# Dryland Agriculture in Australia: Experiences and Innovations

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## 1 Introduction

The vast majority of crop and livestock production in Australia is conducted under dryland or rainfed conditions. The terms 'dryland' and 'rainfed' are used interchangeably to refer to production using only natural rainfall without any form of irrigation. Australia is the driest, inhabited continent in the world and agricultural production is entirely absent from a large part of it, except for extensive grazing, mostly of cattle or sheep. In 2007–08, only 54 % of the land surface was managed for agricultural businesses and, of that area, 87 % was under grazing management and only 8 % was cropped (ABS 2009a).

As might be expected under such low rainfall conditions, the average size of agricultural holdings is large, the population density is low and the distances between settlements are large. Agriculture is highly mechanised, driven by the size of the holdings and the high cost of labour. The average farm size in Australia increased from about 1700 ha to more than 2200 ha from 1990 to 2010 (ABARES 2011). In most of the cropping zones however, the average size of dryland cropping farms has doubled over the last 20 years. In addition, Australian farmers experience greater volatility in yield and price than most other farmers in the world (Australian Farm Institute 2012). Despite these apparent disadvantages for productivity, Australian farmers have managed to keep the cost of production of most agricultural products at relatively low levels. In turn, this has enabled Australian farmers to

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remain competitive, an essential requirement for a country that relies substantially on production for export.

Another feature of Australian dryland agriculture is the very low, and declining, level of government subsidies. The major direct government subsidy comes from matching some of the funds that producers contribute for research into their respective industries (see section on research below). Public research, funded at both state and federal levels, is declining in favour of partnerships with private producer organisations. Research into aspects of the Australian, broad-acre agricultural industries nevertheless has been highly profitable (Mullen 2007).

There have been a series of previous reviews on dryland agriculture in Australia, especially with respect to the cropping industries (Anderson and Impiglia 2002; Freebairn et al. 2006; Passioura and Angus 2010; Anderson and Angus 2011; Stephens et al. 2011; Fischer et al. 2014; Anderson et al. 2016) and the pasture/forage industries (Wolf 2009). These reviews have given detailed descriptions of the situations at their relative times of publication. This chapter is focussed on some general characteristics of Australian agriculture, recent experiences and innovations, with comparatively less discussion of specific agricultural industries.

## 2 Brief History of Agriculture in Australia

### *2.1 Pre-European Settlement*

There is a long history of human habitation on the Australian continent dating back at least 40,000 years. Evidence has been accumulating that the aboriginal peoples practised some form of settled agriculture through harvesting and processing grains and root crops well before European settlers arrived in the late eighteenth century. This early agriculture included management of pastures, and thus native animals, through judicious use of fire (Mitchell 1839; Gamage 2011; Pascoe 2014).

The introduction of hard-footed animals such as sheep, cattle and horses and the widespread clearing of natural vegetation changed the agricultural environment in ways that modern farmers have been striving to remedy ever since. Despite the long-term use of Australian native plants prior to European settlement, no native grain crops have been developed for widespread human use until the present time.

*The Last 200+ Years*

The Australian winter crop yields have gone through four phases (See yield of wheat in Fig. 1). In the first phase, European settlers brought with them crop types and cultivars that proved unsuitable for the local conditions with the result that early settlement on the eastern seaboard almost failed. Subsequently a phase of nutrient depletion prior to about 1900 lead to a steady decline in yield. It was not until James Farrer improved drought resistance, disease resistance and grain quality in wheat (Farrer 1898) that the early colonies began to thrive. The history of wheat yields and the influence of sown legume pastures, as described by Donald (1965), largely

