

Pastures in Australia's Dryland Agriculture Regions

Ann Hamblin

1 Introduction

The focus of this chapter is the Intensive Land Use Zone (ILZ) of Australia, from which much of the original, native vegetation was cleared or modified between 200 and 30 years ago (Graetz et al. 1995). This corresponds to the agricultural belt (Fig. 1) which lies between the latitudes 23° and 41°S—excluding the arid and tropical rangelands (the Extensive Landuse Zone, or ELZ) where inter-annual rainfall variability exceeds the long-term average annual rainfall¹ which is insufficient for dryland cropping. The rangelands support 5 % of Australia's sheep and 45 % cattle. The division between the ELZ and the ILZ (Fig. 1) is an accepted boundary between farmed and pastoral regions, and distinguishes freehold from leasehold tenures.

Sheep were a mainstay of rainfed Australian agriculture until recent decades, reaching an all-time high of 170 million at the end of the 1980s as a result of inappropriate interventionist wool pricing policies that encouraged farmers to keep large flocks for wool (Massey 2011). After the collapse of the export wool market, this number dropped to 72 million (90 % in the ILZ) in 2014 (the lowest since 1910) with a concomitant shift to other animal products and an increase in cropping.

The persistently low returns from wool and relatively better returns to grains during the past 25 years have been a game-changer, resulting in substantial changes in land use and farming systems (Nossal and Sheng 2010; Walcott et al. 2013). There has been an expansion in cropping into wetter areas, while the total area of dryland grain cropping has fluctuated between 20 and 23 Mha. Cattle numbers have increased; by >5 % in medium to low rainfall parts of New South Wales (NSW) and

¹ Index of annual rainfall variability defined as $[90p - 10p] / 50p > 0.5 - 0.75$; $p = 90\text{th}, 50\text{th}$ and 10th percentiles: http://www.bom.gov.au/jsp/ncc/climate_averages/rainfall-variability/index.jsp

A. Hamblin (✉)

The UWA Institute of Agriculture, The University of Western Australia,
LB-5005, Perth, WA 6001, Australia
e-mail: ahamblin@optusnet.com.au

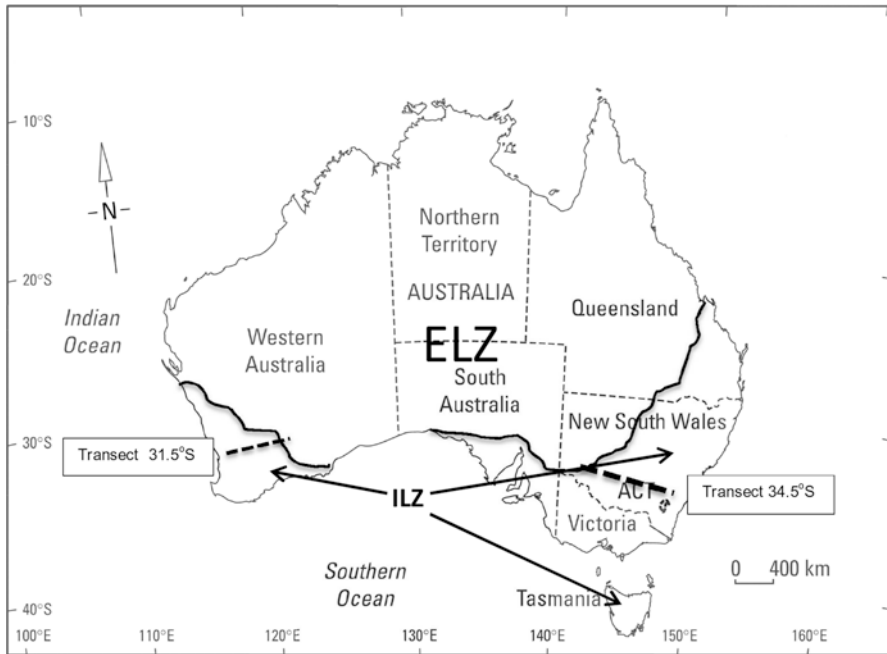


Fig. 1 Location of the Intensive Land Use Zone (ILZ) and Extensive Land Use Zone (ELZ) in Australia showing the transects at latitudes 31.5°S Western Australia and 34.5°S New South Wales referred to in this chapter

southern Queensland, and throughout the high rainfall coastal zone (Bell et al. 2014; Walcott et al. 2013). In southern Queensland and northern NSW, in particular, the increase in cattle numbers has been associated with the development of hundreds of feedlots that source animal feed from surrounding grain-growing areas (Queensland Transport Logistics Council 2014). In 2011, the high rainfall region of the ILZ had 8.5 million cattle (excluding 1.8 million dairy cows) compared with 6.6 million in the mixed-farming zone, and a national total of 28.5 million (Meat and Livestock Australia 2012a). After peaking at 29 million in 2013, cattle numbers are forecast to decline from 2016–2019 due to the persistent droughts in northern farming areas causing increased sell-off. Cattle numbers were fairly stable in the ILZ from 1990 to 2000 but increased to >50 % of the national herd between 2001 and 2012 (Fig. 2).

Despite the expansion of the red meat industry, income from crops has outperformed livestock across most regions in temperate Australia, while meat has replaced wool as the most profitable animal product (Dahl et al. 2014; Robertson 2010). Most rainfed farms have reduced their total flock size, increased their proportion of ewes, focussed on cross-bred lamb rather than wool production, or changed to beef while some have completely destocked (Curtis 2009).

There have been substantial changes in the methods of sale, processing and product development in the livestock industry. The reduction in the number of sale yards and processing plants has been rapid; for instance in 2003, 25 large processors were

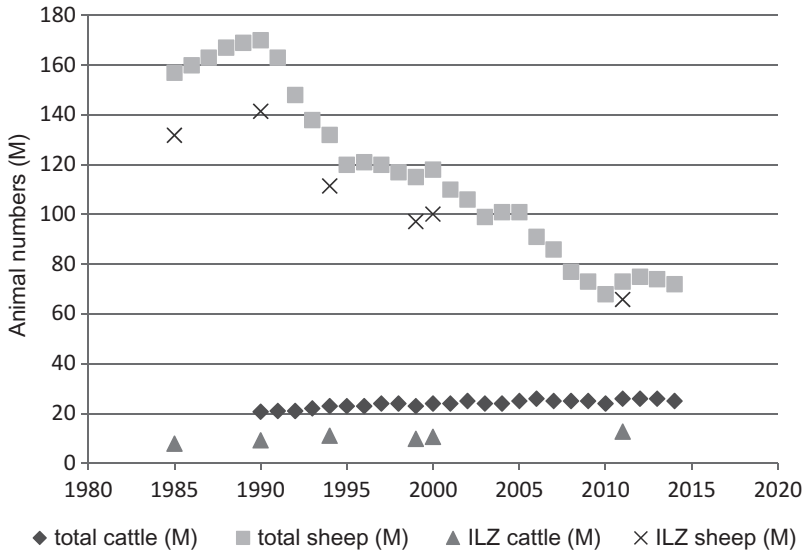


Fig. 2 Total Australian sheep and cattle (millions) and numbers in the ILZ from 1985 to 2014 (Sources: ABS 2014, ABS 1982–1996, National Land and Water Resources Audit 2001 and Meat and Livestock Australia 2012a, b)

responsible for 60 % of production, but by 2015 these had merged into two large, vertically-integrated processing companies (Teys-Cargill and JBS) responsible for 50 % of the red meat processed in Australia. As Asian, and particularly Chinese, demand for agricultural products is projected to increase rapidly over the next 30 years, there is potential for significant expansion in red meat products in future (Linehan et al. 2012).

2 Extent of Pastures and Grazing in the ILZ

Grazing land occurs throughout the ILZ, extending in an arc around the continent, across winter, equi-seasonal and summer-dominant rainfall regimes. Permanent pastures of perennial, introduced grasses and legumes support dairy and beef cattle in wetter coastal regions and eastern slopes of the Great Dividing Range. On the inland lower rainfall slopes and plains, annual and perennial species are rotated with crops in phase farming. Native perennial grasses occur on the western hinterlands of the Great Dividing Range, fenced and later improved with fertiliser and/or introduced species (Hill et al. 1999), variously described as ‘native pastures’, ‘modified native pastures’ or ‘improved pastures’ (Benson 1996; Donald 2012). In south-west Western Australia (WA) and South Australia (SA), introduced annual grasses and legumes predominate. A comprehensive description of Australian pastures has been given by Wolfe (2009).

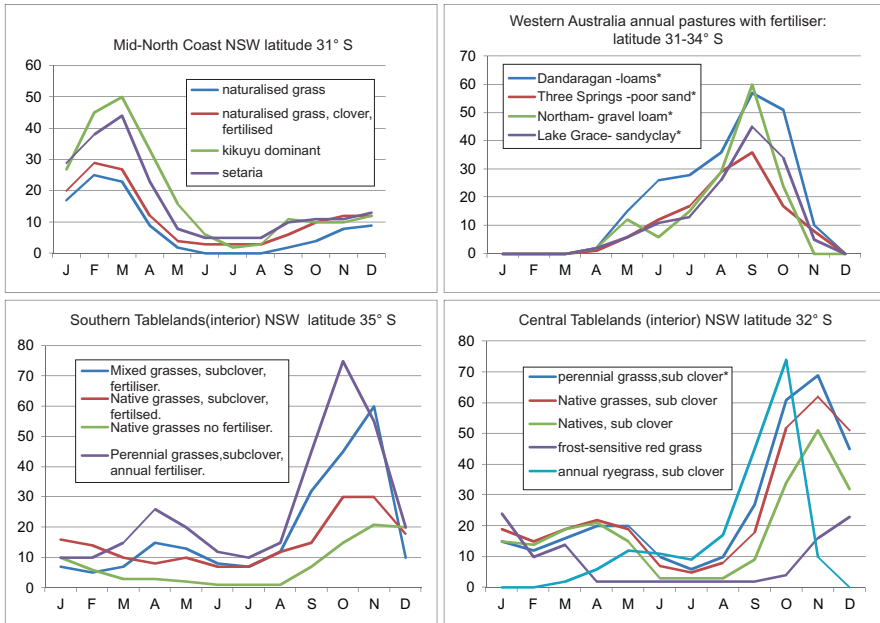


Fig. 3 Pasture growth rates (kg ha⁻¹ d⁻¹) for perennial and annual, exotic and native grass species from summer, equi-seasonal and winter-dominant rainfall regions (Source: Meat and Livestock Australia (MLA) Sustainable Grazing Systems (www.mla.com.au/tipsandtools8.2). ‘kikuyu’- *Pennisetum clausenianum* (Hoscht ex. Chicov), ‘setaria’ – *Setaria shacelata* (Schumach), ‘sub-clover’- subtterranean clover, WA= all sites fertilised pastures of annual ryegrass, subtterranean clover and exotic weeds

Australian livestock producers must manage marked seasonality in rainfall incidence, except in some coastal regions and those with a more equi-seasonal rainfall distribution (Fig. 3).

In the Mediterranean climates of WA and SA, there may be seven or more months without effective rain, restricting the use of perennial grasses and legume species. Fig. 3 demonstrates that native grasslands (Central Tablelands NSW examples) do not achieve the same level of production as sown pastures, even with introduced legumes and fertiliser, and deficiencies in soil fertility or physical properties (Western Australian examples) cannot be overcome by fertiliser and legumes. Native grasslands have undergone many transformations since the European occupation two centuries ago including grazing by introduced herbivores, the addition of exotic grasses, legumes and forbs, and the use of phosphate fertilisers. Sown pastures have been the major focus of research and development, but native pastures extend over a much larger area (Wolfe and Dear 2001). Of all the introduced species, perennial and annual ryegrass (*Lolium perenne* L. and *L. rigidum* Gaud.) and subtterranean clover (*Trifolium subtterraneum* L.) are the most extensively used, but all legumes play an important role in maintaining adequate animal nutrition and contributing to soil fertility. Table 1 summarises the geographical range of the most commonly-used legumes.

Table 1 The principal geographical zones and soils where introduced pasture legumes are sown in rotation with crops (*brackets indicate subdominant legumes*)

Latitude	Winter rainfall (%)	Geographical location	Principal soil types	Length of pasture phase	Principal legumes
25–29°S	<25	Southern Queensland	Medium to heavy loams and clays, neutral pH	Long	Lucerne (alfalfa)
				Variable	(annual medics)
29–32°S	25–40	northern NSW	Medium to heavy loams, clays, neutral pH, some acid sands	Long	Lucerne
				Variable	(annual medics)
32–38°S	40–65	Central-southern NSW, Victoria	Acid light to medium sands or clay at neutral pH	Long	Subclover, annual medics, lucerne
				Short	(balansa clover)
				Long	
				Variable	
38–44°S	70–80	Western Victoria, SA, Tasmania	Neutral-alkaline sandy loams	Short	Annual medics, lucerne, subclover, (balansa clover)
			neutral loams	Long	
				Short to variable	
29–37°S	70–80	South-west WA	Acidic sands	Short	Serradella
			Acidic sands	Short	Subclover
			Sandy loams	Short	Annual medics

Lucerne (*Medicago sativa* L.), Subclover (*Trifolium subterraneum* L.), Serradella (*Ornithopus compressus* L.), Annual medics (*Medicago polymorpha* L., *Medicago truncatula* Gaetnr), Balansa clover (*Trifolium michelianum* Savi)

Adapted from Wolfe (2009)

In mixed-farming regions, pasture legumes traditionally supplied much of the nitrogen (N) demand for crops (Hill 1996) and enhanced the value of animal feed into the dry season. Together with phosphate (P) fertilisers, legumes were the foundation for increasing animal production from native as well as sown pastures (Doyle et al. 1993), but over the past 20 years, crop N demand has been met by increasing rates of fertiliser, and pasture phases have shortened or been replaced by oilseeds and pulses as break crops, apart from the specific use of long-phase lucerne (alfalfa) (see Anderson et al. Chap. 11, this volume).

The total area of land grazed by domestic stock in the ILZ from 1990 to 2015 is difficult to establish because pasture definitions have varied in census questionnaires. Farm land that is grazed but does not qualify as sown pasture has been reported by the Australian Bureau of Statistics (ABS) as 'native, volunteer pasture' (1991), 'all improved pastures' (1996) and 'all grazed land: improved plus other' (2011). Land use areas have been estimated from the Australian Collaborative National Land Use Mapping Program (ACLUMP) since 1992/1993, with

Table 2 Area (Mha) of sown pastures and all sown + modified grazing

Date	ABS censuses *sown pastures ** all sown + modified	NLUM all modified grazing land	ABS resource Management practices surveys ^{##}	ABARES average % of 300–600 mm zone farm not cropped	ABARES average % of >600 mm zone farm not cropped
1989–1990	74.0**	19.9 ^{#3}	–	72	96
1996–1997	70.0**	25.8 ^{#3}	–	80	94
2000–2001	25.8*[-]**	23.8	–	71	94
2001–2002	22.9*[-]**	23.8 ^{#3}	–	75	94
2005–2006	24.5* [§] [-]**	72.0 ^{#4}	–	78	92
2007–2008	–	–	66.7	70	93
2010–2011	19.1*[55.0**]	70.0 ^{§#5}	60.5	73	93
2012–2013	–	–	48.5	70	92

Sources Australian Bureau of Statistics agricultural censuses, National Land Use Mapping (NLUM), ABS Resource Management Practices surveys, and Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) farm surveys for high rainfall (>600 mm) and mixed farm (300–600 mm rainfall) categories (ABARES 2014)

[§]estimate only; ^{#3–5}AgStats (NLUM) data for Versions 3,4,and 5; significantly under-reported in Version 3 which assumed no grazing where native woodland had a crown-cover >50 %; ^{##}ABS (2013, 2014) Catalogue numbers: 46270DO001_2007-13 ‘improved’ grazing areas’

remote-sensed NDVI² (ABARE-BRS 2010), but methods have varied, with grassy woodlands sometimes included but sometimes not (Mewett et al. 2013), so this measure of total grazed areas has fluctuated widely (Table 2).

Fertilised, sown pastures in the mixed-farming and high-rainfall regions have occupied between 19 and 26 Mha since 1990 but the total area of all grazed land on farms is much larger despite an overall reduction of ~15 Mha since the 1980s, due to increased cropland, reduced farm areas from urban expansion, and farm forestry (ABS 1991–2011). The total pasture area on farms can be estimated by subtracting the cropped area from the total operational area of farm holdings. By this calculation, grazing land accounts for 70 % of mixed farms and >90 % of high rainfall farms (ABARES 2014).

As grazing continues to be the largest single land use in the ILZ, domestic grazing animals impact at least two-thirds of the agricultural landscape, except where fencing and watering points have been deliberately removed, for example in north-eastern WA and SA–Victorian mallee (Norris 2009; van Rees et al. 2011). Elsewhere, farmers have retained the infrastructure needed for animal production to provide flexibility in the face of fluctuating seasons and prices. Hutchings and Nordblom (2011) showed that mixed farming with livestock in NSW significantly reduced the risk of financial loss compared with farms devoted solely to cropping. Robertson et al. (2014) found that mixed crop–livestock systems in south-east Australia were financially most robust with an optimum distribution of 45 % pasture

²NDVI= Normalised Difference Vegetation Index, the ratio of near infra-red to visible wavelength reflectance spectra for green vegetation received by satellite sensors.

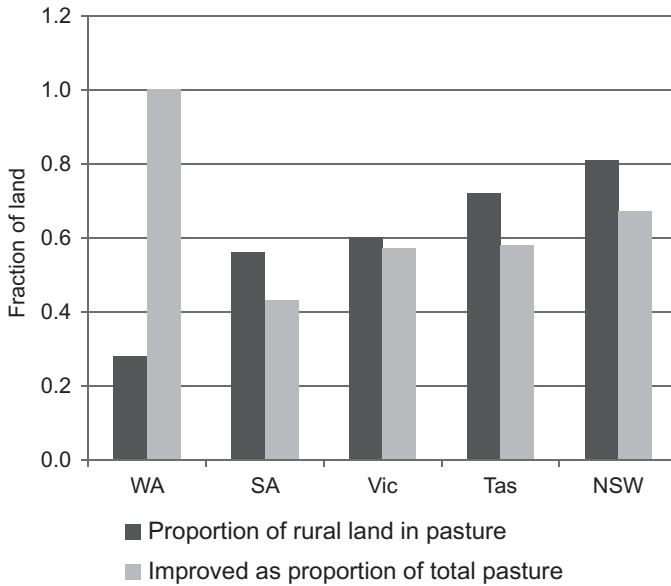


Fig. 4 The proportion of rural land in pasture and in improved pasture by state in southern Australia, after Donald (2012). Values for NSW exclude the Western Division Pastoral Lands which fall outside the ILZ

and 55 % cropped. Recent benchmarking studies undertaken in the mixed-farming zone have shown that most cropping farmers have between 30 and 60 % of their land in pasture depending on rainfall, some of which may be a sown pasture within the main crop rotation, but more is in perennial pasture in longer phase rotation (Burns and Norton 2015; Harries et al. 2015; Llewellyn and D’Emden 2010). Grazing land may not always be fully used, but forms an insurance against crop loss risk, particularly during drought years.

2.1 Regional Differences

The distribution of native grasslands that existed across Australia before white settlement still influences the extent and type of grazing land on farms. Figure 4 draws on data from the 2011 pasture audit of southern Australia (Donald 2012) to compare the extent and type of pastures in each state. In WA there is no native pasture, and sown pasture occupied only 28 % of farmland in 2011, whereas in NSW the total extent of pasture was 80 % of the farmland area, of which only 42 % was sown to introduced species.

