A strategic approach to developing the role of perennial forages for crop-livestock farmers

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Abstract. A substantial proportion of Australian animal production from grazing comes from regions and farms where cropping is the major enterprise. Developing new and improved grazing systems for mixed farms where crop production is the major driver of farm management decisions presents a unique research and development challenge. In this paper we describe a multi-disciplinary farming-systems research approach ('EverCrop') aimed at improving farm profitability, risk management and environmental impacts through the development and integration of new grazing options. It has been used to analyse and target new opportunities for farmers to benefit from perennial species across dry Mediterranean-type and temperate regions of southern Australia. It integrates field experimentation, on-farm trialling, farmer participatory research, soil-plant-climate biophysical modelling, whole-farm bioeconomic analysis and evaluations of adoptability. Multi-functional roles for summer-active grasses with winter cropping, integration of forage shrubs and establishment of new mixes of perennial grasses in crop rotations to improve farming-system performance are identified, along with an analysis of uptake by farmers.

Keywords: Perennials, grasses, shrubs, economics, mixed farming, Australia.

Introduction

Grain cropping in Australia is predominantly carried out in conjunction with grazing and livestock production – so called mixed farming (Bell and Moore 2012). The dominant farming system of the 1970s and early 1980s – cereal crops in short rotations with annual legume-based pastures – arose in response to the combination of high wool prices, declining soil nitrogen fertility and technological opportunities (*e.g.* pasture cultivars, phosphate fertilizers). By the turn of the last century, these annual-based mixed-farming systems were increasingly dominated by cropping due to changes in terms of trade, a reduction in the price of animal products relative to cropping and improved cropping technology. While the narrative of "decline" in mixed farming in Australia has been challenged by Bell and Moore (2012), the farming system does face a number of threats and opportunities that could be met by designing new grazing options and systems.

A majority of grain-producing farms still include grazing enterprises as an important but usually secondary component of the farm business (Bell and Moore 2012). This is also reflected in attitudes to cropping versus livestock management on the farm with a majority of mixed farmers preferring cropping over livestock (Llewellyn *et al.* 2010). This means that special consideration needs to be given to the 'fit' for grazing options if they are to be successfully integrated into the farm business for improved profitability and resource management out-comes. This involves a number of aspects of the mixed-farming enterprise including: potential synergies with cropping enterprises, their place within rotations and/or spatially within the farming system, role in reducing risks and increasing profitability, other non-financial costs and benefits (such as natural resource management outcomes), management demands and performance under typical management conditions on cropping-oriented farms.

Although Australian mixed-farming systems are typically dominated by annual species, perennial forages and shrubs have found a range of roles within them. The current level and scope for further adoption varies with biophysical and socio-economic factors. At face value there is a conflict between expanding the role of perennials and the dynamics of an annual-based cropping system. Oliver *et al.* (2005) and Bell and Moore (2012) introduced ways of incorporating perennials into mixed-farming enterprises, and described the concept of "rotate-separate-integrate". Rotation involves temporal separation (i.e. sequences) of livestock and crop production enterprises on the same area of land. Integration involves both crop and livestock enterprises using the same resources (*e.g.* water or nutrients) simultaneously or in the same management cycle (*e.g.* pasture cropping or under-sowing or the relay sowing of forages with crops). Separation involves the spatially distinct use of perennials and crops, with each contributing to the farm feedbase but not from shared areas of land on the farm (*e.g.* growing permanently planted perennials separate from crops or annual pastures).

Over the past 5 years, a project in Australia with national scope called EverCrop has established a multi-disciplinary research and development approach that works with farmers in order to improve the performance of mixed-farming systems. As part of the Future Farm Industries Cooperative Research Centre the focus has been on perennial-based options. The EverCrop approach (Fig. 1) requires input from disciplines of economics, systems modelling and decision science, in addition to agronomy. It relies on the intimate involvement of end users (early-adopter farmers and their advisers). Whole-farm economic modelling and farm surveys are used to define the potential scale (area) and benefits (per hectare) under a range of scenarios for the proposed options. Some of these are expected to require long timeframes beyond the life of the project before their peak adoption and full impact is achieved. Biophysical modelling is used to define knowledge gaps and provide focus for plot-scale agronomic experimentation. User evaluation and on-farm demonstration scale trials are used to understand the ways in which farmers could implement the options on farm and to quantify the benefits unable to be captured in the agronomic and modelling analysis (*e.g.* impacts on natural resource base or farm labour use; machinery requirements).