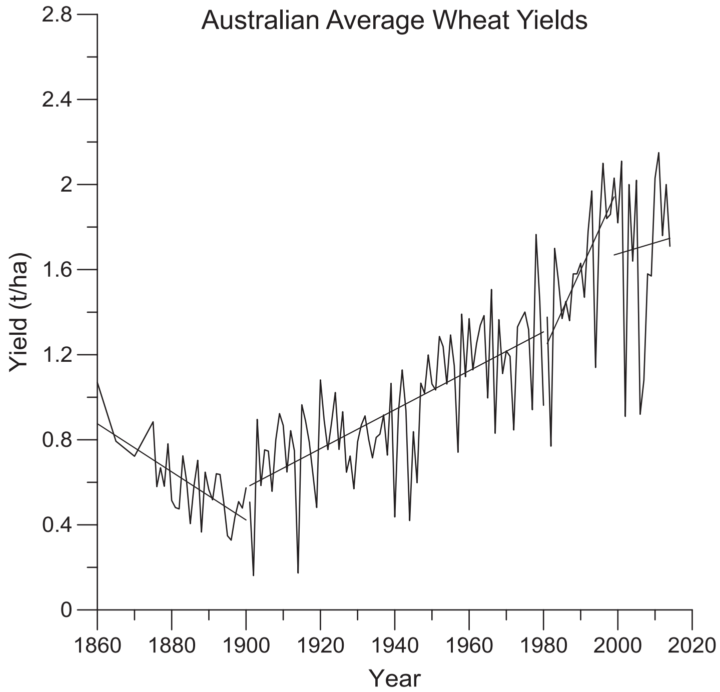

**Fig. 1** Average Australian wheat yields with fitted linear trends for the four main epochs of productivity: 1860–1999 (declining), 1901–1980 (steady increase), 1981–1999 (rapid increase), 2000–2014 (mixed and highly variable)

reflect the history of the development of the wider agricultural industry. The use of superphosphate fertiliser, trace elements, fallowing and new cultivars became widespread, increasing the average yield of wheat above earlier levels (second phase, Fig. 1). The third stage of accelerated yield increase occurred in the 1980s and 1990s, which was accompanied by earlier sowing, the switch to minimum tillage, improved weed control using chemical herbicides, more nitrogen fertiliser and the use of rotation crops, pasture legumes, and eventually semi-dwarf cultivars. All these changes benefited both crops and pastures which were largely integrated into mixed systems. Finally, average yields levelled out after about 2000 as yield variability increased, farmers reduced the use of nitrogen fertilisers and grain legumes, and a severe drought restricted irrigation in south-eastern Australia between 2006 and 2009 (Stephens et al. 2011).

Australian farmers have been relatively quick to adopt innovations that have improved their productivity. This is likely a function of economic necessity (see Pannell et al. 2006). A large proportion of output is exported so it has to compete favourably for both price and quality. The poor soils and low rainfall conditions have also focused the minds of producers on reducing costs to remain viable.

Reducing costs, often at the same time as improving product yield and quality, has only been possible through maintaining soil and environmental quality, a challenging task that would have been impossible without consistent innovation. Reduced or zero tillage, stubble retention, improved herbicides and cultivars and adoption of precision agricultural techniques have proved pivotal in these respects in recent times (Anderson et al. 2005; Derpsch and Friedrich 2009; Kingwell and Fuchsbichler 2011; Robertson et al. 2012; Scott et al. 2013).

Landholdings in Australia have always been relatively large by world standards, often exceeding 2000 ha in the crop/pasture zone. Even when the land was first divided and cleared it was necessary to have larger holdings to support the farming family. Some early subdivisions proved too small to be viable, leading to farm amalgamations; the trend towards increasing farm size has continued from the mid-twentieth century until the present. This has been accompanied by the adoption of larger power units and agricultural machines, driven by the high costs of farm labour.

## *2.2 The Current Situation*

Dryland agriculture in Australia is currently in a period of great change. In addition to the trend towards larger farms and increasing mechanisation, which continues, there is a growing recognition of the need to farm more sustainably to protect the natural resource base (Ogilvy et al. 2015). In this transition, there are many questions yet to be answered such as ‘Does this mean reverting to entirely natural or organic methods?’, ‘What place will there be for genetically-modified plants and animals?’, ‘Do we need to abandon chemical herbicides, pesticides and fungicides altogether?’, ‘Can we restore degraded lands to profitable production?’, ‘How do we adapt to more variable climates in the future?’ and ‘What will be our future sources of energy to work the land?’

Further complicating these questions is the current trend towards decreasing public funds for agricultural research. It appears that the support to address the questions above, and many others, will need to come increasingly from farmers themselves although a case can be made for continued public support given that many of the demands for greater knowledge about production methods is coming from consumers. There is already a small demand from consumers for greater, measurable evidence of the use of sustainable practices in the production of our food and fibre (Ogilvy et al. 2015).

Australian dryland agriculture is also under worldwide pressures from trends such as the increasing demand for food in developing countries and for better quality food from emerging middle classes, from the threat of climate change and from new technologies, in both the genetic and digital areas (Hajkowiczs and Eady 2015).

## 3 Resource Management

### 3.1 Climates and Soils

Dryland cropping zones in Australia mainly occur between the 300 and 600 mm rainfall isohyets (Fig. 2). In the northern part of the dryland agricultural areas, summer rainfall dominates such that production of winter crops and pastures depends on conserving some of the rainfall. This accounts for the occurrence of production on the soils in those areas that can store substantial amounts of water and the widespread use of summer fallow. In the southern and western parts of the agricultural area, winter rainfall predominates so that soil water storage becomes less important for plant production and sandy soils that store less water can be used.

Australian soils used for agriculture are deeply weathered and depleted of plant nutrients. They have been derived from the oldest geology on the earth. Soil types ranging from deep sands (largely in Western Australia) to self-mulching, cracking clay loams (Queensland and northern New South Wales) are used for agriculture in various parts of the continent (Leeper 1964; McGarity 1975; Hamblin and Kyneur 1993; Freebairn et al. 2006).

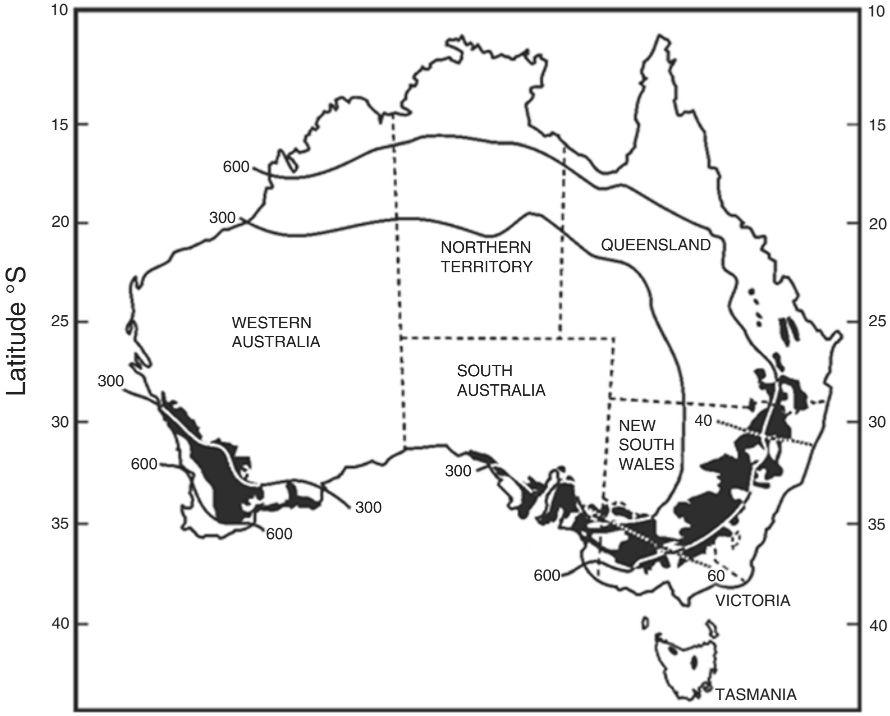

**Fig. 2** Dryland cropping zones in Australia between the 300 and 600mm rainfall isohyets. Dotted lines show average percentage of winter rainfall. All cropping zones in Western Australia receive >60 % of rainfall in the winter months (After Anderson and Angus 2011)

### 3.2 Landcare

Concern among both rural and urban communities in Australia has led to the organisation of local groups of landholders and other groups into a Landcare movement consisting initially of volunteers convened to address issues of natural resource management (NRM), environmental improvement and preservation. The network has spread across both rural and peri-urban areas and has joined the NRM agencies funded by the state and federal governments.

> The following is a quote from the Australian Agriculture website: "Landcare is a unique grass-roots movement that started in the 1980s through initiatives to tackle degradation of farmland, public land and waterways. The movement has expanded and evolved significantly since then, and is achieving results Australia-wide. Individuals and groups ....... are focused on best-practice sustainable agriculture and expert management of natural assets such as soil, water and native vegetation.

> Caring for the land includes a range of activities such as:
>
> - sustainable farm practices
> - restoring native habitats and revegetation
> - controlling weeds and pests
> - developing and sharing local natural resource management skills and knowledge". (landcareaustralia.com.au)

The movement includes Landcare groups, farming systems and farm improvement groups, 'Friends of' groups and Indigenous land management groups. It is estimated there are 6000 groups and over 100,000 volunteers across Australia caring for the land. Many farmers and landholders also undertake this important work but are not always affiliated with a particular Landcare group.

### 3.3 Natural Resource Management

The understanding that the natural resource base, especially the soil, has suffered long-term decline is leading to some gradually emerging trends towards restoring and even improving the agricultural landscape and farming practices (Ogilvy et al. 2015). For example, in the 2006–2007 season over 94 % of Australian farmers reported using some aspect of NRM including control of weeds, pests and diseases, land and soil management (Australian Bureau of Statistics 2009b). Given the naturally-poor soil fertility and fragile landscapes (McKenzie et al. 2004), it is probably unsurprising that concern for the environment is relatively high in Australia. After the initial degradation to the land caused by extensive clearing of native forests following European settlement, much work has been devoted to restoring soil fertility and reducing erosion (e.g., Freebairn and Wockner 1986; Sallaway et al. 1990). A comprehensive review of the status of Australian soils and nutrient balances was summarised in the National Land and Water Resources Audit (NLWRA 2001).

### *3.4 Introduced Pests, Diseases and Weeds*

Many animals that were introduced intentionally or accidentally as a result of European settlement have become feral pests (Bomford and Hart 2002). These include rabbits, foxes, cats, camels, goats, donkeys, horses and pigs. Considerable resources are expended annually to keep these pests at manageable levels and overall productivity has clearly been reduced as a consequence (Canyon et al. 2002). Many introduced weeds and diseases that are found in similar dryland areas around the world also occur in Australia and these have contributed to substantial costs to industry (Groves 2002). However, a rigorous quarantine and biosecurity system has succeeded in excluding others (Nairn et al. 1996).

## 4 Cropping Systems

### *4.1 Yield Improvement – Management and Breeding*

The average yield of crops has not increased at a uniform rate since European settlement but rather at different rates in different periods (Fig. 1). The differing adoption of various practices and improved cultivars of wheat is illustrated in Fig. 3 as an example. However, the adoption of practices and cultivars at given times can only infer causation. Comparisons based on the yield progress of cultivars in variety trials with the yield increases of average farm yields can give an indication of the relative contributions of management and genotypes to overall yield progress (e.g. Byerlee 1994). Such comparisons suggest that about 70–80 % of past yield advances have been due to changes in management practices (Anderson et al. 2005). The term ‘management’ can be further divided into ‘tactical’ or in-season practices and ‘strategic’ or practices that have a long-term impact, largely soil improvement. It is proposed that past yield improvements can be equally attributed to genetic, tactical and strategic factors.

However, data from field trials of wheat over a number of locations and seasons that include both genotypes and agronomic treatments have shown that the environ-

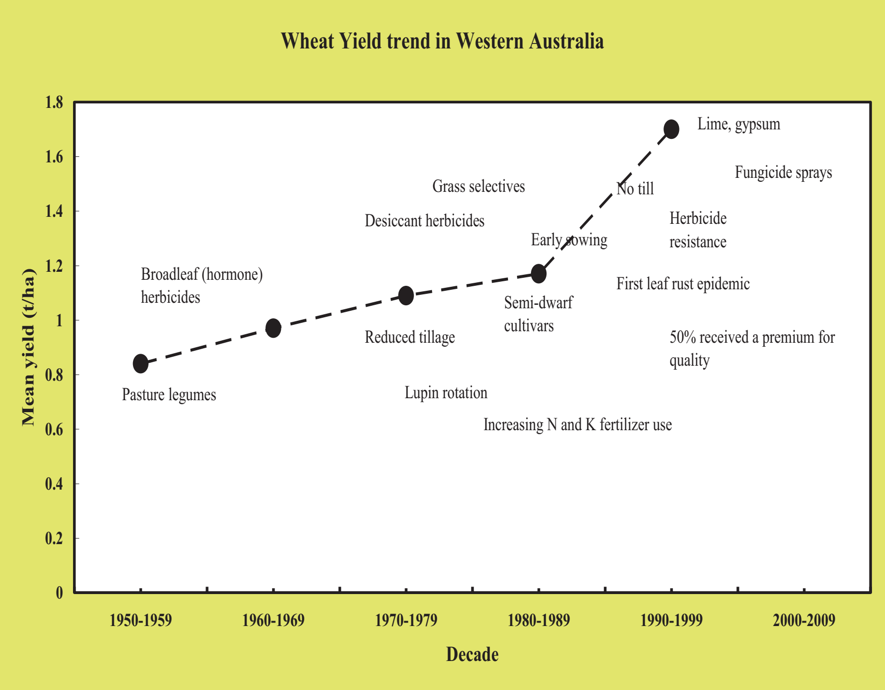

**Fig. 3** Some practices associated with average wheat yield improvement in Western Australia, 1950–2000 (After Anderson et al. 2005)

ment (site × season) can dominate the responses but management (tactical agronomy) and interactions with the environment can account for much more of the yield variance than genotype or its interactions with either environment or management (Anderson 2010).

In the Australian dryland environments since about 2000, average grain yields have either reached a plateau or become much more variable from season to season (Fig. 1). For example, in Western Australia, the season-to-season range of average wheat yield was about 0.8 t/ha before 2000 compared to about 1.7 t $ha^{-1}$ in the new millennium. The reasons proposed for this increased variability range from increased variability in rainfall (climate change) to inappropriate application of inputs, especially N fertilisers, according to seasonal conditions (tactical management).

Breeding advances, often underpinned by physiological research, have made major contributions to yield improvement in the Australian wheat crop (Fischer and Wall 1976; Siddique et al. 1989; Loss and Siddique 1994; Evans 1987; Passioura 2006). Further improvements have been attributed to the interactions that exist between breeding and agronomy or management (Anderson and Impiglia 2002; Hochman et al. 2009; Cooper et al. 2001; Passioura and Angus 2010; Sadras and Lawson 2011; Richards et al. 2014). Improved transpiration efficiency (Evans 1987; Passioura and Angus 2010), competitive ability against weeds (Palta and Peltzer

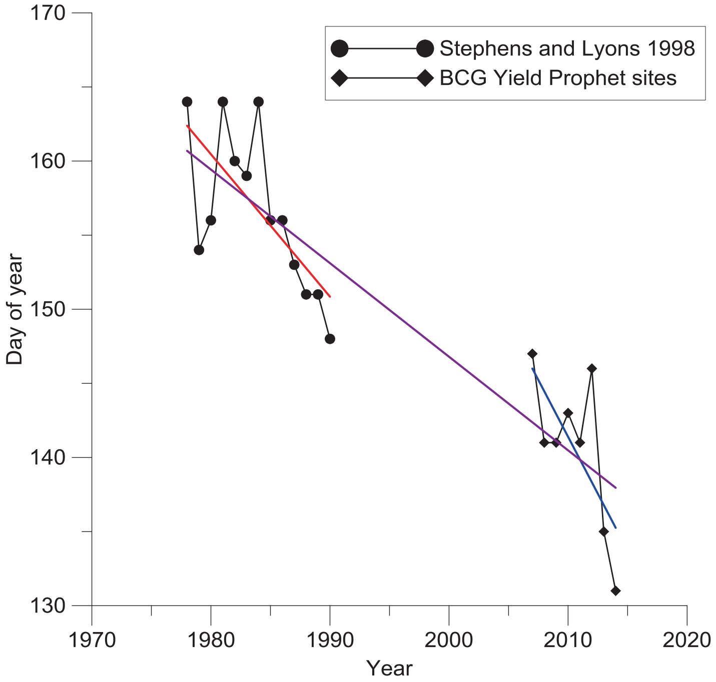

**Fig. 4** The mean midpoint of wheat sowing for Australia from 1978–1990 (Stephens and Lyons sowing date survey 1998), 2007–2014 (Source: Birchip Cropping Group, BCG- sites were spread across Australia)

2001; Lemerle et al. 2004), nutrient use efficiency (Anderson and Hoyle 1999) and suitability for dual-purpose use (grazing and grain recovery (e.g., Anderson 1985; Virgona et al. 2006) are also considered traits likely to contribute to future yield increases.

### 4.2 *Adoption of the Components of Conservation Agriculture*

Australian dryland farmers have adopted zero tillage over more than 80 % of the cropped area (ABS 2009b; Llewellyn and D'Emden 2010; Ward and Siddique 2014). Some of the main reasons that farmers adopted zero tillage were - reduced fuel costs from fewer cultivations, quicker seeding programmes, reduced wind erosion, better water retention and better weed management from herbicides (Scott et al. 2013). One of the biggest benefits of this new technology has been that farmers have been able to sow crops much earlier. From 1978 to 1990, the mean midpoint of wheat sowing progressed a day earlier per year on a national scale (Stephens and Lyons 1998). When the recent midpoint of wheat sowing was calculated, this trend to earlier sowing has continued with farmers now planting in late April and early May (Fig. 4).

The main benefit of this change is that crops are now growing in a period of lower average evaporative demand and better pre-seeding weed management with herbicides.

Adoption of stubble retention has been much less complete and much slower according to a review of Scott et al. (2010). In a further review Scott et al. (2013) again concluded that, in the dominant cropping systems of southern Australia, there is little compelling evidence that retention of crop residues has led reliably to economic benefits.

The practices of zero tillage and residue retention have fitted into the long-standing systems of rotation of cereals either with grain legumes such as field peas and lupins, oilseed crops such as canola (ABS 2009a) or sunflower (*Helianthus anuus* L.), or with pasture legumes such as subterranean clover (*Trifolium subterraneum* L.) and medics (*Medicago* spp., Reeves and Ewing 1993). Crop and pasture sequences are seldom fixed over long periods but vary according to grain prices, requirements for disease, weed and soil management, and demand for animal products (wool, meat, dairy).

Evidence in Australian rainfed crops using direct drilling with residue retention, has indicated that there may be no increase in soil organic matter in a range of soil types even after 10 years unless annual rainfall exceeds about 500 mm (data summarised by Chan et al. 2003). This is likely due to the lower levels of crop yield and residue produced under lower rainfall conditions, or to the likelihood of higher soil temperatures in low rainfall areas which can prevent accumulation of soil organic matter (Hamza and Anderson 2010). This variability in response to the various components of the CA system has likely led to partial adoption by farmers in the various Australian environments as discussed by Kirkegaard et al. (2014).

In higher rainfall areas (>500 mm annual rainfall) and where perennial pastures are part of the dominant farming system, soil organic matter tends to accumulate more across a range of soil types than where continuous cropping is practised (Hoyle et al. 2014). In any case, organic matter largely accumulates in the top 10 cm of soil in a zero tillage system such that, even if the topsoil is saturated with respect to the SOC level, the content below that depth may still be low.

Adoption of precision agriculture methods such as controlled traffic, yield mapping and variable rate technology has been slower but is gaining momentum (ABS 2009a; Kearns and Umbers 2010). Problems with different machinery configurations and the complexity of the technology have slowed uptake. However, farmers who have adopted this technology are finding improved yields from less soil compaction and a more efficient allocation of resources on soils that yield the greatest return per unit of input.

### *4.3 Trends in Water Use Efficiency*

All these varietal and management improvements result in a higher yield per unit of water from water supplied from rainfall. Water use efficiency is related to the amount of grain produced per millimetre of total water used in the crop growing period. To assess water use (or production) efficiency of wheat yields across Australia, state yields and statistical sub-division yields were divided by potential yields ($Y_{pot}$) defined by French and Schultz (1984). However, instead of using a fixed 110 mm of rainfall as soil evaporation, as used by French and Schultz (1984), we assumed that a third of growing season rainfall was lost to soil evaporation. This assumption prevents the actual yield from exceeding the potential yield in drought conditions. Therefore,

$$WUE = \mathrm{Y_a} / \mathrm{Y}_{pot}$$

$$\mathrm{Ypot} = \mathrm{W} \times WUE_{\mathrm{p}}$$

$$= (GSR + SM - \mathrm{E}) \times WUE_{\mathrm{p}}$$

$$= (GSR + SM - (0.33 \times GSR) \times WUE_{\mathrm{p}}$$

where:

WUE = water use efficiency
Ya = actual yield
Yp = potential yield
$\mathrm{WUE_p}$ = potential water use efficiency (20 kg/ha/mm)
W = water used
GSR = growing season rainfall (between sowing and rainfall ‘ending date’ in STIN)
SM = soil moisture at sowing determined by STIN
E = soil water losses to evaporation.

A modelling analysis used this approach to examine regional and state yields with the Australian Export Grains Innovation Centre’s STIN wheat forecasting model (Stephens et al. 1989). This model calculates a daily water balance up to a district midpoint of sowing and then determines a maturity date when rainfall stops contributing to yield. Excess heavy rain in the last three weeks of the season is also removed. This approach has a number of simplifications, like assuming a dry soil profile at the beginning of the soil moisture accumulation on 1 October in the year before sowing. However, since we were more concerned with the changes in WUE over time, this method gave similar results to more complex model calculations. When the water supply at 800 rainfall stations across the Australian grain belt was added and weighted to the proportion of grain planted near each station, state and national potential wheat yields were determined. When the actual yields were divided by the potential yield through time, the increasing water use efficiency for different parts of the country and the variability of WUE with season type is highlighted, as are longer term trends (Fig. 5).

Figure 5 shows that lower WUEs occur in severe drought years which are typically El Niño years where many paddocks were not harvested or were used to feed

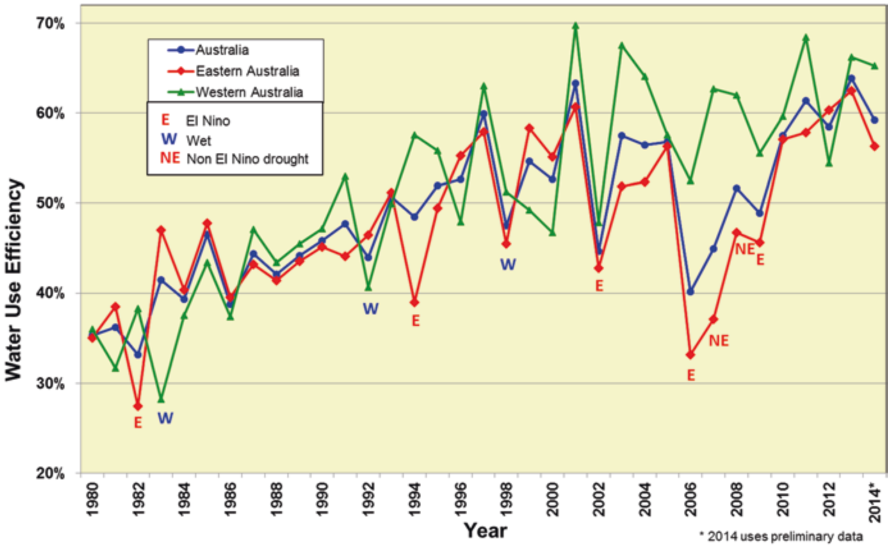

**Fig. 5** Average Australian water use efficiency for wheat 1980–2013, where E is an El Nino drought year, NE is a non-El Nino drought year and W is a wet year

livestock. This is particularly the case in eastern Australia where ENSO (El Niño – Southern Oscillation) events dominate rainfall variability. Lower WUEs also occurred in very wet years in 1983 and 1992 where waterlogging was prevalent in Western Australia and in 1998 in eastern Australia.

In terms of WUE, Fig. 5 shows that the largest increases occurred in Western Australia where almost a doubling in efficiency occurred from about 33 to 64 % over the last three decades. Significant increases appear related to:

- a more steady and significant increase in nitrogen fertiliser, the highest proportion of farmers matching their fertiliser use to soil testing (60–80 %)
- the highest rates of adoption of zero tillage
- spraying out summer weeds
- up to 80 % stubble retention
- a major uptake of dry sowing which enables optimal plant emergence in favourable moisture conditions (Kearns and Umbers 2010; Stephens et al. 2011)
- a doubling of lime application (to over a million tonnes a year) to address acidic soils
- fewer wet winters which contributed to waterlogging on shallow soils (Stephens and Lyons 1998; Ludwig et al. 2009, Stephens et al. 2011).

In eastern Australia, the WUE has also increased by about 70 % since the 2006–2008 drought based on the adoption of much the same practices as in the west.

### *4.4 Product Quality – The Case for Wheat*

There has been an increasing understanding across the supply chain of Australian wheat that improving grain quality for specific products can make a major contribution to the profitability of the crop. Wheat grain that is exported to various countries from Australia can qualify for a price premium if the quality is suitable for various specific end uses. These include white, salted noodles, yellow, alkaline noodles, biscuits, pasta and high-quality bread. The amount of the premium varies according to market conditions of supply and demand, but grain samples that conform to specifications of kernel size and hectolitre weight (related to milling yield), protein percentage and varietal characteristics including flour colour and starch quality may qualify. The premiums vary from about 3 to 20 % of the base price but may mean the difference between profit and loss in some cases. Plant breeders have produced a range of high-yielding cultivars that are acceptable for the various export markets and local research has revealed the appropriate combinations of soil type selection, rotation and agronomy that maximise the probability of achieving quality that will attract premiums (Anderson et al. 1995; Anderson et al. 1997; Anderson and Sawkins 1997; Miyan et al. 2011). The adjustments to crop management that have been suggested by this research can often be made at a very low cost to the farmer and have resulted in major increases in the percentage of the crop that receives a premium (see Fig. 6).

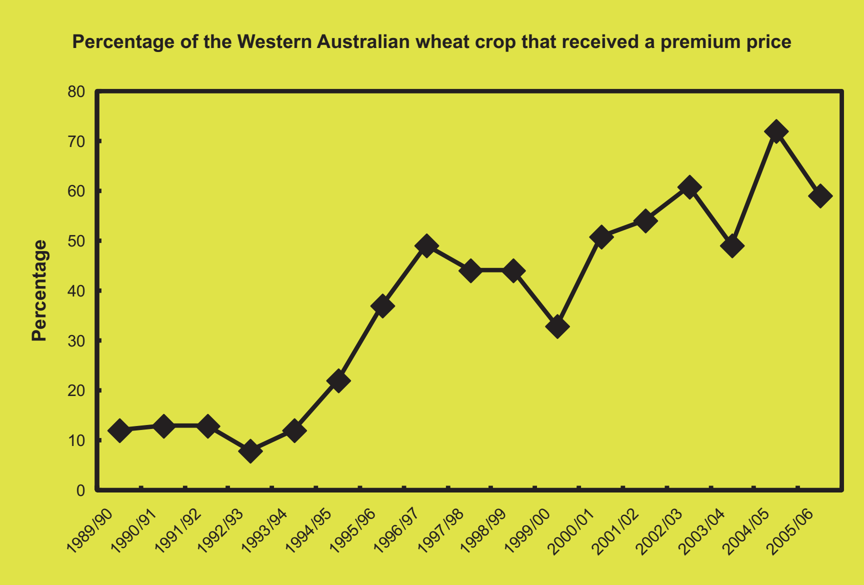

**Fig. 6** Percentage of the Western Australian wheat crop that qualified for a premium price (After Anderson et al. 2005)

## 4.5 Nutrient Efficiency

More precise management of fertiliser application to wheat crops is desirable to increase profits and to reduce soil acidification and nutrient losses from farms. Systems that estimate all components of the nutrient balance and assess the spatial variability of nutrients will ultimately be useful for decision makers. In practice, factors such as the availability of fertilisers and cash, the relative return from other inputs, interactions with factors such as weeds, variable rainfall and the perceived risk to the environment will all modify fertiliser decisions.

Grain yield per unit of applied nutrient (economic efficiency) as a function of uptake per unit of applied nutrient (uptake or recovery efficiency) and yield per unit of nutrient taken up (physiological efficiency) is receiving increased attention from researchers and farmers alike (e.g., Ladha et al. 2005).

Recovery of applied fertilisers by the wheat crop is often low. For example, recovery of applied nitrogen seldom exceeds 50 % in rainfed wheat crops (Fillery and McInnes 1992). Improving the efficiency of fertiliser use, and probably of fertiliser recovery, can be influenced by several management practices:

- Fertilisers applied to early sown crops are often used more efficiently (Anderson et al. 1995, 1997)
- Banding of nitrogen and potassium fertilisers below and at some distance from the seed often achieves better results than broadcasting (Jarvis and Bolland 1990)
- Deep placement can have advantages over shallow placement (Jarvis and Bolland 1990)
- Split applications of nitrogen fertiliser can be most effective in longer season environments or where leaching is likely, leading to increases in grain yield and protein (Mason 1975; Simpson et al. 2015)
- Some cultivars may have greater recovery efficiency associated with either increased yield or protein efficiency (Anderson and Hoyle 1999)
- Soil testing, particularly for potassium and phosphorus, can often be used as a reliable guide to optimal fertiliser use (Peverill et al. 1999).

## 4.6 Use of Electronic Decision Support Systems

Dryland farmers have increasingly adopted various on-line models to assist in decision-making. