Diversity, trends, opportunities and challenges in Australian grasslands – meeting the sustainability and productivity imperatives of the future?

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Abstract. Grassland production systems contribute 40% to Australia's gross agricultural production value and utilise over 50% of its land area. Across this area a broad diversity of systems exist, but these can be broadly classified into four main production systems: 1. Pastoral grazing of mainly cattle at low intensity (i.e. <0.4 DSE/ha) on relatively unimproved native rangelands in the arid and semi-arid regions of northern and central Australia; 2. Crop-livestock systems in the semi-arid zone where livestock graze a mixture of pastures and crops which are often integrated; 3. High rainfall permanent pasture zone in the coastal hinterland and highlands and; 4. Dairy systems covering a broad range of environments and production intensities. A notable trend across these systems has been the replacement of wool sheep with beef cattle or meat sheep breeds, which has been driven by low wool prices. Although there is evidence that most of these systems have lifted production efficiencies over the past 30 years, total factor productivity growth has failed to match the decline in terms of trade. This has renewed attention on how research and development can help increase productivity. In addition, these industries are facing increasing scrutiny to improve their environmental performance and develop sustainable production practices. We propose several areas in which grasslands research and development might help provide gains in system productivity and sustainability. In particular, pasture productivity might be improved by filling gaps in the array of pastures available either through exploring new species or improving the adaptation and agronomic characteristics of species currently sown. Meanwhile there is a need to maintain efforts to overcome persistent and emerging constraints to pasture productivity. Improving livestock forage feed systems and more precise and lower cost management of grasslands would translate into improved utilisation and conversion of forage produced into livestock products. There is significant scope to capture value from the ecological services grasslands provide and mitigate greenhouse gas emissions from livestock production. Multi-purpose grasslands provide not only grazing for livestock but produce other food products such as grain which may also have potential to integrate livestock with cropping. However, reduced human research capacity in pasture science will challenge our ability to realise these potential opportunities unless efforts are made to attract and support a new generation of pasture scientists.

Keywords: Pasture, grazing, breeding, precision agriculture, feed-base, economics, green-house gas, perennial.

Introduction

Grasslands cover a large proportion of Australia and contribute 40% of the value of Australia's agricultural production. Agricultural enterprises cover 400 M ha or 52% of Australia's land area. Only 6.5% of this agricultural area (*i.e.* 26 M ha) is sown to crops (Australian Bureau of Statistics 2012). The remainder is primarily made up of sown or native pastures, which underpin the sheep, beef cattle and dairy industries. In the period 2007/08 to 2009/10, these industries together were valued at AU$15.8 billion per year to Australia's economy (Australian Bureau of Statistics 2012). Beef production is the largest industry, with 24.7 M head in the national herd, and beef cattle slaughter valued at AU$7.4 billion annually. Sheep number approximately 73 M head, which has declined steadily from 170 M head in 1990. The sheep industry produces AU$2.4 billion per year from slaughter of sheep and lambs and $2.0 billion per year from wool. Together sheep and cattle slaughters produce 2.7 M t of meat of which nearly half is exported (1.3 M t). In addition, Australia has a significant live export industry of sheep (AU$338 M) and cattle (AU$572 M). Australia's dairy industry is based on 2.56 M dairy cattle and production is valued at AU$4.0 billion per year (average 2008-2010). Over 50% of the value of the dairy industry ($ 2.1 billion) is generated from irrigated pastures and forage crops. While these irrigated systems cover only 0.2% of the land utilised for livestock production in Australia (0.74 M ha), they contribute more than AU$3 billion annually or 20% of the value of ruminant livestock production (Australian Bureau of Statistics 2012).

Over the past 25 years Australian agricultural industries have been faced with an ongoing 1.6% a year decline in their terms of trade (*i.e.* the ratio of prices received to prices paid for inputs)(Nossal and Sheng 2010). There is a pressing requirement for new technologies and practices that increase productivity and enable farms to remain competitive. However, the total factor productivity (*i.e.* change in output relative to inputs) growth rates of the three main pasture-based industries have been 1.1% in beef (1977/78 – 2007/08), 0.8% in dairy (1988/89-2007/08) and 0.2% in sheep industries (1988/89-2007/08) (Nossal *et al.* 2008; Nossal and Sheng 2010). These are clearly lower than the decline in terms of trade over the same period, and are lower than the broadacre agriculture sector (grazing livestock and crop production) as a whole (1.4%) (Nossal and Sheng 2010). In the dairy and slaughter lamb industries, output has increased significantly over the past 25 years (4.7 and 3.0 % a year, respectively) but this has been associated with increases in inputs (3.9 and 2.8% a year, respectively) so that the net increase in total factor productivity has only been small. Hence, there is a need to maintain and enhance productivity gains in order to ensure future profitability and vitality of Australian grassland industries.

Because Australia's grazing lands cover such a large proportion of the country, their management has significant implications for the economic, environmental and the ecological services they provide. In particular, large proportions of Australia's grazing lands have been relatively undeveloped and are based on a broad diversity of native plant communities. These areas have an important role to play in maintaining Australia's biodiversity. Nonetheless, the development of livestock enterprises in these regions has brought about significant reductions in biodiversity, and decline in some native flora and fauna populations (Bastin and the ACRIS Management Committee 2008). Similarly, land degradation associated with overgrazing, soil acidification, changes in hydrological balance, impacts on water quality, weed incursion and greenhouse gas emissions (*i.e.* methane and nitrous oxide) are environmental issues challenging the ongoing sustainability of pasture-based livestock production systems. Many regions are also likely to be influenced significantly by climate change with predictions of lower and more erratic rainfall which will add further challenges to managing Australia's grasslands sustainably (Howden *et al.* 2008). Consumers and markets are now also increasingly demanding livestock products that are produced in ways that meet environmental stewardship, animal welfare, and product quality expectations. Together these pressures present both challenges and opportunities for Australia's grassland industries.

The challenge for Australia's grassland industries to achieve substantial productivity gains whilst maintaining or decreasing existing costs structures and also meeting increasingly ambitious environmental management expectations is substantial. In this paper we briefly describe the key pasture-based livestock production systems across Australia and explore past and current trends and drivers. We then discuss several approaches that may help overcome some important challenges and capitalise on opportunities to improve productivity, profitability and environmental management of Australia's grasslands.

Diversity and trends in grassland production systems in Australia

Australia's grassland production systems cover a diversity of environments ranging from very low intensity grazing on native rangelands in the arid interior to intensive grazing on productive irrigated or rainfed improved pastures. Figure 1 depicts the distribution of 10 broad agro-ecological regions found across Australia (Williams *et al.* 2002) and against these the reported number, density and proportion of cattle in the livestock production systems across these regions (in dry sheep equivalents, DSE; Fig. 1). In general, these can be broken up into 4 main grassland-based production systems and zones; the pastoral zone, the crop-livestock zone, the high rainfall zone and intensive dairy systems. While these systems differ considerably in their pasture base and overall productivity there are some trends that are common across all these systems (Fig. 2). Most notable of these has been the replacement of sheep with beef cattle, which has been driven by low wool prices since the early 1990's (Fig. 2d-f). Below we briefly describe some of the key attributes, production trends and drivers that have been influencing these 4 production systems.

Pastoral zone

Livestock production in the pastoral zone covers 242 M ha and supports about 30% of Australia's grazing livestock equivalents (63.3 M DSE) primarily grazing native pastures at low densities (0.1-0.5 DSE/ha) on large extensive livestock enterprises (77 000 ha on average) (Figure 1). The majority of these livestock are associated with the northern beef industry in Queensland (60%) and the northern parts of the Northern Territory and Kimberley in Western Australia (25%). The remainder is located in western New South Wales and central Australia (15%), where sheep make up a larger proportion of the grazing livestock. The pastoral zone covers much of inland and northern Australia spread across 3 agro-ecological regions, the 'temperate semi-arid plains and arid interior', 'wet/dry tropics' and 'semi-arid tropical and subtropical plains' (Fig. 1). A range of native grassland communities are utilised across this region, the most important being the Mitchell grass (*Astrebla* spp.) tussock grasslands, Spinifex (*Triodia* spp.) hummock grasslands, Eucalypt woodlands with wire grass (*Aristida* spp.) and bluegrass (*Dichanthium* spp. and *Bothriochloa* spp.), and tall grass savannas based on black spear grass (*Heteropogon contortus*), ribbon grass (*Chrysopogon* spp.) or native sorghum (*Sorghum* spp.) (Tothill and Gillies 1992). The absence of cropping means the Australian pastoral zone is made up of relatively undisturbed ecosystems. While pasture improvement across this region is limited, tree clearing/killing, and in some areas the introduction and naturalisation of buffel grass (*Cenchrus ciliaris*), shrubby stylo (*Stylosanthes scabra*) and Carribean stylo (*St. hamata*) have increased production and/or livestock carrying capacity (Bortolussi *et al.* 2005b).

Productivity of the pastoral zone has increased

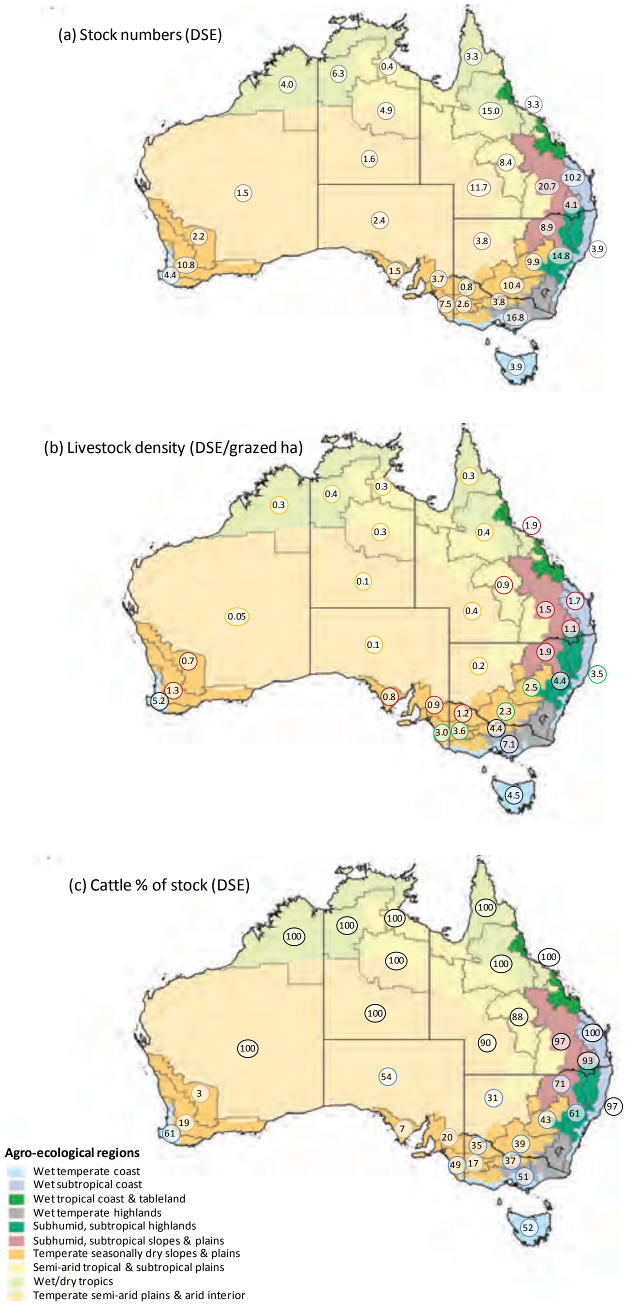

Figure 1. Diversity of Australia's grasslands across agro-ecological regions (from Williams *et al.* 2002) and corresponding (a) livestock numbers (million dry sheep equivalents; DSE), (b) livestock density (DSE/grazed ha; <0.5 DSE/ha – orange, 0.5-2.0 DSE/ha – red, 2.0-4.0 DSE/ha – green, > 4.0 DSE/ha - blue) and (c) the cattle proportion of livestock (DSE; cattle dominated (>85%) in black, mixed cattle/sheep in blue (25-80%), sheep dominated (<25%) in brown) across these various grassland production systems (ABARE 2012). Cattle numbers were multiplied by a factor of 7 to approximate dry sheep equivalents (DSE). Note borders for agro-ecological regions and ABARE reporting regions do not align.

substantially over the past 20 years with livestock densities and turn-off rates increasing by 40% (Fig. 2 c). This has been attributed to improvements in grazing management (facilitated by investments in fencing and water points), increased supplementary feeding to overcome nutrient deficiencies and temporary feed deficits, and a shift in the structure of production enterprises. In the southern Australian rangelands, the declining profitability of wool (Fig. 2d) has brought about a strong move away from traditional Merino wool sheep to production of beef cattle and sheep meat breeds (*e.g.* Dorper, Damaras) increasing turn-off rates in these areas (Khairo *et al.* 2008). In the beef cattle dominated northern region there has been a replacement of *Bos taurus* breeds to better adapted *Bos indicus* based herds. In addition, the growth of the live-export trade from northern Australia to southern Asia has enabled northern beef producers to turn-off younger animals than previously and hence increase the proportion of breeding females in their herds (Bortolussi *et al.* 2005a). Goat enterprises are also increasingly replacing or supplementing traditional enterprises in some regions (such as western NSW and SW Queensland). However, this has also led to a three-fold increase in feral goat numbers contributing to increased grazing pressure in these areas (Pople and Froese 2012). While farm livestock density has increased there has not been a corresponding increase in labour use in grazing enterprises in the pastoral zone. Despite the very low labour intensity in pastoral grazing systems there has been further decrease in labour intensity, so that now the average ratio of stock to a full time equivalent unit of labour is nearly 7000 DSE per full time equivalent (FTE) of labour (*i.e.* 48 weeks) (Fig. 2f). Labour availability pressures are increasingly a challenge in these remote enterprises.

The last 20 years has also seen changes in land management in the pastoral zone. Grazing enterprise changes have been accompanied by pressures to integrate both production and ecological goals (Fitzhardinge 2012). Increasing grazing pressure has raised questions about how to maximise livestock production and maintain the pasture and land resource base in the long-term (Ash *et al.* 1997). The large scale of the rangelands also presents challenges for natural resource management (NRM), especially for issues such as pest animals and plants. In response, the formation of the National Rangelands NRM Alliance has been developed with the aim of improving and coordinating delivery of NRM across the large scale required (Forrest *et al.* 2010). Over the past 20 years, increases in pastoral areas now used for conservation, tourism and by Aboriginal communities has in part contributed to a 30% reduction in the area used by grazing enterprises across the pastoral zone. For example, two conservation organisations (Australian Wildlife Conservancy and Bush Heritage) have purchased over 50 properties covering around 3.5 M ha, most of which have been in the pastoral zone. Indigenous communities now manage large areas of land in the pastoral zone of northern Australia where less land is used for livestock enterprises. For example, 15% of Western Australia's land is under indigenous stewardship including 58 pastoral leases comprising 12 M ha or around 10% of the total pastoral lease area of Western Australia.

Crop-livestock zone

Australia's crop-livestock (or mixed farming) zone includes the 'Temperate seasonally dry slopes and plains', which ranges from the strongly Mediterranean climate of southern Western Australia to the largely 'uniform' rainfall zone of south-western NSW, and the 'Subhumid subtropical slopes and plains', that cover the region with a summer dominant rainfall pattern (Figure 1). These regions are critically important for livestock production accounting for about 40% of Australia's grazing livestock equivalents (50% of sheep and over 30% of Australia's cattle) (Fig. 1a). Breeding, backgrounding and fattening cattle are the dominant livestock production systems in the subtropical region, while in the temperate zone sheep are a much larger proportion of grazing enterprises (Fig. 1b). While grazed pastures constitute the major component of the feedbase in the crop-livestock region, a range of other feed sources are also important for grazing livestock systems such as crop residues, forage crops (*e.g.* forage oats), and increasingly, dual-purpose crops (Moore *et al.* 2009).

Soil characteristics also vary greatly across the region with a range of constraints influencing the choice of pastures grown in these areas (*e.g.* soil acidity/alkalinity, water holding capacity, boron, aluminium or manganese toxicity). Pasture production systems across the temperate crop-livestock zone typically involve pastures grown in sequence with winter-growing crops, usually wheat, barley, canola or lupins. The pasture phase may involve short rotations (1-2 years) of temperate annual pastures in lower rainfall and Mediterranean climates (*e.g.* Western and South Australia) (Revell *et al.* 2012) or longer phases (typically up to 5 years) of temperate perennial species such as lucerne (*Medicago sativa*) or grasses such as phalaris (*Phalaris aquatica*) sown in mixtures with annual legumes (Dear *et al.* 2004). Legume-based pastures have been an important part of crop rotations and contribute significantly to crop N supply. However, fixed N derived from pastures is declining in favour of synthetic N fertilisers (Angus and Peoples 2012). Intensification of cropping where land is continually cropped has seen a decline in traditional phased pasture-crop rotations. On non-arable land native pastures are utilised though these may be augmented with introduced legumes or grass species. In the subtropical crop-livestock zone, tropical summer-growing grasses and temperate winter-growing legumes are widely used, though these tend not to be integrated as pasture leys in crop rotations; cropping occurs mainly on highly fertile clay soils with poorer soil types utilised for pastures.

The past 20 years has seen some clear farm demographic shifts across the crop-livestock zone. Farm size has increased substantially from an average of 1700 ha in 1990 to 2300 ha in 2011, and the average proportion of the farm cropped has also increased, so that now on average 30% of a farm is cropped. This trend is most evident in southern and western Australia where the proportion of cropped area has increased by 50% since 1990 and now cropping makes up >50% of the average farm area; in Queensland and NSW the proportion of farms under crop has changed less. These different trends over this period are associated with the low profitability of sheep enterprises (Fig. 2e). Sheep have been replaced by cropping in southern and western Australia and by cattle in Queensland and NSW. Increased emphasis on cropping along with the 'Millennium drought (2000-2008)' has seen stock density in the crop-livestock zone reduced to as low as 1.2 DSE/grazed ha in 2007 (Fig. 2b), although this has corrected somewhat in the past 5 years. Despite lower stock densities, turn-off rate has increased by 40% from 0.34 to >0.45 (Fig. 2b), associated with a move to beef and sheep meat production, as the importance of wool income from grazing livestock enterprises has declined (Fig. 2e).

High rainfall beef & sheep systems

The high rainfall pasture systems of Australia comprise the wet temperate, and subtropical highlands, as well as regions within the wet tropical, subtropical and temperate coasts (Fig. 1). The coastal regions of this zone in particular also have a large dairy production component (see next section) and commonly a high level of urban development, so not all land within these regions is available for beef or sheep production. The high rainfall pasture zone contains about 30% of Australia's beef and sheep livestock equivalents (Fig. 1a), which are grazed at higher densities than in other regions owing to the greater pasture productivity and intensity of management (Fig. 1b). Particularly in the temperate regions of this zone, there has been a move from traditional fine-wool merino to crossbred meat sheep or beef cattle production (Fig. 2d). However, ABARE data does not show the same increase in turn-off rate in this zone as seen in the crop-livestock and pastoral zones over the past 20 years.

The high rainfall zone is generally defined by areas that receive greater than 650 mm average annual rainfall in southern Australia and >750 mm average annual rainfall in northern Australia. The growing season is much longer, but periodic droughts are still common. Soils across this region are typically shallow and low in fertility, although better soils can be found in localised pockets, particularly associated with alluvial creek flats or changes in parent material (*e.g.* basalt derived soils). However, these well endowed locations are often used for agricultural production with higher economic returns (*e.g.* horticulture, dairy, cropping). Fertiliser application is generally less common in permanent pasture systems relative to cropping systems, although the application of single superphosphate has been a standard practice for decades in order to increase soil P levels and in turn improve the N-fixing capacity of grass/legume pastures. Soil acidity, and associated toxicities of aluminium and manganese, are the other common constraint across this zone (Scott *et al.* 2000) inhibiting pasture growth and N-fixation of long-term pastures.

Because of the longer growing season and lower frequency of water deficit, most pastures in the high rainfall zone are based on perennial species. In southern Australia, phalaris, cocksfoot, tall fescue and perennial ryegrass are the most common sown pasture grasses (Reed 1996), and native pastures consisting of *Microlaena*, *Austrodanthonia* or *Themeda* spp are common. While perennial legumes such as white clover and Caucasion clover are used (Virgona and Dear 1996; Lane *et al.* 2000), subterranean clover is by far the most common legume in grass pastures due to its superior grazing and acid soil tolerance relative to other legumes (Rossiter 1966; Guo *et al.* 2012). In the northern parts of this region, less drought tolerant perennial warm-season grasses such as kikuyu, signal grass (*Brachiaria decumbens*), pangola (*Digitaria decumbens*)

