamentale et science appliquée apportera les meilleures solutions aux agriculteurs, face à la réduction de la recherche et des fonds de développement.*

Mots-clés. *Légumineuses annuelles – Légumineuses vivaces – Graminées vivaces – Cultivars – Australie.*

I – Introduction

Mediterranean climate zones are characterized by mild, wet winters and hot dry summers. Buddenhagen (1990) defines a Mediterranean climate as one where mean annual precipitation ranges from 250 to 900 mm, with at least 65% occurring in the autumn-to-spring period. Such climates typically occur within the latitudes 28° and 45° as transition zones between temperate and dry tropical climates. The Mediterranean basin, which includes the countries surrounding the Mediterranean Sea and extending east to Iraq and Iran, covers approximately 1067 million ha, or 60% of this area. Of the other regions with a Mediterranean climate, southern Australia occupies 22%, California 10%, central Chile 5% and South Africa 3% of the total area, respectively (Nichols *et al.* 2012). Other relatively small areas have quasi-Mediterranean-type climates with a higher proportion of summer rainfall, including parts of south-eastern Australia, New Zealand and Argentina, where plants adapted to Mediterranean climates also grow well.

Farming systems based on grasslands, defined by Peeters *et al.* (2014) as land devoted to the production of forage for harvest by grazing/browsing animals, cutting, or both, are important for Mediterranean regions, and help satisfy the increasing global demand for animal products. Porqueddu *et al.* (2016) note that the Mediterranean climate zones of the Mediterranean basin, southern Australia and Chile support 308 million sheep, 109 cattle and 105 goats. Cereal production is also important. In southern Australia and Chile, this is generally conducted in rotation with legume pastures, where grasslands are predominantly grazed, while cereal-fallow rotations are more typical in the Mediterranean basin (Porqueddu *et al.* 2016).

Mediterranean climates pose significant challenges to plant growth. Plants must cope with summer drought coupled with high solar radiation levels, cool winter temperatures during the growing season, and highly erratic and variable rainfall. Germination-inducing rainfall events followed by periods of drought, referred to as 'false breaks', are common and result in widespread death of establishing seedlings. This climate results in highly seasonal growth which favours annual and drought-tolerant perennial species. Annual plants escape this drought by forming seeds for germination in subsequent autumn-winter periods, while perennials need to have sufficient drought tolerance or drought avoidance mechanisms to survive. Well-managed natural grasslands in the Mediterranean basin are species-rich, particularly for annuals (Blondel and Aronson, 1999). These species have evolved a suite of strategies that enable them to survive the rigours of the climate and human-related disturbance, including seed dormancy and delayed germination, genotypic and phenotypic responses to interactions between temperatures and moisture, and morphological traits predisposing the fruits to dispersal by grazing animals or to soil burial (Blondel and Aronson, 1999).

Many of the plants native to the Mediterranean basin were introduced by early European settlers to other regions with similar climates, such as southern Australia, central Chile, California and the Cape region of South Africa (Nichols *et al.* 2012). Pasture species commonly used in Great Britain and northern Europe, such as lucerne (*Medicago sativa*), white clover (*Trifolium repens*), perennial ryegrass (*Lolium perenne*) and cocksfoot (*Dactylis glomerata*), were deliberately introduced to increase animal production - and remain important today. However, other plants, particularly annuals, were introduced accidentally, by means of seed contaminants in fodder and wool fleeces or as weed seeds, and became naturalized in many of the grasslands in these regions (Nichols *et al.* 2012). In Australia active cultivar development programmes have operated since the 1950s with the evaluation of germplasm collected from the Mediterranean basin and more recently from breeding programmes (Nichols *et al.* 2012). Such commercialisation has been accompanied by the development of a specialized pasture seed industry and many of these cultivars have subsequently been sown in the Mediterranean basin and other Mediterranean-climate areas to improve grassland productivity.

This paper outlines the breeding and selection of pasture and forage legumes and grasses for rainfed, (non-irrigated) Mediterranean climates and the future needs and opportunities for cultivar development. The emphasis is on the Australian situation, where much of this activity has taken place, but reference is made to the Mediterranean basin and other regions with Mediterranean climates where appropriate. We also focus on grasslands in which introduced (improved) grass and legumes have been sown, rather than those based on native vegetation.

II – Grassland improvement in Australia – An historical perspective

Whereas agriculture has been practised in the Mediterranean Basin for up to 10,000 years, it only commenced in Australia slightly more than 200 years ago with British colonization. Prior to the 1920s much of southern Australia was managed in very large landholdings (>100,000 ha) on which grazing animals, primarily sheep for wool, were run on grasslands dominated by native Australian grasses. These landholdings were then subdivided into much smaller properties, which necessitated the intensification of agriculture, resulting in the sowing of improved pasture species and much greater fertiliser usage. Native grasses remain important under extensive grazing systems in high rainfall, non-arable areas of south-eastern Australia, but their use under more intensive farming systems has rarely been successful.

Mixed farms now dominate the low and medium rainfall zones (250-600 mm), with cropping (particularly wheat) being the major agricultural industry, in rotation with wool, sheepmeat and beef production. Grasslands in these areas have traditionally been based on annual legumes grown in rotation with crops (Nichols *et al.* 2007, 2012). Higher rainfall areas tend to have a greater livestock focus, with permanent or semi-permanent pastures based on annual legumes, often with the addition of temperate perennial grasses and lucerne, particularly in south-eastern Australia (Nichols *et al.* 2012). Apart from native grasses and some halophytic shrubs (particularly *Atriplex* spp.) in lower rainfall areas, all other grassland species in southern Australia have been imported, mostly originating from the Mediterranean basin.

1. Annual legume improvement

The majority of native legumes are unsuited to the farming systems of southern Australia and many are toxic. A range of annual legumes, particularly subterranean clover (*T. subterraneum*) and annual medics (*Medicago* spp.), have been introduced into Australia, and are now widespread across the Mediterranean climate regions (Nichols *et al.* 2012). Subterranean clover, first marketed in 1907, is the most widely sown pasture legume, having been sown on moderately acidic soils over an estimated 29.3 M ha (Nichols *et al.* 2012). Fifty cultivars have been registered, enabling it to be grown in environments with annual average rainfall (AAR) ranging from 250–1200 mm (Nichols *et al.* 2013). Nine annual medic species with 40 registered cultivars have been commercialized since 1938, having been sown over an estimated 24.6 M ha (Nichols *et al.* 2012). These consist of the three most widely sown species, *M. truncatula*, *M. littoralis* and *M. polymorpha*, and the less-important species, *M. tornata*, *M. scutellata*, *M. sphaerocarpos*, *M. rugosa*, *M. murex* and *M. orbicularis*.

Other annual legume species have been developed for soil types and farming systems not suited to subterranean clover and annual medics. Cultivars have been based on germplasm collected from Mediterranean basin grasslands. Loi *et al.* (2005) and Nichols *et al*. (2007; 2012) describe 36 annual legume species from among the genera *Astragalus*, *Biserrula*, *Lathyrus*, *Medicago*, *Melilotus*, *Ornithopus*, *Trifolium* and *Vicia*, with Australian registered cultivars. The most important of these species include *B. pelecinus*, *O. compressus*, *O. sativa*, *T. michelianum*, *T. vesiculosum*, *T. spumosum*, *T. resupinatum* and *T. vesiculosum* (Nichols *et al.* 2007, 2012). *Melilotus siculus* is also undergoing commercialisation for saline soils prone to winter waterlogging. These new species were needed because of: (i) poor adaptation of subterranean clover and annual medics to difficult soils; (ii) poor adaptation to false seasonal breaks; (iii) depletion of subterranean clover seed banks from increased cropping frequencies; (iv) soil erosion caused by subterranean clover and annual medic seed harvesting; (v) the build-up of herbicide-resistant weeds; (vi) the need for lower cost seed for re-sowing pastures; (vii) the need for specialist fodder legumes; (viii) the requirement for longer-season plants to maximise production; and (ix) the need for greater diversity within paddocks (Loi *et al.* 2005; Nichols *et al.* 2007, 2012).

Underpinning these programs has been a large genetic resource of almost 60,000 accessions. The first Australian expedition to collect annual legume germplasm was conducted in 1951 and more than 90 expeditions have since been made (S.J. Hughes, pers. com.). Subterranean clover and annual medics were the initial targets, whereas alternative legumes have been the main targets since 1990 (Nichols *et al.* 2007, 2012). A key factor in the development of new legumes has been the selection of root nodule bacteria able to form nitrogen (N)-fixing symbioses (Loi *et al.* 2005). Novel low-cost pasture establishment systems utilizing hard seeds, either under-sown with a grain crop or into dry soil over the summer, are being developed to stimulate increased use of annual legume pastures (Loi *et al.* 2008, 2012). Such systems are now possible with the development of new granular clay inoculum systems, which enable rhizobial survival in dry soil.

There has been a major reduction in annual legume breeding and selection activity in Australia since 2005, following reduced funding by government agencies for pasture breeding, with some support from private seed companies.

2. Perennial legume improvement

Pastures with perennial forage species have advantages over those based only on annuals by extending the feeding season into autumn-early winter and late spring, when annuals have senesced (Volaire 2008). They reduce soil erosion by maintaining year-round groundcover and reduce deep drainage, thereby reducing the potential for dryland salinity. However, few perennial species are suited to the severe summer dry spells experienced in Mediterranean climates (Annicchiarico *et al.* 2011; 2013). Required traits include dormancy or low growth during the summer drought period (Volaire *et al.* 2013) and high water-use efficiency during the growing season (Lelièvre *et al.* 2011). A combination of strategies to overcome drought are present in some plants, including: (i) dehydration avoidance, (Volaire and Lelievre 2001); (ii) dehydration tolerance (Volaire, 2008); and (iii) summer dormancy (Norton *et al.*, 2006; 2012).

A. Lucerne

Lucerne is widely used for dryland grazing and for the production of high quality fodder, particularly in south-eastern Australia. Until the late 1970s, more than 95% of Australian-sown lucerne was the cultivar, Hunter River, derived from original populations introduced by the early settlers (Nichols *et al.* 2012). In 1977 arrival of the aphids, *Acyrthosiphon kondoi* and *Therioaphis trifolii*, caused widespread lucerne devastation, as Hunter River was highly susceptible. This resulted in several publicly-funded breeding programs to develop lucernes with aphid resistance and 21 cultivars were registered by 1990 (Oram 1990). Two public breeding programs continue to operate, in partnership with private seed companies. Australian cultivars with better grazing tolerance, disease resistance and winter productivity have been bred, with over 70 registered by 2012 (Nichols *et al.* 2012). Increasing private sector investment in lucerne improvement is likely to continue, with further declines in public sector investment.

B. White clover

The greatest use of white clover is in temperate climates. In Australia it only reliably exists as a perennial in wet coastal or irrigated areas or in cooler, elevated environments with summer-dominant rainfall. The most significant Australian contribution to white clover development was the release in 1971 of the cultivar Haifa (Oram 1990), which is better suited to Mediterranean climates than traditional forms of the species. Its early flowering and prolific seeding allows cv. Haifa to persist by also utilising an annual habit, because summers are too long and dry in most Mediterranean climatic regions for the species to survive as a perennial. Other cultivars have since been released, but Haifa continues to be important in Australia and internationally. In many ways it woke up the World to the potential of white clover in Mediterranean climate zones.