In northern NSW and south-eastern Queensland, where open scattered woodland occurs with native grasses, sporadic clearing of remnant woody vegetation continues under licence. This has increased the total extent of ‘managed’ or ‘modified’

pasture categories in agricultural censuses. Between 1990 and 1995, clearing increased grazing of native vegetation areas in Queensland and NSW on average by 0.5 Mha year⁻¹. The rate of clearing in Queensland was most rapid, increasing to 654,000 ha year⁻¹ in the last two years of the twentieth century, with 2.2 Mha cleared by 2012 (Accad et al. 2013). The greatest extent of recent clearing has been south of latitude 27° in more fertile brigalow (*Acacia harpophylla* F. Muell. ex Benth.), Mitchell grass (*Astrebla lappacera* Lindl.(Domin) and other *Astrebla* species) and mulga (*Acacia aneura* Benth.) subtropical bioregions where leguminous native shrubs and palatable grasses are traditional cattle-rearing areas. Such clearing maintains ‘improved pastures’ for producers by counteracting woody regrowth, with increased productivity as the competition for light, water and nutrients from trees declines (Scanlan 1991).

2.2 Responses to Changing Climates and Other Stressors

Independent of changes arising from market conditions, some land use changes have occurred in response to changing climates. Since 1990, there has been a 15–20 % decline in winter rainfall and a 25 % reduction in spring rain in south-eastern Australia. In the south-west, there has been a permanent reduction of 20–25 % in winter rainfall since the mid-1970s (Bureau of Meteorology 2014). Cropping has therefore expanded into southern high rainfall pastures (>600 mm) where waterlogging and frost are now lesser problems than in the past. In the interior margins of the wheatbelt in WA (Northampton and Yilgarn statistical local areas (SLAs)), SA (West Coast and Flinders Ranges SLAs) and throughout southern Queensland, the area sown to crops has declined and more grazing now occurs due to the increased variability in growing season rainfall (Mewett et al. 2013).

In the Mediterranean-type environments, deep-rooted perennial pasture legumes and grasses have been introduced with some success to take advantage of increased out-of-season summer rainfall (Wolfe 2009). Warmer average temperatures in the past two decades have increased the opportunity to introduce subtropical grasses and legumes (Bell et al. 2013; Descheemaeker et al. 2013) and increase planting of new lucerne varieties for forage (Moore et al. 2009). Novel systems have been developed for sheep to graze young cereal and canola crops during the winter feed gap in south-western and south-eastern regions, providing autumn feed and reducing grazing pressure during periods of low growth (Virgona et al. 2006; Kirkegaard et al. 2008).

The development of herbicide-resistant weeds such as multiple-resistance annual ryegrass has reduced the reliance on annual grass-based pastures in crop rotation sequences (Powles et al. 1997), and price signals have shifted rotations more toward oilseeds than pulses as break crops from cereals (Harries et al. 2015). These changes have tended to reduce the reliance on traditional legume-based ley pasture rotation systems (Seymour et al. 2012) and contributed to the reduced extent and poorer condition of many pastures in the ILZ.

3 Managing and Maintaining Pastures

Two pasture audits have been carried out across the ILZ since 1990. The first occurred from June to October 1994, across 544 local government areas (LGAs) from southern Queensland to WA using SLA map boundaries (Pearson et al. 1997). An edited database provided information on the proportion of ~2500 plant types across the country (Hill and Donald 1998). Most pastures originally sown to self-regenerating legumes and improved grasses in southern WA, much of SA, and northern and central parts of NSW were reported as weedy, with weeds comprising up to 70–80 % of the ground cover. These weeds, of low nutritional value, included barley grass (*Hordeum leporinum* Link.), silver grass (*Vulpia bromoides* L. and *V. myuros* L.) and capeweed (*Arctotheca calendula* L. Levyns). Exotic temperate perennial grasses such as cocksfoot, phalaris and fescue (*Festuca rubra* L.) in the higher rainfall areas were in good condition in the south and east where there was a wide spectrum of introduced pasture legumes.

The second pasture audit occurred in 2011 across the southern ILZ, omitting south-eastern Queensland, using 404 SLAs as the reporting base (Donald 2012). This survey categorised pastures by type, dominant species and varieties, use in crop rotation and carrying capacity, and estimated pasture condition. Condition was assessed as stable, declining or improving, and given a score of 1–10 on the basis of legume and weed content (Table 3). Of the pastures surveyed, 35 % (17 of 48 Mha) were scored as in decline, which is similar to the results of the earlier audit which reported 32 % of SLAs having the majority of pastures in poor condition.

Table 3 Total grazed area (ha) in ILZ by state, % area in decline and estimated area (ha) of dominant sown species in the 2011 pasture audit

Area (ha)	NSW	Victoria	Tasmania	SA	WA
Total surveyed	22,500,00*	7,391,400	1,186,414	7,576,000	9,462,335
'in decline'	7,016,250	805,340	444,450	4,348,600	3,186,550
Decline as % total	31 %	11 %	38 %	57 %	37 %
Subterranean clover	1,127,082	495,415	69,332	208,203	1,455,555
Annual rye grass	533,960	511,150	48,016	160,086	1,528,430
Medics**	1,401,157	0	0	1,213,500	296,050
Perennial rye grass	305,288	934,521	265,939	47,949	37,742
All other clovers	713,203	261,957	37,839	40,620	51,300
Pasture area with legume	22 %	13 %	11 %	23 %	19 %
Lucerne	1,756,799	208,221	11,598	266,908	33,369
Cocksfoot	372,727	349,068	103,822	23,408	25,424
Phalaris	746,512	912,337	11,227	266,900	21,020

After Donald (2012)

*Excluding Western Division NSW pastoral region; **Principally burr medic (*Medicago polymorpha* L.) and barrel medic, Cocksfoot = *Dactylis glomerata* L., Phalaris = *Phalaris aquatica* L.

Between the two surveys, the area of forage lucerne (alfalfa) increased to 2.3 Mha, and specific legumes adapted to acidic or alkaline conditions, such as *Serradella* spp. in WA and burr medic in SA, were successfully introduced or expanded, with more subtropical perennial grasses and legumes planted in southern localities in response to changing climatic conditions (Nichols et al. 2012). The Millennium drought (2002–2009) contributed to the reduced legume content and seed set in NSW (Donald 2012), but the low status of pastures in Tasmania, WA and SA that were less affected by prolonged drought indicates a deeper underlying problem affecting many sown pastures.

Deterioration of legume-based pastures in rainfed mixed-farming regions has been reported since the late 1980s. Some of the factors listed by Wolfe and Dear (2001), such as insect pests, herbicide damage, effects of drought, acidification and suboptimal fertiliser use, occur today. National initiatives have been mounted by research and development agencies to address the low productivity of pastures across different rainfall zones. Between 1994 and 2001 the Sustainable Grazing Systems Program (SGS) involved 23,700 producers in high rainfall regions, and between 2003 and 2008 the Grain and Graze program involved 6800 mixed farms in the wheatbelt. These programs resulted in topical research findings and practical guidelines based on a network of experimental sites and farmer participation groups (Hacker et al. 2009; Johnson et al. 2003). SGS promoted the extension of rotational grazing to avoid selective overgrazing of more palatable species, rather than set stocking which had been the traditional method of rearing stock in many areas. By 2012, ~30 % of sheep farmers had converted to rotational grazing (Barson et al. 2012) compared with <15 % a decade earlier.

