Commercialisation and Impacts of Pasture Legumes in Southern Australia–Lessons Learnt

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Commercialisation and impacts of pasture legumes in southern Australia – lessons learnt

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Abstract. Forage legumes are a key feature of temperate grasslands in southern Australia, valued for their ability to increase animal production, improve soil fertility and fix atmospheric nitrogen. Of the 36 temperate annual legume and 11 temperate perennial legume species with registered cultivars introduced or domesticated in Australia over the last 100 years, a third have made a major contribution to agriculture, a third have modest use and a third have failed to make any commercial impact. Highly successful species include subterranean clover, barrel medic, white clover, lucerne, French serradella and balansa clover. Species were assessed on the scale of their application, ease of seed production and specific requirements for agronomic management to determine critical factors for maximising commercial success. Of fundamental importance is the need to understand the farming systems context for legume technologies, particularly as it relates to potential scale of application and impact on farm profitability. Other factors included a requirement for parallel investment in rhizobiology, implementing an adequate 'duty of care' problem-solving framework for each new plant product and the need to construct a commercialisation model that optimises the trade-off between rapid adoption by farmers and profitability of the seed industry. Our experience to date indicates that seed industry engagement is highest when they have exclusive rights to a cultivar, can exercise some control over seed production and can market seed for a premium price without having to carry over significant seed quantities from one season to the next. A capability for non-specialist seed production on-farm (with lower associated seed costs) is a disincentive for the seed industry, but may be an appropriate commercialisation model for some public cultivars.

Keywords: grasslands, adaptation, duty of care, seed production, rhizobia, intellectual property.

Introduction

Forage legumes are a key feature of Australian farming systems, valued for their ability to increase animal production, improve soil fertility and fix atmospheric nitrogen (N). Grazing industries have relied heavily on exploitation of exotic legumes because the native species evaluated to date do not have the combined productivity and ease of propagation that can be applied on a commercial scale. Australian farmers have widely embraced the use of new pasture legume species, with 36 annual and 11 perennial legumes having registered cultivars (Nichols *et al*. 2012). They have been developed to match a diversity of climates, soil types and production systems, but few species have achieved the level of commercial success or matched the impact of the species introduced early into Australian agriculture such as subterranean clover (*Trifolium subterraneum* L.), lucerne (*Medicago sativa* L.) and white clover (*T. repens* L.) (Nichols *et al*. 2012). In this paper we examine the development and use of exotic annual and perennial legumes in southern Australia and assess their impact on productivity against their scale of application, ease of seed production and requirements for agronomic management, to determine critical factors for cultivar success.

Pasture legumes in southern Australia

Pasture legumes in southern Australia come from four main pathways: (1) deliberate introduction of cultivated varieties by the early British settlers, including white clover, red clover (*T. pratense* L.) and lucerne; (2) naturalised populations from accidental introductions (predominantly herbaceous annual legumes from the Mediterranean region such as subterranean clover and annual medics (*Medicago* spp.); (3) deliberate introduction from native habitats to expand the genetic resource of both traditional and novel species; and (4) targeted breeding programs (Nichols *et al*. 2012). Since the late 1970s this has been matched by the recognition that systematic effort needs to be directed into improved rhizobial performance, by identifying bacteria better able to colonise soils and fix nitrogen efficiently in symbiosis with specific host legumes (Ewing 1989, Howieson and Ballard 2004).

The range of annual and perennial pasture legume species grown in southern Australia has been reviewed by Nichols *et al*. (2012), who showed their qualitative levels of adoption (described as utilisation) varies widely across the species. Of 11 species of perennial legumes, four are categorised as widely used, two are rated as having moderate use, three have failed commercially and two are too new to assess. Of 36 species of annual legumes, 13 are widely used, 12 have moderate use, 10 have largely failed and one is too new to assess.