C. Other species

Of other perennial legumes for Mediterranean dryland regions, *T. fragiferum* has been the most widely sown, particularly in summer-moist areas prone to winter waterlogging, while smaller areas have been sown to *Lotus corniculatus* and *L. uligonosis* (Nichols *et al.* 2012). *Dorycnium hirsutum* and *T. tumens* have recently been released, but it is too soon to judge their commercial success. Although *Hedysarum coronarium* is widely used in parts of the Mediterranean basin, it has been little used in Australia, but the release of better adapted cultivars may see its use increase. *Bituminaria bituminosa* var. *albomarginata* is a promising new perennial legume being developed in Australia and Spain (Oldham *et al.* 2013), with extreme drought-tolerance (Foster *et al.* 2015). Other perennial legumes from the Cape regions of South Africa are also being evaluated by Murdoch University (Howieson *et al.* 2008). Interest in developing alternative perennial legumes has arisen from a need to overcome soil and climatic constraints affecting lucerne performance and to develop deep-rooted perennial species for soils not suited lucerne, aimed at reducing deep drainage (Nichols *et al.* 2012).

3. Perennial grass improvement

A. Temperate grasses

Initial sowings of imported perennial ryegrass and cocksfoot by the early settlers generally failed because of their poor adaptation to the hotter and often drier Australian conditions. In the few regions where they did survive natural selection produced types better adapted to the Australian climate. Seed production from the 1920s was based on these naturalised populations (Reed 2014). The widely used perennial ryegrass cultivars, Victorian and Kangaroo Valley, are examples of this germplasm (Oram 1990). After the Second World War, exotic temperate C3 perennial grasses including perennial ryegrass, cocksfoot, tall fescue (*Festuca arundinacea*) and phalaris (*Phalaris aquatica*) became more widely sown in the higher rainfall areas of south-eastern Australia. This led to germplasm collections to the Mediterranean Basin from the 1950s aimed at finding germplasm of these species better adapted to more intensive grazing systems under Mediterranean climates (Neal-Smith 1955). The germplasm from these expeditions resulted in a range of grass cultivars, including Medea perennial ryegrass, Currie and Kasbah cocksfoots, Demeter and Melik tall fescues and Sirocco phalaris. Medea, Kasbah, Melik and Sirocco all have summer dormancy, which has proved to be a very important trait for adaptation to Mediterranean climate zones, as it improves survival during drought. This trait has consequently extended the adaptation zone of these grasses into regions previously considered too dry. Indeed, summer-dormant germplasm could enhance adaptation to Mediterranean regions in the future to mitigate the predicted effects of increasing drought periods.

Publically-supported Australian perennial ryegrass and tall fescue improvement programs operated in the 1990s and 2000s, but have since terminated. However, phalaris breeding is continuing. Phalaris is an interesting species because, although it is of Mediterranean origin (Anderson 1961), it is rarely sown in the Mediterranean Basin, even though of the four grasses it is the most productive during spring (Norton *et al.* 2008) and persists through drought (Oram and Freebairn 1984). Its use is primarily restricted to Australia, where it is sown over 2.7 M ha. The reason why phalaris is little used in other Mediterranean climate zones is probably related to historical reasons associated with species commercialisation choices during seed industry development in Europe. Around 1900, when phalaris was first introduced and promoted in Australia, there were no other suitable temperate, perennial grasses, due to failure of European imported populations. Thus, Australian farmers came to appreciate its advantages while coping with occasional toxicity problems (R.A. Culvenor, pers. com.).

B. Sub-tropical grasses

Summer-active, C4 perennial grasses have been widely sown in sub-tropical areas of north-eastern Australia. However, since 2000 they have been increasingly sown in Mediterranean areas, particularly in Western Australia (WA). *Megathyrsus maximus* and *Chloris gayana* have been sown on >50 000 ha of infertile sandy soils in the agricultural area north of Perth, which has relatively mild winter temperatures (Moore *et al.* 2014). These grasses have excellent drought tolerance, persisting through extended hot, dry periods of 6–7 months over summer–autumn. A key to their use has been an agronomy package to increase establishment reliability in the Mediterranean climate zone (Moore *et al.* 2014). *Pennisetum clandestinum* has been sown along the coastal strip of southern and south-western Australia for many years, where summer temperatures are milder than most Mediterranean areas with a higher proportion of summer rainfall. Its use has increased markedly over the past 20 years, with >150 000 ha sown in the south-coast region of WA alone (Moore *et al.* 2014). Producer interest in these grasses is due to increased pasture production in autumn–early winter, provision of out-of-season green feed, and their ability to reduce wind erosion by maintaining groundcover throughout the year and reduce deep drainage. Until recently sub-tropical grass cultivars used in the Mediterranean climate zone have originated from selection programs for sub-tropical areas. However, two new cultivars of *M. maximus* have been selected for their adaptation to a Mediterranean climate.