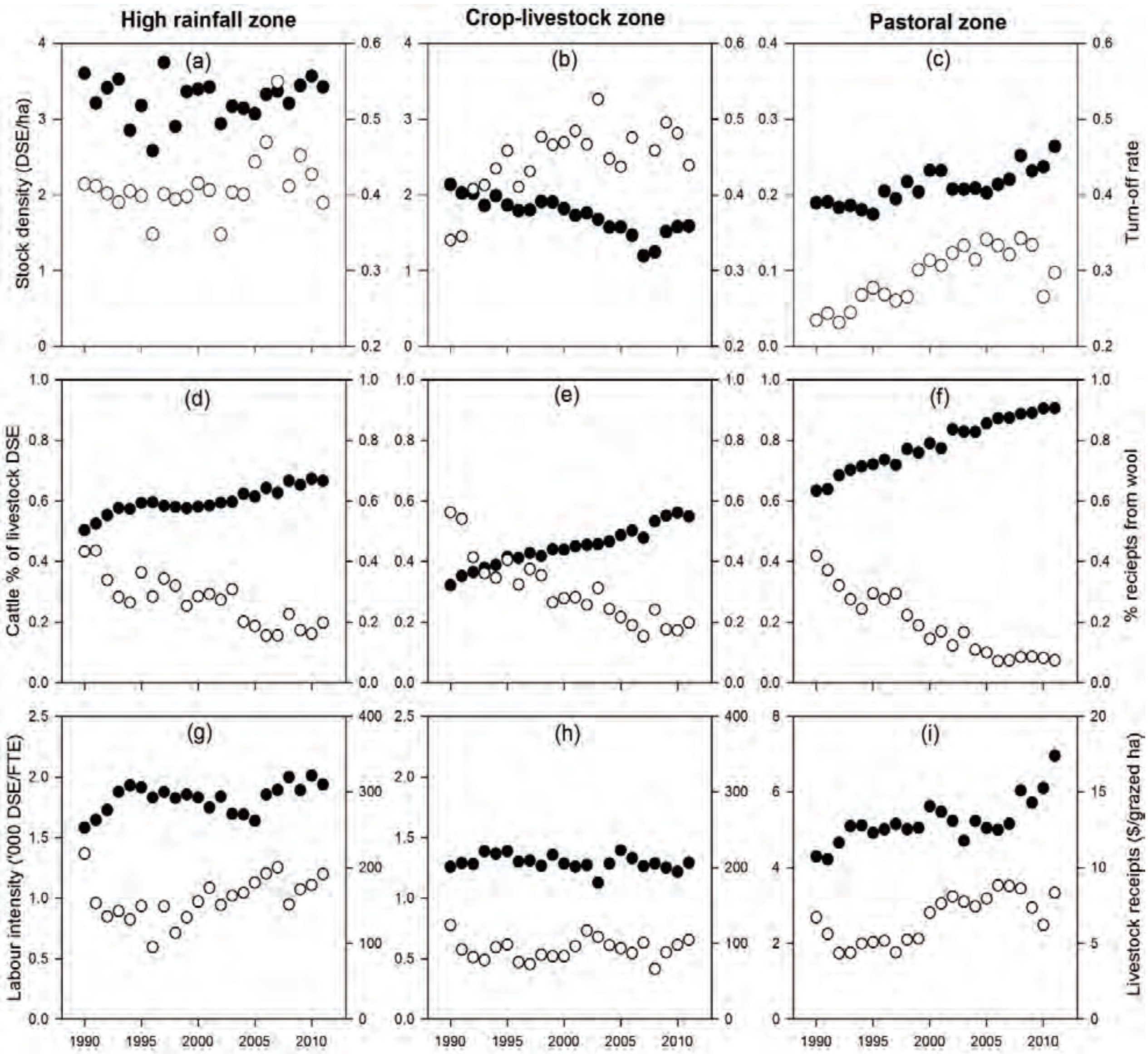

Figure 2. Changes in (a-c) stock density (solid) and turn-off rate (*i.e.* animals sold/animals retained; hollow), (d-f) cattle % of livestock (solid) and % of income derived from wool (hollow), and (g-i) labour intensity (solid) and income from livestock (hollow) across the high rainfall, crop-livestock and pastoral zones of Australia's grassland livestock production systems over the past 20 years (1989/90-2010/11). Stock density combines sheep and cattle (assumed as 7 DSE) on 30 June each year divided by the grazed area on farms (i.e. area operated minus area sown to crops); turn-off rate was calculated as DSE sold or turned-off farms per DSE at 30 June each year; labour FTE was defined as 48 weeks of labour. Data sourced from ABARE 2012.

and Rhodes grass are common, and a wider variety of both temperate and tropical legumes are adequately adapted.

Dairy systems

The dairy industry is situated over a broad range of environments from the wet tropical tablelands in north Queensland through to the wet temperate highlands and coastal regions of Victoria, Tasmania and Western Australia. Significant areas of production with access to irrigation can be found in the seasonally dry slopes and plains region in south-eastern Australia. This broad range of environments coupled with variations in land capabilities and water availability, milk payment structures and socio-economic conditions has shaped a diverse range of dairy productions systems. These systems range from mainly pasture grazing where minimal concentrate (*e.g.* grain) is fed during milking (<1.0t/cow/year) to completely feedlot-based systems with no free grazing (Little 2010). Nonetheless across these systems the degree of home-grown forage consumption is a key driver of dairy business success (Ho *et al.* 2012). In general, the low and relatively stable feed cost of pasture based dairy systems in Australia provides a competitive advantage compared to the dairy industries relying more on purchased inputs common in the northern hemisphere (Dillon *et al.* 2005; Rawnsley *et al.* 2007).

National dairy production rapidly grew in the decade from 1988/89 (6 262 M litres) to 2001/02 (11 271 M litres), but since this peak has declined steadily to 9 480 M litres in 2010/11 (Fig. 3). The total number of cows in the Australian dairy herd has followed much the same pattern. However, cow numbers since the peak have returned to 1979/80 levels (1.6 million cows). Over this period annual milk production per cow has steadily increased from 2850

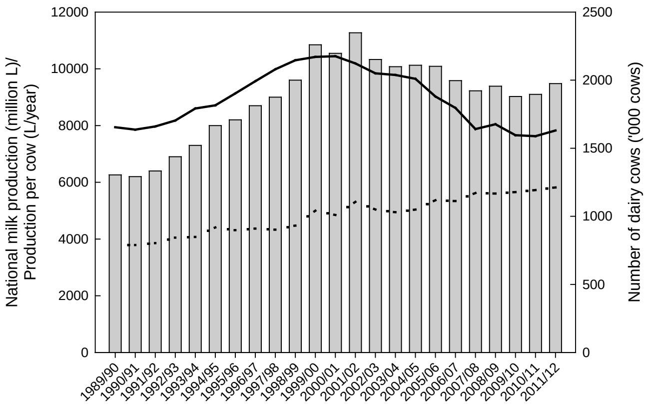

Figure 3. Australian milk production (bars), number of dairy cows (solid line) and milk production per cow (dotted line) from 1989/90 to 2011/12. Source Dairy Australia and Dairy Manufactures.

l/cow in 1979/80 to 5930 l/cow in 2011/12 (Fig. 3). In addition to improved cow genetics and increases in the feed purchased (both grain and forage), increased use of N fertiliser which has increased pasture production, and improved utilisation of forage grown on the farm via forage conservation as hay or silage have driven these increases (Mackinnon *et al.* 2010). However, several constraints are emerging that will limit further increases in productivity. Many farms are now moving closer to their potential pasture production and ability to make significant further gains are limited (Rawnsley *et al.* 2007). Increasing external inputs to achieve greater production levels often comes with substantial risk and infrastructure costs, consequently increases in milk production don't necessarily translate into profitability improvements (Cullen *et al.* 2012). Furthermore, increasing inputs and production intensity means that the nitrogen losses, greenhouse gas emissions and the environmental footprint of the dairy industry is increasing (Gourley *et al.* 2007; Christie *et al.* 2011).

Dairy farm stocking rates and area have also steadily increased, reflective of both an expansion of farms and an intensification of production (Mackinnon *et al.* 2010). However, in some regions (*e.g.* south-east Queensland, Goulburn Valley Victoria) the price of land and/or pressure to take land out of production is constraining further increases in farm size (Garcia and Fulkerson 2005). The Australian dairy industry is a major user of water, accounting for 17% (2834 GL) of national agricultural water use and 25% of surface agricultural water (Khan *et al.* 2010). Water availability reductions within the major irrigated dairy regions has seen the implementation of structural changes and practises on irrigated dairy farms to better manage limited water resources (Ho *et al.* 2007).

Improving sustainability and productivity of Australian grasslands

It is clear that over the past 30 years economic and environmental pressures have brought about considerable changes across the diversity of Australia's grassland production systems. In response, the research agenda has also evolved over this time. For example, grassland management has been central to tackling ecological issues such as dryland salinity, loss of biodiversity, and improving land management to improve ground cover, reduce soil erosion and improve quality of water leaving agricultural land. Adaptation responses to climate change and strategies to reduce agriculture's green-house gas emissions and sequester carbon in grassland systems are now important issues in grassland research. At the same time large technological gains in computing systems, access to detailed data and information, and advances in genetic techniques have created new opportunities for grassland scientist to provide solutions to issues faced by grassland production systems. Together these have brought about challenges and opportunities for grassland research.

In this section we provide some perspectives on areas where there are opportunities and needs for gains in system productivity and sustainability of Australia's grasslands. While there are a wide range of innovations that would also have implications for livestock productivity (*e.g.* animal genetics), we have focused on how grassland management, agronomy and breeding can deliver these outcomes. Overall these revolve around 3 key objectives: (1) Improving pasture productivity by overcoming constraints or providing more productive options; (2) Devising systems that better utilise the feed-base available; and (3) broadening the economic commodities derived from grassland production systems.

Novel species for filling gaps in the array of pastures available

While a wide diversity of pastures are utilised in Australia, there are still some situations where pasture productivity and quality could be improved significantly by filling gaps in the array of species available. In several of these situations filling these gaps would also provide significant environmental benefits by providing perennial plant options to help manage problems such as soil erosion, dryland salinity, sub-soil acidification and declining soil carbon and nutrients. We identify four key examples where a lack of available adapted forage species substantially inhibits these sown grasslands to reach their potential productivity and stability.

<u>Temperate perennial legumes for permanent pastures in the high rainfall zone</u>. Adapted perennial legumes in mixtures with perennial grasses in the high rainfall zone would help overcome N-deficiency and drive pasture productivity. Soils in this zone are generally too shallow and acidic for optimum lucerne growth (*e.g.* Flemons and Siman 1970). Periodic drought occurs too frequently for white clover to perform reliably, although amelioration of acidic topsoils can help reduce this constraint (Lane *et al.* 2000; Hayes *et al.* 2012a). Caucasion clover is well-adapted (Dear and Zorin 1985; Virgona and Dear 1996) but slow establishment, unreliable seed production and reliable supply of rhizobia have combined to render this species non-viable in the present domestic seed market. Two other species hold promise to fill this gap. Recent breeding efforts have aimed to widen the adaptation of birdsfoot trefoil (*Lotus corniculatus*) by reducing its photoperiod requirement for flowering and to increase drought tolerance (Real *et al.* 2012). Still in the process of commercialisation it is too early to predict the extent to which this species may

fill the required niche. Talish clover (*Trifolium tumens*) is the other candidate, which reputedly is more drought tolerant than white clover and the first cultivar was recently released in Australia. Although initial results in southern NSW have been mixed, the species requires wider testing across the target region.

Perennial grasses for the low rainfall temperate crop-livestock zone. Temperate perennial grasses have been rarely used on short-term rotations with crops. However, with some crop rotations evolving to include a longer pasture phase there is a call for perennial grasses to improve pasture productivity, stabilise mineral N from legumes and build soil organic matter, and simplify pasture and livestock management (*e.g.* animal health benefits). In exotic perennial grass species, summer-dormant ecotypes of phalaris and cocksfoot are more persistent in medium rainfall environments (400-600 mm) than summer active cultivars (Norton *et al.* 2006; Hayes *et al.* 2010). Dear *et al.* (2004) demonstrated that perennial grasses can be used successfully in phased rotations with winter crops without sacrificing grain yield. However, there are a range of agronomic issues such as weed control and subsequent N management that need to be resolved before perennial grasses can be successfully integrated into pasture-crop rotations on a broader scale.

Perennial forages for crop-livestock systems with Mediterranean climate. While winter-growing annual pastures are widely used in the Mediterranean crop-livestock systems, very few perennial pastures are able to persist during the hot, dry summers on shallow, sandy or acidic soils. However, problems such as dryland salinity have prompted a range of efforts to find perennial options in these environments. A variety of novel introduced perennial species, particularly legumes, have been evaluated in this environment, but few had the persistence or agronomic traits desirable for a successful pasture species (*e.g.* Bell *et al.* 2008c; Li *et al.* 2008). Tedera (*Bituminaria bituminosa*) is reportedly the most promising option (Foster *et al.* 2012) and a breeding program is currently underway to develop this plant further (D. Real *pers. comm.*). A range of undomesticated Australian native species that might display useful agronomic characteristics have also been tested. This has identified tall verbine (*Cullen australasicum*) to have broad adaptation across the crop-livestock zone (Dear *et al.* 2007; Hayes *et al.* 2009; Bennett *et al.* 2011) but further development or commercialisation of this species remains uncertain. Thirdly, some tropical grasses have been found to be surprisingly effective, particularly on sandy soils where they provide protection from wind erosion. However, exploring ways that these species can be more widely integrated into farming systems is required; the practice of pasture-cropping (Ward *et al.* 2012) is showing some early promise.

Legumes in tropical and sub-tropical grass pastures. As permanent tropical grass pastures age they increasingly tie-up available N (especially buffel grass), which greatly reduces pasture productivity. The incorporation of legumes into these pastures is the most cost-effective approach for dealing with this 'pasture rundown' (Peck *et al.* 2012). However, establishment and maintenance of legumes in competitive grass swards is particularly challenging (Whitbread *et al.* 2009). Winter growing annual legumes (mainly medics) are used, but highly variable winter rainfall means that productivity of these species is unreliable (Bell *et al.* 2012). Several tropical legumes have been released to provide additional legume options, particularly on clay soils, but these have not yet been widely successful in grass-based mixed pastures (*e.g.* *Desmanthus virgatus*, *Stylosanthes seabrana*, *Macroptillium bracteatum*) (Pengelly and Conway 2000). Hence, there is a need to reconsider alternative species or the agronomic requirements of these species in order to more successfully utilise them in grass-legume pastures. Reliable establishment is still a factor impeding broader adoption despite a long history of research on the topic (*e.g.* Cook *et al.* 1993).

One of the largest challenges for developing new species that may fill gaps in the current array of options is the relatively small domestic pasture seed market in Australia. There are also few other regions internationally that have similar climate, soil and production systems and hence cultivars developed elsewhere are usually poorly adapted. As a consequence, many of the pasture species and cultivars used in Australia were developed locally, despite them being introduced from elsewhere (Nichols *et al.* 2012). Historically this has been supported by public research agencies, but publically funded efforts into further pasture breeding have declined with the expectation that the commercial sector would fill this void. However, commercial entities find it difficult to justify investment in research and development of new pasture cultivars specifically for the small Australian market. Perhaps the best example of this market failure is with summer-dormant cocksfoot cv. Kasbah, which has shown to have significant potential across the medium and low rainfall areas of the crop-livestock zone (Hayes *et al.* 2010). However, a combination of agronomic factors (described above) as well as lower seed yields compared to other cocksfoot cultivars has meant the market for this cultivar has not developed and the commercial seed companies have been reticent to invest to enhance it.

Breeding for improved tolerance and agronomic applications

While development of new pasture species might broaden the range of pastures available, there is still a significant role for targeted plant breeding to work towards overcoming limitations in adaptation or to diversify the range of systems applications for successful and widely sown forage species. In Australia, developing varieties with greater tolerance to salinity, waterlogging, soil acidity, and drought tolerance are all significant breeding priorities, where breakthroughs are possible and could yield significant benefits. Large variations in salinity and waterlogging tolerance have been identified in *Lotus* that could yield significant improvements in adaptation (Teakle *et al.* 2007; Teakle *et al.* 2010). Selecting for traits that confer greater drought tolerance in perennial pastures (*e.g.* summer dormancy in perennial grasses, as discussed above), would broaden the environments where they are used. Hybridisation of *Phalaris aquatica* with a related species, *P. arundinacea*, (Oram *et al.* 1993) has improved its aluminium tolerance and ability to establish on acid soils under moisture stress conditions (Culvenor *et al.* 2011). Developing lucerne for acid soils has also long been an objective for researchers in Australia and elsewhere, due to its inherent sensitivity to soil acidity and associated toxicities of Mn and Al (Humphries and Auricht 2001). This is challenging as it requires combining tolerance to a range of constraints in an inherently sensitive species, along with a tolerant root-nodule bacteria to ensure effective nodulation and performance of plants in the field. Some success has been made via mass recurrent selection for enhanced seedling root growth in high-aluminium solution culture, which has developed elite strains of lucerne which have up to 40% higher root growth under acidic soil conditions (Scott *et al.* 2008; Hayes *et al.* 2011). A strain of lucerne root nodule bacteria has also been identified (RRI 128) from collections of 227 naturalised rhizobia from acidic soils in southern NSW. The aspect upon which there has been less progress to date is in incorporating tolerance to Mn toxicity (Hayes *et al.* 2012b).

There are also several examples where Australian pasture plant breeding could improve agronomic characteristics and/or diversify systems applications for new varieties (Nichols *et al.* 2007). Seed production characteristics that enable farmers to grow and process their own seed and ensure a cheap and reliable seed supply are a high priority (*e.g.* pod-holding in medics). Tolerance to herbicides that allow control of crop weeds during pasture phases and to manage pasture weeds would certainly improve the adoptability of pastures in cropping systems. The introduction of tolerance to sulfonylurea residues in barrel medic for example, will improve its ability to be used in crop rotations where these herbicides are commonly used (Peck and Howie 2012). Increased grazing tolerance would enable lucerne to better coexist with other species in mixed pastures, and reduced winter activity and prostrate habit to reduce competition might produce lucerne cultivars suited to intercropping with cereal crops (Humphries *et al.* 2006; Humphies 2012). Several other current examples where breeding is aimed at improving agronomic applications of pastures include selection of soft-seeded legumes for phase cropping rotations (*e.g.* Sulla, French serradella), improving forage quality (*e.g.* saltbush) and reduced toxicity (*e.g.* phalaris, tall fescue).

Maintaining breeding efforts is also needed to respond to re-emerging or new pathological threats. The importance of this is highlighted by the identification of a new blue-green aphid biotype that is widespread across much of eastern Australia to which previously resistant cultivars of both annual medics and lucerne are highly susceptible (Humphries *et al.* 2012). Genotypes that are resistant have been identified but now need to be incorporated into breeding programs in order to safeguard these species from major losses. A similar situation is also likely to exist for other pathogens which have caused large losses in important pasture species (*e.g.* anthracnose in Stylos, powdery mildew in *Medicago* spp.).

New genetic techniques and even genetic modification are likely to provide tools to make further gains in pasture breeding. Increasing acid soil tolerance of phalaris briefly described above is one successful example. However, the high cost of these investments mean that their application needs to be evaluated relative to the benefit and market size, and therefore, is only likely in the most widely sown pasture species or those utilised widely overseas (*e.g.* lucerne, white clover, perennial ryegrass). Australia has developed world-class genetic resource collections across the diversity of sown pastures. This is a vital resource that needs to be maintained to ensure out future capacity to respond to emerging challenges is not diminished.

Addressing limitations to pasture productivity

In many grazing systems across Australia, low economic returns from livestock has seen reduced farm investment and effort dedicated to optimising pasture productivity. Pasture enhancement is often challenged by poor establishment, persistence, and nutrition and, hence gains in pasture productivity are less than expected. By overcoming common management and soil fertility constraints large gains in pasture productivity are possible, but greater evidence of their value proposition is needed. Establishment of sown pastures remains a challenge across many environments, though some novel approaches (*e.g.* twin sowing) are providing simplified options that also increase pasture production (see Loi and Nutt 2010).

Nitrogen deficiency remains the key limitation to grassland productivity in Australia. Apart from high input dairy systems, most Australian grasslands are almost completely reliant upon biologically fixed N, though there is increasing interest in using N fertilisers to boost pasture production in some regions (*e.g.* grass pastures in subtropics). Nonetheless, the legume content of pastures and the N-fixing efficiency of those legumes is a primary concern when considering strategies to lift the productivity of grasslands (Peoples *et al.* 2012). Poor legume inoculation and problems with root nodule bacteria persistence are particular challenges to legume N fixation efficiency. In several legumes (e.g. balansa clover, *Biserula pelecinus*), poor competitiveness of effective Rhizobia strains with background soil rhizobia can lower N fixation, particularly in the years following establishment (Howieson 1995; Ballard *et al.* 2002). Increased use of seed coating of pasture legumes and the inability of these to reliably deliver sufficient populations of root nodule bacteria at establishment may also be reducing legume performance in pastures (Hartley *et al.* 2012). Simple and reliable rhizobia delivery mechanisms and identification of rhizobial strains for improved field performance would greatly enhance adoptability and productivity of legumes in pastures.

Declining use of P fertilisers and lack of awareness of P deficiencies is also reducing pasture productivity, particularly in legume-based pastures. For example, a recent survey of sown pastures in southern Queensland found 50% of sites had available surface soil P (Colwell) below 15 mg/kg, which is well below the requirement for most legumes. Grazing industries in Australia currently also have low P efficiency of 20-40%, which means 2.5 to 5 units of P are applied as fertiliser per unit of P exported in products (Simpson *et al.* 2011). This inefficient use of P along with increasing prices for P fertilisers suggests there is a large scope and desire to develop systems to increase P

Table 1. Effect of complementing a native pasture with oats, improved sown grass and a combination of the two on frequency of feed deficits on a mixed farm in southern Queensland. Whole-farm modelling scenarios assume an average annual stocking rate of 3.5 DSE/ha (0.5 AE/ha) of a *Bos Indicus* self-replacing breeding cow herd. Forage production was simulated with APSIM and GRASP at Roma, Queensland between 1957 and 2008.

Feed-base scenarios	CV of annual feed supply	% of years with >30% utilisation	% of months with <500 kg DM/ha residual	% months when monthly ME supply<demand	% months with farm feed deficit
Native pasture only	0.40	0.44	35	41	9
¼ improved grass	0.38	0.29	27	26	4
$^1/_8$ oats	0.35	0.31	25	22	5
$^1/_8$ oats/$^1/_8$ improved grass	0.34	0.25	18	16	3

efficiency in grazing systems. This may entail developing or using pasture species that are productive at lower soil P concentrations or can release unavailable sources of P from the soil. For example, some native Australian legumes with potential as pasture species have been shown to be particularly efficient at accessing and utilising P (Denton *et al.* 2006; Pang *et al.* 2010). New fertiliser technologies may also enable more efficient delivery and reduced binding of P to the soil.

Improving agronomic management of soil acidity and its related toxicities (*e.g.* manganese and aluminium) through the incorporation of lime is a feasible response in systems where pastures are used in rotations with crops; however this does not overcome sub-soil acidity (Scott *et al.* 2000). Benefits from surface applied and unincorporated lime are limited, so in permanent pasture systems there are few options to alleviate soil acidity. One option emerging to address soil acidity in the permanent pasture zone is through use of dual-purpose crops which allow lime to be added and paid for by crop production (Bell *et al.* 2013).

Diversifying livestock feed systems

Year-to-year variability and seasonality in forage supply cause a mismatch between forage supply and animal demand in many livestock production systems in Australia. This induces inefficiencies in production in terms of excess feed wasted or unmet animal demand. Producers are often compelled to adopt more conservative stocking rates to ensure the risk of feed deficits or the associated costs (*e.g.* supplementary feeding) remain low. Hence, diversifying feed systems to provide feed at times when forage quantity and quality are low can have large benefits for overcoming feed gaps and enable overall stocking rate and productivity to be increased. However, it is important to realise that simple economic analyses, such as gross margins or partial budgets rarely capture the interactions and dynamics of feed supply and demand over time. Whole-farm approaches are required to ascertain the full scale of possible benefits relative to the cost of implementation (Bell *et al.* 2008b). Some examples of recent research aimed at improving the continuity of feed supply to improve productivity and risk across different production systems include:

Forage crops in dairy systems. Growing annual forage crops that complement the existing feed-base on dairy farms is widely considered an avenue to increase farm-grown forage supply, improve diet quality and reduce external forage and grain inputs in dairy production systems (Rawnsley *et al.* 2013). In northern NSW, a forage system involving forage rape, annual clovers and maize in combination with pastures demonstrated the potential to increase home-grown feed production and reduce supplement feedings and increase farm profit (Farina *et al.* 2011). However, in south west Victoria, the use of annual forage crops for conservation (*e.g.* silage) and grazing increased overall farm forage production by 30% , but this did not increase farm profit significantly (3%) due to higher costs and wastage associated with forage conservation (Cullen *et al.* 2012). Major inefficiencies in this system were associated with the conserved forage. Consequently redesigning forage cropping systems with a focus on grazing may be a more profitable option (Rawnsley *et al.* 2013).

Integrating forage sources in mixed crop-livestock systems. Mixed crop-livestock farms have particularly complex livestock feed systems but alternative feed sources that can fill feed gaps and improve livestock productivity have large potential, particularly in the face of evolving livestock production systems (Moore *et al.* 2009). In southern Australia, complementing annual pastures with lucerne, forage shrubs or dual-purpose crops have all been shown to significantly improve the continuity of feed supply, reduce supplementary feeding and increase potential productivity of these systems (Doole *et al.* 2009; Byrne *et al.* 2010; Monjardino *et al.* 2010). These changes in feed supply have a strong interaction with the livestock enterprise, with perennial pastures like lucerne providing greater benefit in prime lamb rather than traditional wool-sheep production systems (Byrne *et al.* 2010). However, few studies have evaluated the risk management implications of diversified feed systems. Table 1 shows a long-term modelling analysis in southern Queensland, which suggests that variability in annual feed supply, the frequency of years with over-utilisation of pasture, and the frequency and intensity of a feed gap were reduced when a native pasture dominated feedbase was supplemented with improved grass pasture and/or oats.

Mosaics of irrigated forages in pastoral beef systems. An intervention currently under evaluation is the development of distributed areas of irrigated forages to compliment pastoral beef enterprises in northern Australia (Hunt *et al.* 2013). The cost effectiveness of this intervention requires assessing the capacity to match the timing and type of forage to the demands of the livestock enterprise, or classes of livestock, in order to determine improvements in production or marketability of livestock relative to the development costs for irrigation. Initial results from whole farm bio-economic analysis reveal that large benefits could be obtained from relatively small additional feed supply

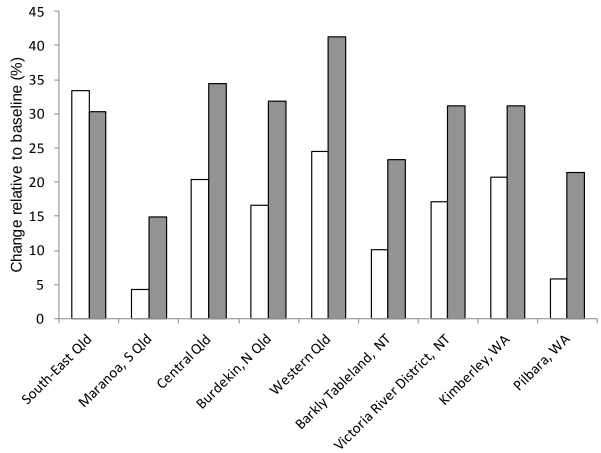

Figure 4. Relative gain (%) in gross margin per adult equivalent (white) and beef turnoff (grey) from integrating irrigated forage into rangeland beef production systems in several districts across northern Australia. Adpated from Hunt *et al*. (2013).

at key times of the year across a range of production systems and regions (Fig. 4). For example, in north Queensland, 250 ha of irrigated forage sorghum as part of a 30 000 ha grazing enterprise enabled steers to be finished a year earlier. Without the additional cohort of steers, the herd could be restructured with a higher proportion of breeders so that while overall herd numbers increased by 5%, beef turnoff could be increased by 30% and overall farm profit by nearly 40% (Hunt *et al.* 2013). In a similar way, in breeding only systems, targeting high quality irrigated forage to lift the nutrition and probability of reconception of heifers following their first calf, the reproduction rate of the whole herd could be improved.

In addition to the direct production benefits from improved continuity of feed supply, diversifying the range of forage sources on farms is likely to also have a range of benefits for animal health. For example, forage shrubs which can be used as out-of-season forage may also have anthelmintic benefits (Kotze *et al.* 2009). Problems such as bloat or endophyte toxicity could be reduced by utilising alternative feed sources to reduce intake of forages causing these issues when risks are high.

Precision and remote management in grassland systems

Precision and remote management provides a potential opportunity for improved efficiencies in the management of forage resources, particularly accounting for inherent spatial variability in grasslands. Increases in labour efficiency by either reducing labour requirements or through increased management intensity without increasing labour demands can be achieved *e.g.* robotic dairies (automated and voluntary milking systems), using remote sensing for heat detection in cattle and remote telemetry for monitoring water in extensive grazing systems (rangelands) are all labour saving technologies being tested widely in industry currently. Precision Pastoral Management software tools are currently being developed that combine precision spatial data (*e.g.* ground cover) with individual livestock performance allowing more efficient management at large spatial scales; more than sixty technology products (either cattle or pasture based) have been recently identified for potential use the northern Australian beef industry (Leigo *et al.* 2012). Pastures from Space™ is one example which uses remote sensing combined with simulation modelling to enable producers to monitor pasture growth rates, feed-on-offer and pasture quality and adjust management accordingly (Sneddon *et al.* 2001). Individual livestock identification systems combined with remote drafting systems and walk-over weighing also hold some promise for targeting supplementation to individual animals in grazing enterprises (Bowen *et al.* 2009). Variable rate irrigation and fertiliser application systems are beginning to be tested on commercial dairy farms, which are likely to reduce costs of these inputs and improve the efficiency of their use and result in environmental benefits from avoiding their overuse. A recent development in the use of NDVI (Normalised Difference Vegetation Index) sensors to detect urine patches within pastures made it possible to avoid applying nitrogen fertiliser to already nitrogen rich urine and dung patches (Mackenzie *et al.* 2011; Yule and McVeagh 2011). An initial evaluation of the technology within temperate pastures identified a 6% reduction in nitrogen use out of a theoretically possible 23% reduction (Snare 2012). Finally, the evolution of cheap and robust virtual fencing technologies could significantly reduce capital expenditure and would equip producers with the ability to implement zonal management of pastures and grazing across the landscape (Umstatter 2011). This would facilitate more optimal pasture utilisation and potentially increase carrying capacities. Livestock could also be excluded from sensitive parts of the landscape (e.g. riparian zones) or be corralled to enable easier mustering on extensive grazing properties to further reduce labour inputs in those systems.

Capturing value from ecological services

Grassland systems provide a range of ecological services (*e.g.* mitigation of drought and the impacts of climate change, cycling and movement of nutrients and maintaining biodiversity). In the past, the intrinsic value of these ecosystem services has been recognised but the financial value overlooked because they sit outside economic markets. Globally this situation is changing and it is likely that new opportunities for producers to obtain benefits from managing their production systems will emerge. For example, the Enterprise Based Conservation (EBC) – West 2000 Plus program encourages conservation management activities on pastoral leases in the rangelands of western NSW. Within this program, the ‘ground cover’-based incentive pilot program run over 5 years (2007-2012) paid financial incentives for privately managed grasslands to maintain levels of ground cover aimed to achieve positive NRM outcomes. This program recognised that in order to retain ground cover primary production income was forgone (through un-utilised pastures) thus incentives were paid to landholders to cover this cost. An important component of this program was that it allowed NRM outcomes at a property scale compared to the tradition ‘set-aside’ approach where conservation areas are taken out of production. Improved land condition also improved response following drought and ability to capitalise on good seasonal conditions. The feasibility and cost effectiveness of these market-based instruments appears to be most successful when they align with landholder decisions, are well communicated and avoid arduous monitoring (Whitten *et al.* 2012). The success of such pilot programs, (despite a lack of ongoing mechanisms for payments) serve to signal a change in grassland management that recognises their multi-functional nature which includes conservation values beyond more traditional grazing or pastoral production values.

Carbon sequestration is an ecosystem service that is currently topical where grassland management may have a role to play. While the influence of grazing management on soil carbon levels in rangelands are currently being examined it is expected that grassland management that results in shifts towards increased perennial species represents a potential option for sequestering carbon (Waters *et al.* 2012). Australian grasslands are a large potential sink of carbon, and the assessment and implementation of practices that increase the storage of carbon in grassland production systems may provide a future opportunity for producers to obtain carbon credit payments. Importantly, such carbon-based enterprises may offer the potential for grassland restoration, particularly in the rangelands where the cost of active restoration is precluded by the scale of pastoral activities. The co-benefits associated with C payments have been highlighted in a recent carbon accounting survey in the Kimberley-Pilbara region of Western Australia (Alchin *et al.* 2010). Major obstacles for capitalising on carbon enterprises include difficulties in measuring changes in SOC due to high spatial and temporal variability of SOC, particularly in the rangelands, a lack of benchmarks and an unpredictable future policy setting at both Federal and State levels. Currently, several proposals have been submitted to Australia's Carbon Farming Initiative that outline grassland management practices that are eligible to obtain carbon credits. For example, a change in time of burning savanna from predominately late dry season to early dry season reduces fire intensity and reduces the area burnt and fuel consumed. A range of other practices to either increase soil carbon or vegetation storage or mitigate green house gas losses are likely to have some eligibility for such schemes.

Reducing greenhouse gases emissions

The beef, sheep and dairy industries account for 47, 19 and 10% of Australia's agricultural green-house gas (GHG) emissions, respectively, and together this is 16% of national emissions (DCCEE 2011). This puts grazing industries under particular scrutiny to reduce their contributions to net GHG emissions. Methane emissions from grazing livestock also represent a considerable energy cost and potential production loss; equivalent to 33-60 days grazing per year for beef steers (Eckard *et al.* 2010). Several proposed avenues for reducing enteric emissions that do not involve interventions in grassland management (*e.g.* genetic selection of animals, direct modification/ manipulation of the rumen biota) are well reviewed elsewhere (see McAllister and Newbold 2008; de Klein and Eckard 2008 ; Cottle *et al.* 2011).

Modifying livestock diets is one of the most effective methods for reducing enteric CH_4 emission intensity and possibly N_2O losses. Increasing energy content or quality of ruminant diets reduces enteric CH_4 production intensity, but achieving this via feeding concentrates (*e.g.* grain) does not necessarily reduce gross GHG emissions (*i.e.* associated with transport and grain growing). On the other hand, providing forage with higher digestibility (*e.g.* legumes or higher nutritive value grasses) will lower enteric CH_4 emission intensity (Beauchemin *et al.* 2008). Forages containing condensed tannins, saponins or other secondary compounds (*e.g.* birdsfoot trefoil, leucaena) can also reduce enteric CH_4 production through a direct toxic effect on methanogenic rumen bacteria and/or N_2O emissions by increasing the proportion of dietary nitrogen to the less volatile dung rather than urine (Carulla *et al.* 2005). However, some forages containing secondary compounds can increase methane production (Mayberry *et al.* 2009). Balancing energy and nitrogen in the diet increases animal nitrogen retention and so nitrogen partitioned to urine decreases which can reduce the N_2O emissions from urine patches. For example, Miller *et al.* (2001) found that urine N was reduced by 29% and total nitrogen excretion was reduced by 18% when dairy cows were grazing higher sugar accumulating cultivars of perennial ryegrass. Together this suggests that pasture mixes and feed systems could be developed that reduce enteric CH_4 emissions and enable animals to more effectively convert energy consumed into production.

Another option for reducing N_2O emissions from grasslands is direct intervention in the nitrogen cycle to reduce the likelihood of emissions from the soil. Where high rates of N fertiliser are used (*e.g.* dairy systems) emission rates could be reduced by using NH_4^+ based rather than NO_3^- based fertilisers (de Klein *et al.* 2001). There is also scope to directly inhibit the nitrification of NH_4^+ to NO_3^- with nitrification inhibitors. These can reduce N_2O emissions associated with fertiliser use by up to 80% when coated on the fertiliser granule (de Klein *et al.* 2001) and by 61 to 91% from urine patches when sprayed on the pasture (Di *et al.* 2007 ; Kelly *et al.* 2008). Despite reported increases in pasture production of up to 15 % (Zaman and Blennerhassett 2010), the cost of nitrification inhibitors currently limits their use in Australia. Furthermore, community concern regarding the broader environmental impact and safety of these compounds could potentially limit their use into the future. Precision agriculture technologies that enable nitrification inhibitors to be applied only to urine patches within a pasture could reduce the amount used while still achieving similar emission reductions (McMillan 2010). Further development is required, but this technology would make nitrification inhibitors viable to use within intensively managed grasslands.

Most methods reduce enteric CH_4 and N_2O emissions discussed above have the potential of improving production as well as reducing emissions. Hence, improvements in production potential will likely increase total emissions but reduce emission intensity of production (*i.e.* GHG produced per unit of product). Whole-of system analyses of dairy, beef and lamb production systems have shown that improvements in forage quality increased CH_4 emissions per ha as a result of increases in stocking rate, but emissions per animal and per unit of produce were reduced (Alcock and Hegarty 2006; Eckard *et al.* 2010; Hunt *et al.* 2013). Eckard *et al.* (2010) found that if nitrification inhibitors reduced nitrogen losses and increased pasture production overall farm emissions would increase due to an increase in stocking rate, while if inhibitors allowed for decreased nitrogen fertiliser use but maintained pasture growth, overall farm emissions were reduced. These whole of system analyses highlight the challenges when attempting to implement grassland management strategies aimed at reducing the net greenhouse gas emissions compared to reducing emission intensity of the Australian pastoral industries.

Grain producing grasslands?

The future may also offer some novel systems to produce grain in conjunction with perennial-based grassland grazing systems. Pasture cropping (also known as intercropping) involves sowing a winter-growing crop directly into a summer-active perennial pasture once this has become dormant. This system has been successfully implemented by several producers in the uniform rainfall zone of Australia's crop-livestock zone, where fertiliser applied to the crop have residual benefits for pasture production (Millar and Badgery 2009). In winter dominant rainfall zones (*e.g.* south-western Australia) pasture cropping into tropical pasture grasses is currently being tested (Finlayson *et al.* 2012). However, significant questions remain about the environments (soil and climate) where this system has high probability of success. The possibility of developing perennial grain crops such as perennial wheat or domestication of native grasses such as *Microleana stipoides* could also enable both grain and forage for livestock to be produced in combination (Bell *et al.* 2010). Economic analysis in southern Australia shows that perennial cereal crops that provide additional forage early in the pasture growing season and after its harvest could increase farm returns significantly (Bell *et al.* 2008a). In such a way, a potential target for the development of perennial crops may be a crop that is primarily used for grazing but opportunistically harvested. Initial evaluations of wheat x wheatgrass derivatives would suggest that the target environments for early generation perennial cereal crops are likely to be in the higher rainfall regions that are currently dominated by permanent perennial grass-based pasture stands (Hayes *et al.* 2012c).

Future human capacity challenges in grassland research

While there are a range of opportunities for grassland research to improve our production systems, having the human capacity and resource to capitalise on or service these opportunities is one of the major challenges facing Australia's agricultural sector. Current and future skill shortages in agriculture have been widely discussed in Australia's agricultural education sector (Pratley and Leigh 2008). However, the situation in pasture science is more dire than in the agriculture sector as illustrated by trends in Australian university data (see Robson, this p. 101, conference). While it is difficult to obtain long-term data on the number of pasture scientists working across Australia, the predicament is illustrated in an analysis of employment by CSIRO, state departments and university pasture research and development scientists across northern Australia (Table 2). During the 1960's, 70's and 80's there were more than 40 full time pasture scientists in CSIRO and a similar number in state departments and universities. In CSIRO in 2012, the retirement of 2 experienced pasture researchers left one research scientist focussed on pasture research in northern production systems. A similar decline in tropical pasture research capacity has also been occurring in state departments and universities; a further 3 pasture scientists from these agencies included in the count in 2011 will retire in the next 5 years. Admittedly the numbers derived here only include public sector research. Private sector are expected to take up many roles previously funded through government (*e.g.* breeding, farm advice), but a cursory tally of private sector pasture scientists in northern Australia number less than or similar to those in the public sector (*i.e.* 4-8). The situation with pasture science research and development capacity in southern Australia was not assessed here. Nonetheless there are clearly difficulties ensuring sufficient early and mid-career scientists are being developed to replace those late in their career.

Table 2. Trends in numbers of full time pasture science research and development scientists in tropical and subtropical Australia within CSIRO and combined including state departments and universities over the past 60 years. Numbers exclude technical staff and rangeland ecologists not focussed on pasture production. Data collated by Dr Ted Henzell (former Chief of CSIRO Tropical Crops and Pastures 1970-1988, Brisbane). *Excludes local plant introduction specialists.

Year	CSIRO	Total
1951	8	
1956	20*	
1959	23*	
1975	57	130
1984	42	
1994	33	
1999	12	
2006	6	14
2011	3	10

There is beginning to be some recognition by research funders and providers that the situation with pasture science capacity in Australia is unsatisfactory. Attracting, training, and supporting the next generation of pasture scientists is vital if the industry is to overcome the challenges of meeting the productivity growth and environmental expectations required to maintain profitable and sustainable pasture-based industries in Australia. This is not a trivial challenge. The industry and research organisations need to provide incentives and an indication of a clear and promising career path to attract more talent to the discipline of pasture science. Perhaps reintroducing scholarships with bonded graduate positions as used in the 1960's and 70's may be a useful way of encouraging another generation of pasture scientists. Nonetheless, once trained there is a need to support these researchers with reliable funding that enables them to build their career in the discipline. New-age scientists are expected to be capable of cross-disciplinary research covering aspects varying from ecology, breeding, genetics, agronomy, modelling and economics. To be successful pasture scientists must have effective relationships and communicate regularly with industry including producers, their advisors, seed industry, government and fellow researchers. In Australia, the pathway for delivering research outcomes to producers has changed, with increased involvement of advisors and farmer driven networks (*e.g.* Dairy connect, grower groups). Incentive structures within research organisations are also not amenable to pasture research which often requires longer-term investments and is slower to produce outcomes.

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