Perennial Legumes

White clover and lucerne are the most important perennial legumes in southern Australia and their use dates back to the early 1900s. White clover is confined to high rainfall (>750 mm annual rainfall) and irrigation areas, while lucerne has a much greater geographic and climatic coverage (restricted by acid, shallow and waterlogged soils). Lesser used species include red clover and strawberry clover (*T. fragiferum* L.), which have much smaller target environments. Species that have had little or no industry impact to date include Caucasian clover (*T. ambiguum* M. Bieb.), sainfoin (*Onobrychis viciifolia* Scop.), birdsfoot trefoil (*Lotus corniculatus* L.), greater lotus (*L. pedunculatus* Cav.) and sulla (*Hedysarum coronarium* L.). A major challenge for further development of perennial legumes is adaptation to the predictions of a drying climate with more within-season variability (Howden *et al*. 2008). In this context, new cultivars of birdsfoot trefoil and talish clover (*Trifolium tumens* Steve. Ex M.B.) have been developed in the last 10 years for high rainfall permanent pastures to provide more drought tolerant alternatives to white clover (Real *et al*. 2012, Nichols *et al*. 2012). Perennial legume options for summer-dry environments (< 600 mm annual rainfall) are limited, despite exhaustive genetic prospecting (Dear *et al*. 2008, Real *et al*. 2011), and lucerne continues to be one of the few options. However, recent plant selection efforts have identified tedera (*Bituminaria bituminosa* C.H. Stirt. var. *albomarginata*) as having a remarkable ability to retain green leaves and persist under drought (Real *et al*. 2008, Foster *et al*. 2012).

Annual Legumes

Subterranean clover (ssp. *subterraneum*) has been the dominant annual pasture species since the early 1900s occupying large areas of acidic soils. The zone of adaptation expanded over the 1940s-50s with the development of ssp. *yanninicum* for waterlogged soils and ssp. *brachycalycinum* for more neutral cracking soils. During the period from 1938 to 1969 a range of annual medic species adapted to alkaline soils were first released and became widely adopted, including barrel medic (*M. truncatula* Gaertn), strand medic (*M. littoralis* Rhode ex Loisel) and disc medic (*M. tornata* L. Mill.). These were complemented by common vetch (*Vicia sativa* L.) developed in the 1920s as a grain and forage legume. A major change in the direction of annual pasture breeding and selection occurred in the mid-1980s as a result of sustainability and economic challenges to existing farming systems and recognition that the available species were not suited to all agro-ecological niches. The drivers are discussed in detail by Loi *et al*. (2005) and Nichols *et al*. (2007, 2012) and include the search for species with: (1) tolerance of highly acid soils, waterlogging and/or salinity; (2) improved seed ecology for coping with false breaks of season (germination followed by drought causing seedling death) and intensive cropping systems; (3) deeper root systems to extend length of the growing season; (iv) increased pest and disease tolerance; (4) ease of seed harvesting; and (5) capability for specialist fodder production. Since 1992, 14 annual pasture and fodder legumes new to Australian agriculture have been released including seven species new to world agriculture (Nichols *et al*. 2007, 2012).

Highly successful new species include balansa clover (*T. michelianum* Savi) and French serradella (*Ornithopus sativus* L.), while species of low to moderate impact include biserrula (*Biserrula pelecinus* L.), burr medic (*M. polymorpha* L.), yellow serradella (*O. compressus* L.), rose clover (*T. hirtum* All.), crimson clover (*T. incarnatum* L.) and Persian clover (*T. resupinatum* L.). Species which have had little or no industry impact include milk vetch (*Astragalus hamosus* L.), dwarf chickling (*Lathyrus cicera* L.), grass pea (*L. sativus* L.), murex medic (*M. murex* Willd.), slender serradella (*O. pinnatus* Miller Druce), cupped clover (*T. cherleri* L.), purple clover (*T. purpureum* Loisel), Eastern star clover (*T. dasyurum* C. Presl) and purple vetch (*V. benghalensis* L.). Future challenges for annual legumes include adaptation to climate change (Revell *et al*. 2012), increased pest and disease tolerance and further expansion of species into difficult environments (*e.g.* messina (*Melilotus siculus* (Turra) B. D. Jacks) for saline soils prone to waterlogging (Bonython *et al*. 2011)) and into new farming systems (*e.g.* short phase pastures in cropping systems or as companion legumes for perennial grasses). New pasture establishment techniques, based on a better understanding of seed dormancy release (hard seed breakdown), are also being developed to reduce the cost of re-sowing and have yielded promising results for species like French serradella and bladder clover (*T. spumosum* L.) (Loi and Nutt 2010).