The aim of this paper is to illustrate the use of the EverCrop approach across a diverse range of farming systems in Australia. The research explores different modes of integration of perennials (separate, rotate, integrate) across a range of agro-ecological regions ranging from very low to moderate current levels of use of perennials and varying scope for increasing perennial use by mixed farmers. The options explored ranged from those suited to rotation with crops on cropping land, others integrating perennials with crops on marginal land, to those suited for separation of perennials from crops onto non-arable land.

Use of perennials in cropping systems in contrasting agro-ecological zones

The diversity of the three agro-ecological zones that are the focus of the EverCrop project is demonstrated in Table 1 and described below. In all regions, cropping is typically the dominant enterprise relative to grazing. Only in the uniform-rainfall zone are perennial pastures a substantial component of current land use.

The low-rainfall zone of South Australia and Victoria (SA-Vic Mallee)

This region is characterised by 250-350mm annual average rainfall and dune-swale soil-landscape systems. The dryland farming system is largely cereal-based with components of wheat, barley, annual pasture and relatively small areas of canola and legume crops such as peas and lupins in rotation. Mixed-farm businesses remain common (Table 1), however more intensive cropping rotations have evolved relatively recently in the Mallee with the use of no-tillage systems reducing erosion risk on the light-textured sands. The use of no-till by SA-Vic Mallee farmers has increased from around 45% of farmers prior to 2004 to 70% in 2008.

Of particular relevance to EverCrop and the potential niche for perennials is the relatively common application by Mallee farmers of site-specific management by soil-based zone. For example, the Victorian Mallee region has one of the highest proportions of farmers using some form of zonal management for fertiliser inputs (Robertson *et al.* 2012). The dune-swale land system commonly results in very large within-paddock variation in plant production, with fine-textured, often chemically constrained soils on the lower land, and coarse-textured, often erosion-prone sands on the slopes and dunes (Whitbread *et al.* 2008). This usually involves reducing inputs on poor-performing soils. Interest in alternative uses for such soils is also increasing, with cereals for grazing being one example. The perennial options being explored in this region hence use the "separate" mode of integration.

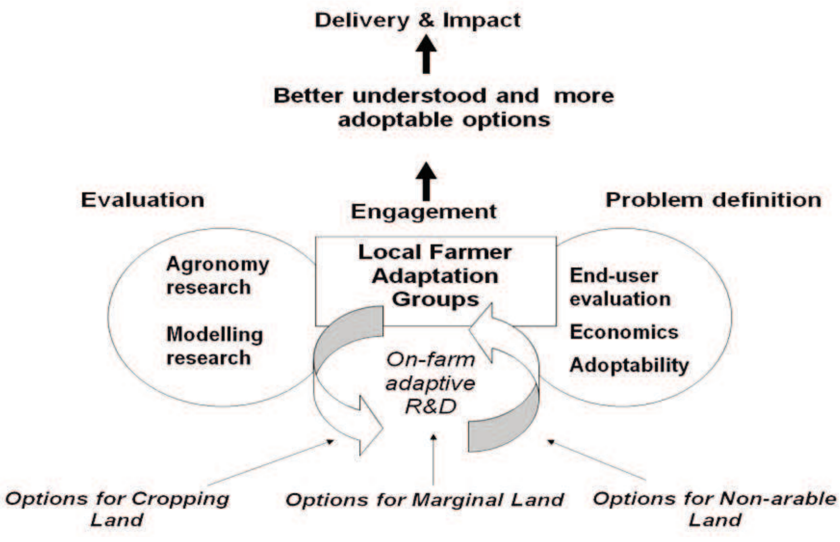

Figure 1. The approach taken in the EverCrop project that links evaluation, engagement and problem definition in research and development for perennial-based options in mixed farming systems in Australia.

Table 1. Characteristics of grain-producing farms and farmers in the EverCrop regions: low-rainfall zone of South Australian-Victorian Mallee (250-350mm annual average rainfall (AAR); medium-rainfall zone (350-450mm AAR) uniform-rainfall zone of Southern NSW (450-600mm AAR).

	Low rainfall SA-Vic Mallee	Medium rainfall Northern & Midlands WA wheatbelt	Uniform rainfall Southern NSW
Farm area managed (mean arable ha)	2820	4403	1836
Proportion of arable land cropped (%)	65	64	62
Farms with sheep (%)	70	73	83
Farms with >1000 head of sheep (%)	48	78	74
Farmers with stated preference for cropping over livestock (%)	71	91	58

Data collected 2008 (from Llewellyn *et al.* 2010). WA data include some low-rainfall regions.

The area of perennials in the Mallee region is currently low. The use of perennial grasses and lucerne (*Medicago sativa*) is very low and EverCrop engagement with previous lucerne growers confirmed that the area of lucerne is not increasing. This reflects its limitations in low-rainfall environments, low willingness for intensive livestock management over the past decade and the general shift to more intensive cropping given lucerne's requirement for soil types that are well suited to cropping. It is likely that new plant options better suited to the cropping-oriented low-rainfall farming system will need to emerge if perennial legume adoption is to increase. The most commonly grown perennial forage shrub is Old Man Saltbush (*Atriplex nummularia*). A study in South Australia (Llewellyn *et al*. 2010) found that while there were plantings found on 124 farm blocks in the study area, they were generally small in area; 75% were in sandier paddock locations rather than on the loamier swale soils where crop growth is more constrained and only a very small proportion of farmers had established multiple forage plantings. Again, it was concluded that improved plant options are likely to be needed if substantial increases in perennial forage shrub plantings were to occur.

The medium-rainfall zone of northern Western Australia (WA)

The northern Agricultural Region of WA has a Mediterranean-type climate and is dominated by broadacre cropping (Table 1), based around wheat in rotation with narrow-leaf lupins and canola. The region is highly susceptible to wind erosion due to a high proportion of sandy soils. van Gool (2008) describes the mounting concerns of the sustainability of continuous cropping, particularly on the 25% of the region occupied by pale sands, due to the expectation of drier winters and more frequent droughts in the future, rapidly increasing fertiliser costs, and concerns about soil fertility and weed problems including herbicide resistance. With more variable seasons, there is increasing emphasis on risk management and a need for lower-input/lower cost cropping systems. A number of mixed farmers grow tropical perennial grass pastures including panic (*Megathyrsus maximus*) and Rhodes grass (*Chloris gayana*), although only on soils unsuited to continuous cropping. A current estimate of the area of tropical perennial grass pastures in the region is ca. 50,000 ha (Geoff Moore, pers. comm.), with around 10% of farms having some area of perennials (unpublished survey results).

Pasture cropping, a form of synchronous integration of perennials and crops, has been identified as a potential option for farmers (Millar and Badgery 2009). Pasture cropping involves planting a winter crop into a living summer-active perennial pasture. The growth period of the winter-active crop complements the high summer activity (and very low winter activity) of the C4 perennial grass, reducing competition between the two species grown together on the same ground at the same time. The expected benefits for livestock-dominant farms are that the crop could provide feed to supplement the perennial pasture, with crops allowed to grow through to grain harvest only in years with excess feed. For cropping-dominant systems, where feed is a secondary consideration, pasture cropping can stabilise fragile soils, improve soil quality and prevent growth of summer weeds. Currently, fewer than 10 growers have trialled this form of pasture cropping in the region, typically on small areas (< 100 ha) and only over the last four years. Clearly, adoption of this option is in its early stage and requires increased adoption of tropical grasses followed by adoption of pasture cropping.

The uniform-rainfall zone of southern New South Wales (NSW) and northern Victoria

Rainfall in this region has a relatively uniform average monthly distribution although monthly rainfall is not reliable, particularly during summer months. Farm enterprises typically comprise a combination of cropping (wheat, barley, canola, oats, grain legumes) and livestock activities (sheep and cattle for meat and wool) based largely on pastures grown typically for 3-6 years in phased rotations with crops (Table 1). This combination of livestock and crops confers a number of advantages including income diversification, minimisation of risk from variation in climate and commodity prices as well as production advantages including weed control, restoration of soil fertility and improvement in soil structure. However, the disadvantages associated with a complex enterprise mix and reduced specialisation can be substantial (Casburn *et al*. 2013).