III – Issues, future challenges and opportunities for pasture and forage improvement in Mediterranean climate zones

1. Climate change

Climate change is forecast to have a great impact on agricultural production systems in regions with Mediterranean climates. In south-western Australia, rainfall has declined by 10% over the past 30 years, with this decrease most evident in the autumn-winter period, while projections to 2050 indicate a further decline and increased inter-annual variability in rainfall, accompanied by average annual temperature increases of 0.7-1.2ºC (Watterson *et al.* 2007). Similar changes are expected in the Mediterranean basin (Giorgi and Lionello, 2008). This change in climate has important implications for Mediterranean grassland productivity and farming systems will need to adapt. Shorter growing seasons are likely to have the greatest impact on pasture growth (Revell *et al.* 2012).

Drought escape is the main adaptive strategy of annual species, as they survive the dry summer period as seeds. In legumes, seed dormancy is determined by hardseededness. This enables a proportion of seeds in the seed-bank to remain dormant for germination in subsequent seasons, allowing regeneration after years of little or no seed-set. The amount of hard seeds and the timing of their softening differ between and within species, and often the timing of seed softening may be more important than the level of hardseededness (Loi *et al.* 2005; Nichols *et al.* 2007). The predictions of lower, more variable autumn rainfall and shorter springs mean that annual legumes will need: (i) earlier maturity for reliable seed set in shorter growing seasons; (ii) more delayed softening of hard seeds, to reduce seedling losses from false breaks; (iii) greater hardseededness, to allow for more frequent seasons of little or no seed set; and (iv) a less determinate flowering habit to take advantage of longer growing seasons when they occur (Revell *et al.* 2012).

Warmer, drier climates will pose significant productivity challenges to perennial-based pastures. The major research need is to identify traits that confer enhanced drought survival, including: (i) increasing the depth and density of grass root systems to strengthen dehydration avoidance; (ii) exploring the biochemical, molecular and hydraulic bases of dehydration tolerance and improving techniques to measure them ; (iii) breaking the trade-off between summer dormancy and forage yield potential and improving understanding of environmental, biochemical and genetic controls over summer dormancy; and (iv) identifying non-toxic endophyte strains compatible with summer-dormant tall fescue cultivars to enhance its drought survival. While not directly associated with climate change it will be necessary to ensure that new cultivars have sufficient seed production to be commercially viable. The development of agronomic management packages for promoting stable mixtures combining perennial grasses and legumes will also be required.

2. Overcoming soil constraints

Soil acidity is increasing in much of southern Australia (Scott *et al.* 2000). If liming becomes uneconomic, it will require cultivars of existing species with more acid tolerance or replacement of them with more acid-tolerant species. Phosphorus (P) fertiliser is becoming more expensive and the response of many farmers has been to reduce their application rates, which usually reduces pasture production. The development of more P-efficient pasture legumes, that can produce the same amount of biomass with less P inputs, would result in greater profitability (Simpson *et al.* 2011).

3. Development and commercialisation of locally adapted cultivars

Improved forage legumes and grasses are seen as crucial to increase productivity of Mediterranean grassland systems and there is an urgent need to develop new cultivars. In the Mediterranean basin a wide range of species is currently used but very few locally adapted cultivars are sown, apart from lucerne, due to the lack of a pasture seed industry. Seed of most available perennial grassland species is selected and multiplied in Central Europe, Denmark and New Zealand, whereas most annuals are selected, multiplied and imported from Australia. For example, over the past 40 years cultivars of annual legumes, particularly subterranean clover and annual medics selected in Australia, have been increasingly utilized in the Mediterranean basin, but, these cultivars have often been poorly adapted to local conditions (Porqueddu *et al.* 2016). Native genotypes of these species have been selected, but efforts to promote their seed multiplication have largely been unsuccessful. Selection among local strains is likely to identify the most promising types for these regions, but this needs to be accompanied by the development of a pasture seed industry. Indeed, involvement with seed companies is essential to develop these markets to ensure they are profitable and sustainable.

4. Increased recognition of the value of pastures in cropping systems

On mixed farms, the perceived value of pastures is related to the value of livestock products compared to grain prices. As a result of higher grain prices, traditional crop-pasture rotations have changed in southern Australia over the past two decades. More farms have reverted to continuous cropping and fewer pastures are managed for high legume content, with crops reliant on inorganic N. This has resulted in a generation of farmers, extension officers and consultants with little pasture knowledge. This has been mirrored in research-funding priorities, with increased priority given to cropping, at the expense of pastures. Future investment in improved pastures and cultivars, however, is likely to increase at some stage. A major issue for mixed farming systems concerns the management of crop weeds, with many target weeds now resistant to common herbicides (Nichols *et al.* 2007, 2012). The pasture phase is likely to become increasingly important for controlling crop weeds. The issue of soil residues of some crop herbicides, particularly the sulfonylurea group, also needs to be addressed, as they can severely affect germination and growth of pasture legumes. Therefore, weed management strategies need to be deployed that better integrate pastures into mixed farming systems (Nichols *et al.* 2012). The cost of N fertiliser is likely to increase and its application may eventually become uneconomic. This will stimulate better management of legume-based pastures to increase N supply for subsequent crops. Furthermore, under future climate scenarios livestock production is likely to provide greater resilience to mixed farming systems by reducing risk and providing cash flow to farmers in seasons unfavourable for cropping.

5. Improved ecosystem services and amenity value of grasslands

Well-managed grasslands produce positive externalities, such as recreational activities, public goods and generic environmental services, which are of particular importance in the Mediterranean basin (Porqueddu *et al.* 2016). Improved pasture and forage plants, in conjunction with sustainable grazing management, can enhance grassland ecosystem services and amenity value. They can be used to rehabilitate degraded landscapes from soil erosion or overgrazing; such plants need an ability to bind the soil and persist under grazing. Grasslands play an important role in the global carbon (C) cycle with more productive grasslands resulting in higher C sequestration. However, more studies are required to quantify the contributions of key pasture species (Porqueddu *et al.* 2016).

Australian data indicate 70% of agricultural methane emissions come from ruminant livestock as a bi-product of microbial fermentation of feed in the rumen (Garnaut 2008). Studies have shown variation between fodder species for methanogenic potential in the rumen, suggesting that pasture plants can be developed with low methanogenic potential, thereby helping mitigate greenhouse gas emissions (Makkar and Vercoe 2007).

Research in southern Australia has shown adapted perennial pasture species can have major benefits to farming system sustainability, largely through increased soil water use. This acts to reduce nitrate leaching, which in turn reduces soil acidification, and also reduces the risks of dryland salinity (Ridley *et al.* 1990).

6. Use of pasture and livestock production modelling

In Australia there has been an increasing emphasis since the late 1990s on use of biophysical models, such as Grassgro and the SGS Pasture Model, to predict both pasture and associated grazing livestock production (Moore *et al.* 1997). These models are driven by weather data, while also accounting for local edaphic and grazing management factors that impact on forage production. The predictive capability of modelling has meant this approach is greatly valued by farmer advisors and consultants. Leading graziers are also increasingly using these models as it allows them to compare different pasture species and livestock production enterprises and strategies. However, such models have their limitations. For example, neither Grassgro nor the SGS Pasture model predict pasture plant demography (Moore *et al.* 1997) and have limited ability to predict outcomes of the severe droughts that can cause wide-scale pasture plant deaths in Mediterranean environments. Nevertheless, as the robustness of such models increase, they are likely to become increasingly useful for decision making at the farm-scale, in addition to determining research and policy priorities.