Role of the seed industry

Private seed companies and distributors play an important role in the pasture seed supply chain, with functions including production and supply of pedigree and certified seed to Australian and international markets, marketing of proprietary cultivars, provision of pasture management advice and the application and maintenance of Plant Breeders Rights (PBR), where appropriate. Seed companies are increasingly forming partnerships with public pasture breeding programs to develop new pasture cultivars, with greatest interest in the more established species like lucerne, white clover and subterranean clover (Nichols *et al.* 2012). Pasture cultivars have been commercialised using different types and levels of Intellectual Property (IP) protection, including public release (unprotected), PBR (comprehensive protection) and Trade-marking of cultivar names (limited protection). This has been coupled with single or multiple license options available for each model. The PBR system has been the preferred model as it offers the greatest IP protection and an opportunity to generate royalty payments in recognition of the breeding effort.

However, royalties are not always fully captured because of an open supply chain. The pasture supply chain is not compatible with an end-point royalty system, as is often applied to crop cultivars. Seed companies have favoured exclusive licensing of cultivars to maximise their return on investment and minimise 'over the fence' trading of PBR-protected cultivars. A seed market of at least 20 t/yr is regarded as the low threshold benchmark for sustained commercial viability of a cultivar, similar to that in New Zealand (Rolston 2003).

Critical success factors and lessons learnt

When examining the characteristics of species based on their commercial success or failure of uptake, several important features emerge. These are described here in terms of the ADOPT decision support tool (Kuehne *et al*. 2011), designed to predict farmer's adoption behaviour when faced with agricultural innovations.

Distinctiveness of species and cultivars (characteristics of the innovation)

Successful species clearly have distinguishing features that include a capacity for broad adaptation across a range of soil types, climate and farming systems (*e.g.* lucerne, subterranean clover), meet acceptable levels of productivity and persistence or have specific adaptive traits such as waterlogging tolerance (*e.g.,* balansa clover, white clover), tolerance to acidity (French and yellow serradellas) or seed dormancy attributes compatible with cropping systems (barrel and burr medics). It is rare for a lack of distinguishing features at the species level to be a direct constraint on adoption but species with intermediate use are often restricted by a small (or niche) target market (*e.g.,* non-waterlogged saline soils in the case of sweet clover, *Melilotus albus* Medik.). The larger the target market the more likely is species success and the more likely that the seed industry will be engaged and allocate resources to marketing. For example lucerne is grown on 3.2 M ha in Australia with the potential for a further 27 M ha (Robertson 2006) and subterranean clover is already grown on nearly 30 M ha (Hill and Donald 1998, cited in Nichols *et al.* 2012). It is also clear that species with international markets (*e.g.,* lucerne, white clover, subterranean clover and Persian clover) are more likely to gain seed industry support.

In some situations, unforeseen negative characteristics have constrained adoption (*e.g.,* susceptibility to pests and diseases in some annual medics, lucerne and Eastern star clover and a photosensitive reaction by livestock grazing biserrula) but have, or could be, overcome with further breeding and selection. The passage of time inevitably plays an important role in the long term success of a species, as barriers or constraints to adoption arise and are then addressed through research/breeding. Even a successful species like subterranean clover took several decades to fully reach its potential as significant barriers were overcome, such as the issue of oestrogenic iso-flavones affecting sheep reproduction and the development of technologies for seed harvesting. Undertaking an adequate 'duty of care' in plant improvement programs based on the anticipation of likely problems can reduce the risk of species and cultivar failure (Revell and Revell 2007) but adds to the overall cost and time for development.

Impacts on paddock and farm profitability (relative advantage of using the innovation)

Relative advantage is encapsulated in the concept of paddock and farm level profitability and in pay-back periods for the investment in pasture improvement. Perceptions of marginal effects on farm profitability from long pay-back periods to recover investment costs and the availability of competing technologies are recognised as major barriers to adoption of new pasture technologies. Successful species are generally characterised by clear profit drivers such as filling seasonal feed gaps to reduce grain feeding (*e.g.,* lucerne) and supplying N to crops grown in rotation to reduce fertiliser N (*e.g.,* subterranean clover, annual medics and French serradella). For well established species, the uptake of new cultivars can be constrained by a lack of distinctiveness, particularly where relative advantage is more difficult to demonstrate.

Analysis of farming systems and impacts on farm profit has been greatly helped by the use of bio-economic whole-farm models such as Model of an Integrated Dryland Agricultural System (MIDAS), where the relative advantage of new technical innovations for pastures can be tested alongside competing and established technologies. They also allow analysis of the impact of externalities such as changing commodity prices for wool, meat and grain. Such analyses have highlighted the advantage of alternative annual legumes to subterranean clover by extending the length of growing season (Bathgate *et al.* 2009) and the ability of the perennial legume tedera to fill the autumn feed gap and reduce supplementary feeding (Finlayson *et al*. 2012) in mixed farming systems of Western Australia.

Seed cost directly influences profitability (Rolston 2003, Nichols *et al*. 2012) and is clearly a characteristic that separates successful from unsuccessful species. High cost seed can be linked to low seed yields or to high costs of production (*e.g.,* need for pollination vectors or irrigation), seed collection (*e.g.,* constrained by pod shatter) and/or seed processing (*e.g.,* pod threshing or dehulling). Some of these factors have been responsible for the failure of species like Caucasian clover, Greater lotus, sainfoin, purple clover, murex medic, cupped clover and slender serradella. It has also been a constraint to the wider use of species like yellow serradella and sulla. The future of subterranean clover and annual medic seed harvesting is threatened by concerns over the potential for soil erosion during the harvesting operation and may impact on future seed availability. The deliberate focus on pasture cultivars that are readily harvested on-farm with conventional cereal harvesting machinery (Loi *et al.* 2005) has led to the development of a number of aerial seeding species including French serradella, gland clover (*T. glanduliferum* Boiss.), arrowleaf clover (*T. vesiculosum* Savi) and pod-holding annual medics. While such traits aid rapid adoption, cultivars that can be easily produced on-farm are of much less interest to seed companies because supply management is less regulated, resulting in lower seed sales, greater price instability and lower profit margins.

Adoptability (learning of the relative advantage of the innovation and ease of management)

Adoptability of new pasture technology is substantially influenced by the ease of on-farm trialability and complexity of agronomic management. Farmers are less willing to invest in a new technology unless they can be convinced of the economic benefits and its implementation and management is simple and compatible with existing farming operations. Adoption of new species will be limited if they require special attention to grazing management in order to be successful (*e.g.,* deferred grazing for seed production or rotational grazing) or have specific requirements for management (*e.g.,* need for pollination vectors in outcrossing species, limited selective herbicide options or regular pest management). Champion research and extension practitioners (that may include farmers) are critical to promote and support the uptake of new technologies. For seed companies, there is less risk attached to traditional species like subterranean clover and less investment is required to educate farmers and the supply chain on their merits (Nichols *et al*. 2012). The need for special management requirements relating to herbicides and/or grazing have limited the uptake of some aerial-seeded annual legume species like Eastern star clover, crimson clover, yellow serradella and gland clover.