A survey of mixed farmers in NSW indicated that, at any one time, about 52% of land is under crop, 29% contains perennial pasture and 19% annual pastures (Dear *et al.* 2010). Lucerne is the dominant perennial pasture species grown, on 84% of farms. Pre-experimental bioeconomic modelling (Bathgate *et al*. 2010) showed that current levels of perennial pasture adoption were already close to the theoretical optimum. Small plantings of other perennial pasture species such as chicory (*Cichorium intybus*, currently grown on 26% of farms) and perennial grasses such as phalaris (*Phalaris aquatica*, grown on 48% of farms) could offer additional financial and non-financial benefits, though practical constraints such as establishment issues continue to hamper the use of these and other species in cropping environments (Hayes *et al*. 2012). The focus of research in the uniform-rainfall zone was therefore less about increasing the adoption of perennials and more about refining the role, balancing multiple enterprises and improving the performance of mixed pastures swards.

The case for increased adoption of perennials

The case for increased adoption of perennials ("Problem definition" in Fig. 1) was established through: surveys and workshops with farmers to detail the existing levels of adoption and perceived benefits; whole-farm bio-economic modelling to quantify potential monetary benefits of increased adoption and estimates of the likely rate and peak extent of adoption based of the complexity of the relative advantage of the new option and the characteristics of the adopting farmers. A range of tools was used for evaluating the potential role of perennials in each region and the outputs were used as a basis for discussion on research, development and extension needs with regionally-based farmers and advisers (called local adaptation groups). Research tools used in each region included existing bio-physical simulation models such as APSIM (Keating *et al.* 2003) and AUSFARM/ GRAZPLAN (Moore *et al.* 1997) and the bio-economic model MIDAS (Kingwell and Pannell. 1987; Pannell 1996), and the development of a socio-economic tool (ADOPT) to evaluate likely rates and peak levels of adoption for a particular technology by a specified target population of farmers (Kuehne *et al.* 2011).

In the uniform-rainfall zone the benefits of perennials are well recognised, and current adoption rates, particularly of lucerne, are already high. The researchable questions therefore largely revolve around refining management strategies to maximise the profitability of the technology, particularly in the context of a complex enterprise mix (Casburn *et al*. 2013) and farm business risk (Hutchings and Nordblom 2011). In large part, this involved considerable emphasis on improving the success of pasture establishment, as success at establishment had enduring benefits to productivity throughout the pasture phase and into the cropping phase. A case was made in this zone for relatively small increases in the adoption of alternative pasture species (Bathgate *et al*. 2010), specifically phalaris, chicory and cocksfoot (*Dactylis glomerata*). At this stage, the continued promotion of these species for cropping environments is hampered; for the grasses due to the prolonged unavailability of commercial seed of appropriate cultivars, and for chicory by the lack of cultivars developed for drier Australian cropping environments (Hayes *et al*. 2012). Assuming these technical issues are resolved, analysis with the ADOPT tool predicted the potential peak adoption of 70% for the new perennial options, with an estimated time to reach this of *ca.* 20 years from introduction. This is a typical rate of adoption for complex innovations that require integration into existing systems.

In the medium-rainfall zone, farmers report the main benefits of perennial grass pastures being stabilising soils prone to wind erosion, providing out-of-season feed in response to summer rainfall and improving soil quality (water repellence, soil organic matter). EverCrop has also demonstrated its potential in the low-rainfall zone (Descheemaeker *et al*. 2013). The case for pasture cropping rests on perceived benefits of additional income from a crop (for grain or forage) (Ferris *et al*. 2010, Barrett-Lennard *et al*. 2012). Bio-economic modelling (Finlayson *et al*. 2012) showed that the profitability and adoption of tropical grasses is likely to be strongly influenced by the proportion of the farm with pale sands, where perennial pastures are comparatively more productive than crops or annual pastures. Other important factors were the feed quality of the tropical grass; whether the production emphasis of the farm is on grazing or cropping, and the biomass production in summer and early autumn. Pasture cropping has the additional factor of yield penalties due to competition between the arable crop and the perennial. Pasture cropping was more profitable and likely to involve a larger area of the farm when a meat- rather than a wool-dominant sheep system was present. These results suggest adoption of tropical perennial pastures and associated pasture cropping will more likely occur on farms with livestock production based on meat, a high proportion of pale sands and where the yield penalty with the crop can be minimised through agronomic means. Even with this favourable combination of circumstances, pasture cropping would be unlikely to exceed 10% of the arable area on most target farms in the region (Finlayson *et al*. 2012). The main constraints to adoption of pasture cropping cited by farmers are the likely crop-yield reductions and opportunity costs to establish perennial pastures (Ferris *et al*. 2010, Barrett-Lennard *et al*. 2012). Analysis with the ADOPT tool estimates that for farmers who have already adopted perennial pastures, it will take around 10-20 years to achieve a peak adoption level of around 10-20% of farms in the region. By comparison it may take 20-30 years to achieve a peak adoption of 10% for farmers who have not yet adopted any perennial grasses.

In the low rainfall zone, farmers report the main benefits of saltbush plantings to be providing summer-autumn feed that can reduce supplementary feeding costs and/or maintain livestock after crop stubbles have been utilised; providing a productive option for land that is unprofitable for cropping due to soil constraints (*e.g.* fine-textured constrained soils; sandy erodible soils; stony soils) and; providing feed and containment options during critical farm-management periods, such as when lambs are weaned. Bio-economic modelling (Monjardino *et al.* 2010) shows that small gains in average farm profit can typically be achieved with an allocation of 5-10% of the farm to shrub plantings, with larger areas being profitable where farms have larger areas of soil that is marginal for cropping, or if forage shrub options with higher feed quality become available. New options beyond the current main commercial options (De Koch Old Man Saltbush forage blocks and existing lucerne types) with improved feed quality are likely to be the main driver of wider perennial use. Further, a substantial number of growers have at least trialled currently available commercial forage shrubs, though the limitations such as high establishment cost and low feed quality have meant diffusion has been weak (Llewellyn *et al*. 2010). The area of land currently cropped in the Mallee with low profit-high risk cropping potential is one indicator of scope for wider adoption. Detailed in-field and simulation analysis of a set of Mallee cropping paddocks showed a substantial proportion of highly constrained areas (Whitbread *et al*. 2008). Some can be profitably cropped using very low input levels to minimise risk; other areas may be better suited to non-crop options. To estimate the total area of such zones across the SA-Vic Mallee region, 12 years of Landsat-based NDVI imagery and biomass-yield-growing season rainfall relationships were used to examine cropping land in terms of riskiness and profitability. The total area of currently cropped land estimated to have very low average potential gross margin and a greater than 50% probability of loss based on returns from wheat was 33,000ha. Assuming modest levels of profitability can be achieved, the outputs of the ADOPT tool indicate that the adoption of both improved forage shrub systems by Mallee mixed farmers will involve periods to peak adoption of approximately 20 years and peak levels of adoption by 20% of mixed farmers. The primary requirement for further adoption is developing and demonstrating the feasibility and profitability of perennial-based options with improved feed quality, particularly on poorer soils with relatively low inputs.

Measuring performance of new perennial-based systems and decision support

The evaluation of the bio-physical performance of perennial-based systems (see "Evaluation" in Fig. 1) was conducted through plot-scale experimentation and farm-scale trialling. The plot-scale experimentation produced data to fill key information gaps and has informed the bio-physical simulation modelling. Identified gaps and opportunities have informed the development of tools for workshop learning and decision support.

In the uniform-rainfall zone, pasture-phase establishment is an important constraint to maintaining a major perennial component in crop rotations. The majority of farmers in this zone establish pastures under a cover-crop (Dear *et al*. 2010), a different form of synchronous integration of perennials and crops as pasture cropping used in WA. A common lack of evaluation of the tradeoffs involved with using cover cropping for the establishment of perennial phases was identified. The effects of different establishment methods within modern cropping systems were addressed through experimentation over multiple years (Li *et al.* 2012; Peoples *et al.* 2010). This has supported the development of a cover cropping decision support tool prototype (McCormick *et al.* 2012) that incorporates the likely biophysical response and economics to assist decision-makers to identify the circumstances (pasture phase length; crop value etc.) under which establishing pasture phases without a cover crop is likely to be most beneficial.

In the medium-rainfall zone, lack of knowledge about the degree of crop yield penalty under pasture cropping was identified as a major constraint to adoption of pasture cropping by existing adopters of perennial pastures (Barrett-Lennard *et al.* 2012). The level of the potential crop yield penalty and the agronomic strategies to mitigate it was addressed in plot experiments. The field experimentation has generated new understanding of the bio-physical drivers of yield penalties (Ward *et al.* 2012) and demonstrated the possibility for very low crop yield penalties. A combination of field measurements and simulation modelling has supported the development of a workshop tool for evaluating the range of factors likely to determine the value of pasture cropping using a base of sub-tropical grasses.

In the low-rainfall zone, it was recognised that

Table 2. Summary of perennial options, adoption by farmers and benefits for three agro-ecological regions in Australia's mixed-farming zone.

Agro-ecological region	Uniform rainfall	Medium rainfall	Low rainfall
Method of incorporating perennial options	Rotate	Integrate	Separate
Perennial option and landscape niche	Phase farming with lucerne and "new" perennials chicory, cocksfoot and phalaris	Pasture cropping with sub-tropical perennial grasses on soils unsuitable for continuous cropping	Saltbush and other perennials on land with low production and high risk for cropping
Current level of perennial use in farming system (% target region)	Medium-High (25%)	Low (2%)	Very low (<1%)
Estimated time to and level of peak potential adoption (% farmer population)	70% over 20 years	10-20% over 15 years	20-30% over 20 years
Estimated potential whole-farm financial benefits	+40%	+22%	+21%
Financial gains achieved by increases in:	Stocking rate; biological N_2 fixation	Grain production in addition to summer-autumn feed supply	Livestock production; reduced supplementary feeding costs
Non-financial benefits	Soil fertility, protection from soil erosion	Protection from soil erosion	Reduction in farm business risk during dry periods.
Key constraint to adoption	Cost and reliability of establishment of perennials in crop sequences	Risk of crop yield penalty. Limited extent of sub-tropical grasses.	Adequate feed value to justify cost of establishment

farmers were considering forage shrub plantings on a range of soil types but little work had been done on the likely influence of soil type on production by season. The production of three types of saltbush at three positions along a dune-swale soil-landscape catena was monitored over three seasons in addition to a simulation model constructed in the APSIM framework that simulates leaf (edible) biomass per shrub in response to daily weather, soil type, and grazing. The measurements showed a two-fold difference in production between the swale and dune soil types and the model was able to account for this through differences between soil types in water availability for plant growth. A range of location x soil type x grazing management scenarios can be simulated to provide a database of saltbush productivity. Such information can be used to engage with farmers about the potential and reliability of saltbush contributing to the farm feedbase, particularly during the late summer-autumn feed gap and during drought conditions when the feed is of most value**.**

Conclusion

Mixed farming remains common to grain-producing regions of southern Australia, although increased management emphasis on cropping has meant that consideration of compatibility, labour demands and risk are increasingly important to the successful introduction of grazing options. This requires a multi-disciplinary approach involving substantial farmer and industry contribution to the research and development process at the regional level. The complexity and long-time frames also means that analysis benefits from modelling in combination with field experimentation. Table 2 summarises the differences and similarities across the three agro-ecological zones where EverCrop is examining new perennial-based options for mixed farmers. The greatest potential for widespread use and financial benefits for mixed farmers remains in the higher-rainfall areas but valuable niches are also identified in lower-rainfall zones. In each case, a combination of local-level partnerships with farmers, field experimentation, on-farm trialling, simulation modelling and socio-economic analysis has worked to identify the fit and value proposition for specific grazing options within cropping-oriented systems.

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