7. The role of biotechnology in developing improved grassland cultivars

DNA-based molecular marker technologies have a range of potential applications for pasture and forage improvement programs, but this is only likely in the most economically important species. They can be used for marker-assisted selection (MAS) to select among genetically variable breeding populations for closely-linked target traits, while major reductions in the cost of genome sequencing and high throughput technologies have heralded 'genomics-assisted breeding', in which selection can be conducted for many traits simultaneously using molecular markers. Their applications are likely to increase as more molecular markers for specific traits are developed and they become more economic to use. A more controversial technology is genetically modified (GM) plants, in which genetic material is incorporated from other species. Such technology has the potential to deliver quantum leaps in productivity, but public and industry concerns need to be allayed before they can be introduced onto the market.

Among pasture legumes, the genomes of barrel medic (Young *et al.* 2011) and subterranean clover (Nichols *et al.* 2012) have been sequenced in Australia. Core collections, which maximise species diversity in a small number of varieties, have been developed and will allow better utilisation of genetic resource collections for screening new traits and parent selection. Molecular markers for important traits are also being developed in these species. However, no white clover, red clover or lucerne breeding programs have used MAS to date, due to their complex polyploid and out-crossing genetics. Among the grasses, genomic selection methodologies are being developed in the Australian phalaris breeding program.

Some investment in molecular biology technologies for pasture and forage improvement is justifiable, as they have the potential to deliver outcomes that conventional plant breeding programs may never achieve. However, such programs are expensive, technically challenging and likely to be confined to the major species. To achieve commercial outcomes strong linkages are needed to practical breeding and agronomy programs to ensure traits are relevant to cultivar improvement and developed products perform well agronomically in the field.

8. Changed funding landscape

Porqueddu *et al.* (2016) raise concerns about decreasing public sector support for grassland research and development (R & D). This is particularly evident for pasture breeding and selection. With the withdrawal of public funding for applied R & D, it is not clear where new on-farm innovations will come from. Private industry will provide some input, but only for the most profitable species. This means the smaller Mediterranean seed markets are likely to be poorly serviced. Conversely, the priority for Universities will continue to be more fundamental research. In Australia many pasture breeding activities have transferred in the last decade from the public to the private sector. With the perennial grasses, the larger transnational companies acknowledge that the relatively small global market for Mediterranean regions means they are unlikely to invest heavily in breeding for these regions. Indeed, it is invariably cheaper for these companies to import varieties bred in Europe and North America into Australia, in the hope that some will be adapted, rather than initiating specific breeding programs. As this trend continues it is likely that new perennial grass cultivars will exhibit narrower adaptation to Australian conditions than the older publically-bred varieties. These developments are also likely to impact on other Mediterranean regions, given their previous reliance on Australian-bred cultivars.

The implication for applied grassland R & D is the need for greater international cooperation between the remaining scientists and institutions in Mediterranean areas of the World, in order to provide innovative and sustainable solutions to farmers. With Australian R & D rapidly declining in this area, other countries will need to take a greater leadership role. Researchers should also involve farmers as a key priority – they keep research applied and relevant, there are learning opportunities from farmer's observations and experiences, and it means research outputs are more likely to be adopted. However, while such participatory research is important, there is still the need to write papers to properly document research.

IV – Conclusions

Mediterranean climate regions continue to be important for high quality animal products and cereal production. Plants in natural Mediterranean grasslands have evolved to cope with the extremes of hot, dry summers and intermittent droughts, while sown cultivars have been developed to optimise pasture and forage production. Further cultivar improvements are needed to make additional productivity and sustainability gains, particularly utilising local germplasm from the Mediterranean basin, but this needs to be accompanied by development of a local pasture seed industry. Multidisciplinary investigations are needed to identify the best-adapted and most productive grassland species, cultivars and mixtures for animal production in each region, along with the most appropriate grazing management. This work must occur in the face of drier and more variable seasons, soil constraint issues, an increased focus on cropping at the expense of animal production, and declining R & D investment in grassland science. Greater cooperation between scientists and agencies in Mediterranean climates will help maximise technological advancements from a smaller R & D base, while involvement of farmers in R & D will help maximise adoption rates. Greater vertical integration between basic and applied science will also provide greater opportunities for innovative solutions to reach farmers.

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