Commercialisation framework

Pasture legume development initiatives without explicit attention to the potential for commercial application runs the risk of irrelevant research outcomes. We suggest the commercialisation of pasture plant cultivars can be described in a simple framework that has evolved over the last five decades (Table 1). The framework relates a range of pasture seed and agronomic characters to three commercialisation categories (General, Specialist and Niche) involving varying degrees of seed industry engagement and seed price (driven by seed yield and ease of harvesting and processing). The General category is typical of species suitable for on-farm seed production with conventional grain harvesters that require little additional skills, such as French serradella. The Specialist category is typical of species requiring specialist seed growers with specific management skills or harvest technologies, such as subterranean clover, annual medics and lucerne. The Niche category is typical of species with high seed costs (low yields or very specific production requirements), such as sulla and yellow serradella. Species (and cultivars) can move from one category to another as particular constraints are overcome by breeding or technology improvements. For example, subterranean clover moved from the Niche to Specialist category as suction harvesting technology was developed in the 1960s, bladder clover may move from the Specialist to General category if sowing methodology using hard seeds is more widely embraced and yellow serradella and sulla may also move between these categories with the development of cultivars with easier seed processing. A species in the General category could potentially be shifted to a Specialist category (to make it more attractive to seed companies) if a required technology (*e.g.,* a specific rhizobia or a requirement for seed scarification) is linked to its commercialisation for greater control of the seed market.

Adoption is potentially highest under the General and Specialist categories, particularly where the scale of market is large (and pre-existing), the relative advantage is high and there are few agronomic constraints to seed production and pasture management. However, seed industry engagement is likely to be more difficult with the General category, particularly where PBR protection is important and this model is perhaps more relevant for commercialisation of public cultivars. The Specialist category may be the compromise position that will encourage seed industry engagement and allow marketing of seed at a price that will not be a barrier to adoption**.**

Conclusions

Australia's grazing industries have relied heavily on the exploitation of exotic legumes. While there has been a steady stream of new (domesticated) species, few have achieved the same level of commercial success or matched the impact of the early introduced species such as subterranean clover, lucerne and white clover (recognising that these were developed over several decades). Understanding past breeding and research outcomes provides a platform for future decision making that will maximise the potential for field scale impact and the appropriateness of any commercialisation strategy, including the merits of IP

Table 1. Framework for considering commercialisation of pasture legumes in Australia

Characteristic	General category	Specialist category	Niche category
Species examples	French serradella, arrowleaf clover, gland clover	Subclover, annual medics, lucerne, white clover, bladder clover	Sulla, yellow serradella, purple clover
Farmer seed costs at establishment	<\$40/ha (often <\$20/ha)	\$40-80/ha	>\$80/ha
Specialist seed producers	Not essential, compatible with on-farm production	Highly desirable	Essential
Agronomic management	Cost-effective options generally available	Cost-effective options generally available	Often limited or complex options (*e.g.* herbicides)
Seed production and processing	No specialist equipment required for harvest, seed processing easy	Often specialist techniques (*e.g.* suction harvesting, pollination)	Often specialist techniques *(e.g.* harvesting, dehulling, pollination)
Seed company engagement (production and marketing)	Often limited or short term <5yrs (less demand for repeat sales)	Generally high (attractive to private investment in breeding)	Often limited (constrained by small market or high seed price)
IP protection	Suited to public cultivars, PBR & Trademark difficult to protect (need to recover costs up front)	PBR, Trademark appropriate	PBR, Trademark appropriate

protection and engagement with the seed industry. We suggest that species or cultivar success is governed by the interaction of four key features of the product; its characteristics and distinctiveness, its relative advantage over other options (impact on farm profit), its adoptability and on-farm trialability and the nature of the arrangements for its commercialisation. All these elements need to be optimised for success – if one is missing, then low cultivar uptake or failure is likely. High cultivar adoption is typically a function of a large target market, low seed cost, a high relative advantage compared to existing technologies and a low complexity of agronomic and grazing management. Future work will endeavour to link these features in a model or decision tool to help guide future investment in plant improvement.

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