Many native grasslands in the interior plateaux (the Tablelands) of NSW, Victoria, southern Queensland and central Tasmania became severely degraded and invaded by exotic grasses of low herbage value after decades of set stocking. Remedial management systems were developed, where stock are grazed at low densities in winter then at high levels in spring to suppress flowering of annual exotic species and allow later-flowering native grasses³ to flower and seed (Kemp and Dowling 2000). Native species, adapted to nutritionally-poor soil conditions, can then compete more effectively against introduced grasses. This system, however, requires active paddock monitoring, subdivision of large paddocks into smaller cells, additional fencing and watering points, and frequent movement of sheep (Evergraze 2014). Existing land degradation (bare scalds and gullies) and a preponderance of unpalatable grasses such as serrated tussock (*Nassella tricotoma* (Nees) Hack ex. Arechav) can make restoration of these degraded native pastures a long and costly process.

Stocking density—the number of dry sheep equivalents (DSE) per unit area—is the simplest indicator of pasture productivity. A rough calculation demonstrates a reduction rather than an increase in stocking density since 1990. At that time, the ILZ had 142 million sheep—213 million DSE (assuming a half ewe, half wether

³such as *Microlaena stipoides* Labil (stipa), *Themeda australis* (kangaroo grass) and *Austrodanthonia bipartita* (Link) H.P. Linder (wallaby grass).

national flock)—and 9.2 million cattle—74 million DSE (using a rate of one cattle animal to eight sheep)—totalling 278 million DSE. In 2011, cattle numbers had increased to 10 million (80 million DSE) while sheep had declined to 66 million (110 million DSE for a 70 % ewe flock composition), totalling 190 million DSE. During this time (1990–2011), the estimated total area of grazed land declined from 74 million to ~65 million hectares (Table 2) and the overall stocking density fell from 3.8 to 2.9 DSE ha⁻¹. Such a generalised calculation does not reflect the actual variations in different regions (Walcott et al. 2013; Mewett et al. 2013), but it does suggest no overall improvement in productivity. In the mixed-farming zone, Angus and Peoples (2012) calculated that the stocking rate had decreased from 1990 to 2010 by ~20 % and Bell and Moore (2012) reported a decline from 2.8 to 2.1 DSE ha⁻¹ from 2002 to 2010. The only areas where regional stocking rates have either remained the same or increased are the temperate, medium-to-high rainfall regions where perennial legumes and grasses of high nutritional quality dominate and grow for 6–8 months of the year, such as the lucerne–phalaris pastures in Central NSW which are estimated at 9–11 DSE ha⁻¹ (Bell and Moore 2012) and in western Victoria–south SA at 11–12 DSE ha⁻¹ (Donald 2012).

3.1 *Managing and Maintaining Pasture Productivity*

One of the challenges in maintaining or improving pasture is that many are located in areas of the farm that are too steep or too stony where soils are nutritionally poor, or too acidic or alkaline for profitable crop production. Such land can be difficult to access and/or expensive to fertilise, lime or reseed, with the net result that dry matter production per mm rainfall is less than that on more fertile, flatter land on the same farm. In addition, most annual pasture plants, which dominate pastures in southern Australia, have shallow rooting systems that deplete soil water only in the top 50 cm compared with deeper-rooted perennial grasses, such as phalaris, cocksfoot, native grasses (e.g. stipa and kangaroo grass) and lucerne, which can extract water to >2.5 m (Dolling et al. 2005; Singh et al. 2001). On most Australian rainfed farms, pastures with lower water use efficiencies (WUE) can become water-limited earlier in the growing season than cereal crops. Careful grazing management is needed to maximise WUE by maintaining the production of young shoots without overgrazing which results in premature senescence. While 20 kg ha⁻¹ mm⁻¹ is used as a potential WUE for crops (Anderson et al. Chap. 11, this volume), pasture growth models use an average potential WUE of 15 kg ha⁻¹ mm⁻¹ rainfall for improved pastures and 10 kg ha⁻¹ mm⁻¹ for native pastures (Section 4.1 this chapter). Water use of shallow-rooted annual ryegrass pasture and deep-rooted perennial phalaris grazed pastures in >600 mm regions can typically differ by +40 mm year⁻¹, with more water extracted under the perennial pasture (Heng et al. 2001). On undulating and sloping terrain, the planting of deep-rooted fodder shrubs, such as tagasaste or tree lucerne (*Chamaecytisus palmensis* (H.Christ)) and saltbush (e.g., *Atriplex nummularia* Lindl), has improved grazed land WUE as well as helped to control secondary salinity and waterlogging (Lefroy 2002).

3.2 *Soil Nutrient Status and Management*

The N status of Australian pastures has changed substantially since the 1980s when the pasture phase in mixed-farming regions was longer, and crops obtained up to half their nitrogen from the carry-over of N mineralised by legume fixation (Ellington 1986). Legume-dominated pastures that produce 3–6 t ha⁻¹ will fix between 90 and 160 kg N ha⁻¹ annually (Unkovich et al. 2010), but this requires active rhizobia, a soil pH >5.5 and <8.4, and adequate available soil P. In equi-seasonal and winter-rainfall environments, the proportion of atmospheric N₂ fixed by all legumes is high, ranging between 65 and 94 %, and is regulated by biomass production, with 20–25 kg of shoot N fixed for every tonne of shoot dry matter produced (Peoples et al. 2001). However, in northern, summer-dominant rainfall regions the higher rainfall variability, fluctuations in soil stored water, and irregularity of crop–pasture phases produces large variations in N₂ fixation with a less reliable supply to subsequent crops.

Biological N₂ fixation in pastures has declined sharply since 1990 (Angus and Peoples 2012), even in permanent pastures due to a decline in legume content, often to <10 %, so that N₂-fixation supplies only 15 % of requirements (Spiers et al. 2013). However, the overall use of N fertilisers on mixed farms has doubled since 1990 as the benefit of additional nitrogen to crop water use efficiency became widely appreciated (see Anderson et al. Chap. 11, this volume), compensating for the reduced biological-N₂ input from the loss of pasture legumes in rotations (Lake 2012). In 2011–2012, N fertiliser was applied to 20.6 Mha farmland, but only 1.9 Mha of this was applied to pastures (ABS 2013). Nevertheless, the loss of the slow, steady supply of biological-N₂ from soils on mixed farms is a cause for concern for the long-term sustainability of mixed-farming systems (Moore 2014).

Historically, pastures were regularly dressed with subsidised single superphosphate fertiliser—because P is deficient across many Australian soils—but subsidies were phased out in 1988 and P use has been influenced by world prices. P-fertiliser consumption continued to increase, from 580 kt P₂O₅ in 1990 to 1059 kt in 1999, but dropped from 2006 when the price doubled (Ryan 2010). P-fertiliser use has risen since 2010 but is applied mainly to crops in mixed-farming regions; in 2010, an estimated 455 kt P₂O₅ was applied to crops and 290 kt to permanent pastures (White et al. 2010). The use of single superphosphate (SSP), traditionally applied to permanent pastures by topdressing, has declined steadily since 1990 due to the low value per tonne carted (Blair 2008). A minority of farmers test the nutrient status of their pasture soils each year and these numbers declined from 20 % in 2007–2008 to 16 % in 2010–2011 (Barson et al. 2012).

In 1999–2000, the National Land and Water Resources Audit mapped the nutrient status of agricultural soils across Australia from large archived data sets (National Land and Water Resources Audit 2001). Most soils in the mixed-farming zone (300–600 mm rainfall) had Colwell⁴ P values between 5 and 30 mg P kg⁻¹

⁴A test for the amount of P available to plants in soils where soil pH in water <7.4, suitable for most Australian pasture soils. Soils require a Colwell P kg⁻¹ >30 mg P to reach their equivalent 'critical value' (CV) that provides 90–95 % of maximum plant production.

indicating P deficiencies (Wong et al. 2012). In permanent pasture regions receiving >600 mm rainfall, Colwell-P values were often >40 mg P kg⁻¹, but most soils had a pH_{Ca} <5.0. These soils had adequate or even excess P, but their high acidity inhibited good plant growth. A decade later, Weaver and Wong (2011) analysed soil and farm records from 2007 to 2010, creating P balance sheets for different farm industries. Soil P levels on 78 % of cropping farms and 63 % of animal farms were higher than their critical values (CV) and more than half of all farms had a 0–10 cm pH_{Ca} <5.5. Many moderately-acidic soils with Colwell-P values of <40 mg P kg⁻¹ in 2001 (National Land and Water Resources Audit 2001) had values of >40 mg P kg⁻¹ by 2010, indicating continuing build up of P beyond the capacity for plant uptake, which was constrained by low pH and other nutrient deficiencies, such as potassium (49 % of soils deficient), and sulphur (61 % deficient). In the north eastern part of the ILZ (latitude 31° northwards) long-farmed soils were P-deficient because, although originally of high natural fertility (Vertisols, Chromosols and Sodosols) they had received no fertiliser since clearance.

Many pasture soils are therefore currently nutritionally imbalanced and too acid for high levels of production. There is substantial scope for improving the productivity of many Australian pastures if producers invested more in soil testing and balanced fertiliser regimes to overcome the run-down in soil fertility that occurred over the past two decades when drought and low prices restricted on-farm inputs.

3.3 Acidity and Liming

Legume-based pastures in higher rainfall environments in Australia have been acidifying since the 1950s as a result of excess NO₃⁻ ions leaching into subsoils, thus increasing their natural acidity (Helyar 1976). Between 1957 and 1995, measured acidification rates ranged from 0.001 to 0.06 units per year depending on soil type, farming system and climate (Porter et al. 1995). In 2001, approximately 50 Mha of farmland soils in the ILZ had a surface pH_{Ca} <5.0 (National Land and Water Resources Audit 2001). A decade later, further acidification had occurred in most farming regions (Australian State of the Environment Committee 2011). Table 4 shows that a higher proportion of both permanent and rotational pasture soils continue to have lower pHs than associated cropped land, even in medium rainfall regions.

Since 2000, only 8–12 % of livestock properties needing amelioration have spread lime, gypsum or dolomite in any one year; Barson et al. (2012) estimated that 21 % of pastures were at high risk of further acidification. In WA, where the extent of acid soils is greatest, 0.8–1.0 Mt of lime have been spread each year over the past decade, which is only half the calculated need (Gazey and Gartner 2009). One strategy (Section 4.2 in this chapter) that has successfully overcome the problems of soil acidity, particularly for subsoils that are only slowly amenable to liming, is to select for acid-tolerant legume species.

Table 4 Percentage of soil samples in each pH increment with a soil pH_{Ca} between <4.5 and 8.5 (0–10 cm), sampled from 2006 to 2015

pH _{Ca}	Landuse	<4.5	4.5–4.8	4.9–5.5	5.6–7.5	7.6–8.5	No. sites
S inland NSW	C	3	20	51	25	1	75
	C+P	6	19	44	30	1	141
	PP	16	24	37	23	–	107
SW Central WA	C	4	18	50	28	–	64
	C+P	10	35	44	11	–	119
	PP	65	16	18	1	–	135

Source: www.soilquality.org.au open-source website

C cropped, C + P crop and pasture rotation, PP permanent pasture

4 Supporting Technologies

Two different strands of advanced technologies underpin efficient and profitable animal industries. One is information and electronic management systems. The vast pool of data gained from decades of animal and agronomic research and development is today captured by a wide range of electronic tools, in software packages and mobile devices. On-farm microchip ear tags and barcodes are used in automatic stock monitoring, herd/flock management and animal tracking, used in conjunction with the National Livestock Identification System and Property Identification Code to trace stock movements and disease-free status. Novel applications such as drones and video cameras point to future solutions to the growing problem of a labour shortage in the animal industries (Doole et al. 2009). One area that urgently requires further development is the design and implementation of cheap, virtual fencing systems to assist in grazing management and the exclusion of livestock from conservation areas (Umstatter 2011). The other strand is animal breeding which lies outside the scope of this chapter but is a critical component in the development of successful animal breeds to withstand heat stress, maintain disease resistance, and provide superior energy conversion rates and desirable market traits.

4.1 Decision Support and Remote Sensing

Agronomic experiments conducted on grass and legume species across the ILZ in the 1970–1990s formed the basis of simulation growth models used in pasture, animal and farm management today. These models have passed through many iterations to become user-friendly decision-making tools. For example, simulation models were developed from the SGS program in 2001–2003 as the SGS Model with GrazeMod, DairyMod and EcoMod modules (Johnson 2013). Public sector and livestock industry agencies maintain and update software derived from such models online, ranging from spreadsheet calculators such as Meat and Livestock Australia’s ‘More Beef from Pastures’ (www.mla.com.au) to CSIRO’s GrazPlan©

(www.grazplan.csiro.au) which contains modules such as Grazfeed© (feed calculator) and Grazgro© (pasture growth, Clark et al. 2000). Specific software programs include Prograze for livestock production (Bell and Allan 2000) and AusFarm©, a whole-farm support tool for mixed crop and stock farming. These decision-support models calculate production, feed requirements, management of stock attributes and numbers, and farm budgeting, with location-specific input variables. They are used collaboratively by producers and consultants to manage physical and business components of farms.

Remote sensing has also been harnessed to pasture production. An application of multi-spectral MODIS-NDVI satellite imagery has operated since 2003 using the ratio of red and near-infrared wavelength detection of photosynthetic activity to derive aboveground dry matter (DM) and feed-on-offer (FOO) via empirical modelling of growth estimates with daily climate data (Donald et al. 2010; Hill et al. 2004). Products are available from paddock (90 m² resolution) to regional scale on an open-source platform *Pastures-from-Space* (PGR[®], www.pasturesfromspace.csiro.au). This provides farmers with real-time information on the amount and variation over large expanses of pasture more easily and accurately than can be obtained on the ground as well as synoptic assessments of regional production. Figure 5 gives an example using the *Pastures-from-Space* (PGR[®]) data to assess the inter-annual variations from 2003–2014 in total DM ha⁻¹ year⁻¹ across the transects identified in Fig. 1.

The localities along each 600 × 200 km transect have progressively lower annual rainfall toward the interior, and nearly three-fold variation in production over the period, which included both a severe and prolonged drought (2003–2009 in NSW) with annual rainfall in the lowest tenth percentile of long-term averages and two exceptionally wet years (2010–2011). One-third of the annual aboveground DM values in southern NSW and 50 % of those in WA were ≤2.5 t ha⁻¹ year⁻¹. These low pasture growth values are typical in large parts of the mixed-farming belt and illustrate the observed low levels of pasture production.

4.2 Plant Improvement

Over the past 70 years, an estimated 8,200 exotic pasture plants have been collected and introduced intentionally for use in Australian pastures by scientists, predominantly from public sector organisations (Cook and Dias 2003). In the past 15 years, public breeding programs have focussed principally on pasture legumes of Mediterranean origin with 58 new annual and short-lived perennial pasture legumes released, principally for southern Australia (Nichols et al. 2006). Newer varieties are adapted to a wider range of edaphic conditions, such as fluctuating rainfall regimes, and tolerance to acidity, drought, waterlogging and disease.

Traditionally, funding for pasture plant breeding was shared between public agencies and the research and development (R&D) levy organisations, but the role of public research and extension organisations has diminished in the past two

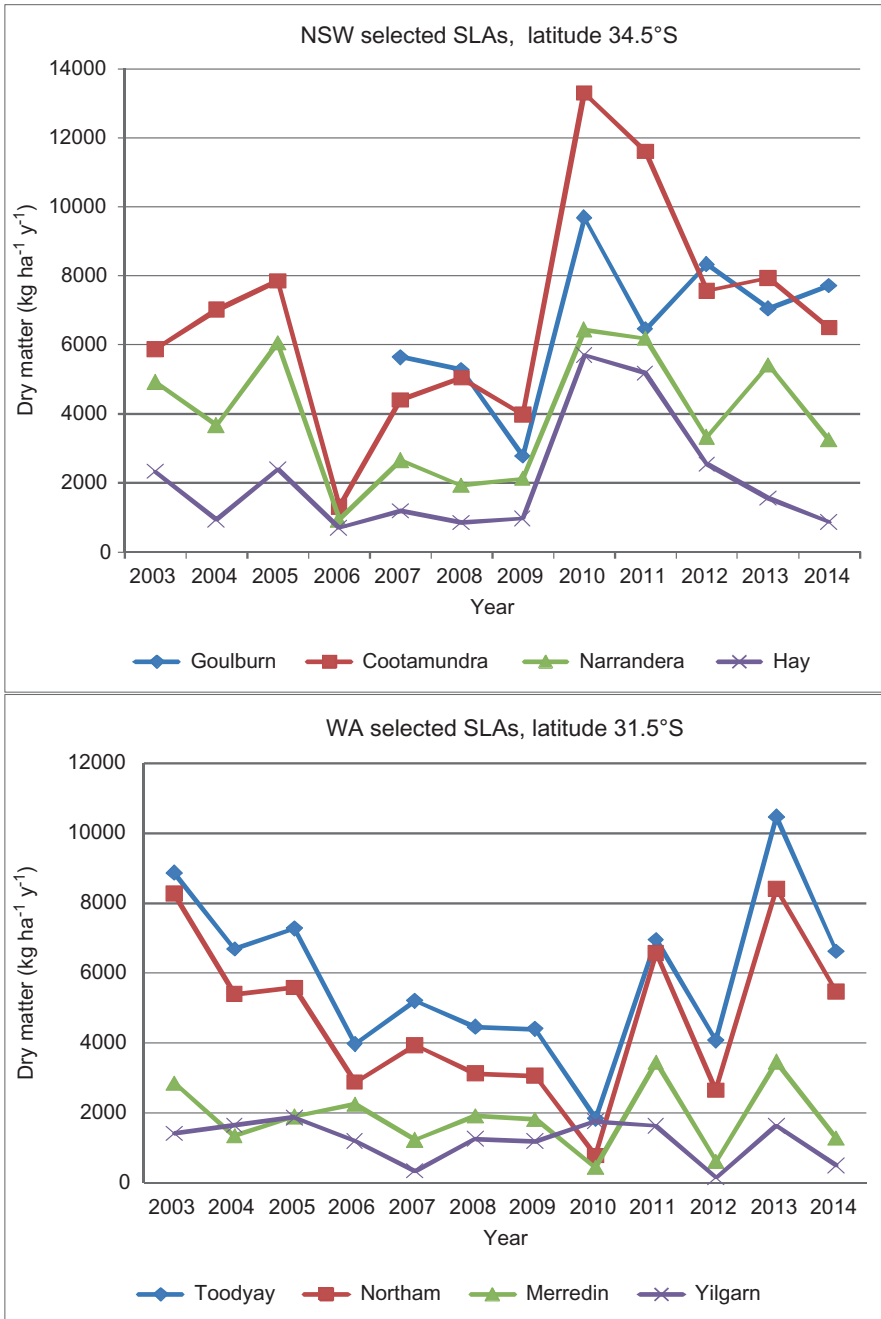


Fig. 5 Remote-monitored total pasture growth ($\text{kg ha}^{-1} \text{ year}^{-1}$) from 2003 to 2014 averaged across statistical local areas (SLAs) in eastern Australia at latitude 34.5°S and western Australia at latitude 31.5°S . Long-term annual rainfall (mm): Goulburn 628, Cootamundra 650, Narrandera 433, Hay 433. Toodyay 521, Northam 428, Merredin 326, Yilgarn 303

decades and, since 2007, an integrated service has been formed called Pastures Australia. Pasture breeding achievements include the selection of species and breeding of varieties adapted to low and high pH with their species-specific symbiotic rhizobia (Howieson et al. 2000) and the introduction of new annual legumes with high growth rates and seed set that can revitalise old pastures (Wolfe 2009). The adoption of new varieties has been variable, and the benefits to animal and crop production need further quantification to build confidence in producers. Unlike dryland crops, pasture breeding has not been attractive to commercialisation due to the long-lasting nature of pastures, small opportunity of annual revenues to breeding companies, high costs to farmers in ensuring establishment or persistence in some environments (Burns and Norton 2015) and the difficulty of demonstrating an immediate benefit (Whitbread et al. 2005). Seed companies report that many recent varieties enter the market for only a short time, and many old varieties retain a strong market share (Grains Research and Development Corporation 2007). The loss of most specialist pasture agronomists with a wide local knowledge of soils, climates and plant growth habits over the past 20 years has made many farmers cautious of attempting to introduce new cultivars or species in periods of financial uncertainty (Bell et al. 2014; Nichols et al. 2012).

5 Current Restrictions and Future Opportunities

Farm performance studies consistently show a large difference in profitability between the top 10–20 % of producers and the industry or regional average. In a comprehensive benchmarking study Hooper and Levantis (2011) found the top 10 to 20 % most profitable farmers of mixed farms across 13 agro-ecological zones in Australia used higher inputs compared with the average grower in each zone. Intensification is greatest in most profitable groups. For example in the high rainfall (Gippsland) region of Victoria the top 20 % of profitable farms ran 30 % more stock than other farms, irrespective of the enterprise (beef, lamb, wool or a mix of these), translating into 50–100 % higher gross margins per hectare (Webb Ware 2014). It is more difficult for small to medium sized livestock-dominant farms to achieve profitability than for larger enterprises; their unit costs of production (c/kg live weight gain) are fifty to a hundred percent higher than for large farms, and for some, getting bigger has increased their debt in the past decade as a result of land purchases (Thompson and Martin 2014).

As demonstrated by research and advisory programs, the key to greater profitability is good management, a substantial investment in pasture production and farming by soil type. This was the main principle of the extensive SGS and Grain and Graze programs (Price and Hacker 2008). Despite the success of those popular programs, much grazing land is currently underused or deteriorating. Both financial and social reasons are implicated. Labour costs and scarcity have been identified as restricting animal industry productivity more than cropping in the past decade (Doole et al. 2009; Rose and Kingwell 2009). Comparisons of different broadacre

industries show that many farms have maintained positive total factor productivity (TFP) only by reducing input costs when output values decline, with specialised sheep farms having had the lowest TFP (ABARES 2014; Nossal and Gooday 2009). In parts of more-densely settled NSW and Victoria, many smaller grazing properties have been subdivided as hobby farms close to towns, and greater investment can be made from capital appreciation than from on-farm income. Behrendt and Eppelston (2011) found that the returns from capital appreciation were three- to ten-fold that of conventional grazing returns for farms within one hour's drive from regional centres. Across NSW, Eaves (2010) found that between 1990 and 2008, the returns on rural land devoted to mixed farming outperformed the returns from traditional high rainfall grazing farms, but with higher risk from price volatility. On smaller properties, social factors are also influential. In a survey of Victorian farmers, Wilkinson et al. (2011) found that many livestock farms were small and run by older farmers, two-thirds of whom had gross annual incomes of less than half the industry average. Of these, 33 % of sheep and 45 % of beef farmers used no agency or other advisory services, and farmers were essentially semi-retired and marking time. Small to medium-sized farms are also inhibited from intensifying their livestock systems because of the increase in complexity of the farming operation, exposing the farmer to higher risk and uncertainty (Kingwell 2011).

6 Conclusions and the Way Ahead

While grazing still forms the largest land use in the Australian farming belt, many pastures are in no better or poorer condition than 20 years ago. Red meat production has risen but at a much slower rate than grain production. The initial trigger for the lower performance of the animal industries came from the negative returns in wool production in the early 1990s, but pressure on input costs from the constant cost-price squeeze during that decade also shifted the production focus to more immediate returns from crops than the longer lifecycle of meat industries (Nossal and Sheng 2010). Cash receipts on animal-dominated farms have been low as a result of the Millennium drought, a high Australian dollar and export market competition, so mixed farms have concentrated their efforts on cropping with low expenditure on pasture renovation, soil nutrition and liming, and negative effects on pasture productivity. The upturn in prices since 2013 has increased cattle and sheep sales by 12–23 % in 2014–2015 and returns to farm business profit (Martin 2015). If such conditions continue, confidence may return to livestock producers with more investment on-farm.

Changes to regional climates have also interacted with farm financial conditions to reduce the focus on pastures with the reduction in rainfall in southern Australia, thereby shortening the growing season and increasing variability in summer rainfall regions with adverse effects on legume persistence. These trends are projected to continue, and future research directions need to incorporate changing climatic parameters into all aspects of production research (Bell et al. 2014; International

Panel on Climate Change 2007). Research on intercropping, the greater persistence of legumes within grass–legume pastures, and the introduction winter-dominant lucerne and summer-dormant perennial grasses into southern Australia are continuing priorities. The mismatch between pasture production and animal demand often lowers the effective use of rainfed pasture, resulting in conservative stocking rates. Trends in diversification of the feed base, such as grazing winter cereals, production of on-farm forage crops, increased use of no-till stubble for grazing, and more feed-lotting, are useful strategies to increase livestock production, but the decline in soil fertility from loss and deterioration of pastures requires more research and extension if most farms are to achieve higher overall long-term productivity.

There is considerable scope for increasing pasture productivity in higher rainfall districts where more reliable rainfall regimes reduce investment risk, and where higher winter temperatures are more favourable to grass growth. Most farms retain livestock-related infrastructure and the capacity for intensification of animal production systems so reversing the run-down in soil fertility and pasture condition may be less costly than maintaining the high levels of soil nutrition, weed and pathogen-free soil environments needed for high-yielding continuous cropping. This would be a fruitful area for economic modelling. The key driver that is often lacking for improving pasture production, and hence higher profits from animals, is the incentive of clear information that links the prices paid for quality meat products to the quality of the pasture. The red meat industry recognises that this requires a shift from a supply-chain mentality to whole-of-value-chain approach, but it also implies a further shift in market power from producers to retailers, and from smaller to larger producers (AMPC 2013; Jie and Parton 2009).

In general, producers on small farms, or farms where livestock forms a minor part of the business, are vulnerable as price-takers; their business profits are less and rates of return on capital lower than for large-scale enterprises (Martin 2015). Alternative financing systems and farming structures are needed, such as cooperatives and partnerships among neighbours, with clearer information flows through the whole-of-value chain to provide incentives for large-scale reinvestment of pastures. Many animal-dominant farms are too small to gain the economies of scale enjoyed by large farms which are also mainly run as family businesses (Thompson and Martin 2014). Research into alternative business structures would be valuable; for example, individual adjacent farms might form associations to lease out larger areas of adjoining land on long leases to animal management specialists (or vertically-integrated meat processing firms) thus providing a more regular and consistent type of animal aimed at specific market requirements (Kingwell 2005). Opportunities exist in expanding exports to Asian markets that demand higher value products such as red meat of high quality, where Australia's guaranteed food security is advantageous. Together with the recent signing of several international free trade agreements (2015–2016), this may provide the needed incentives to greater investment in underperforming parts of the livestock industry.

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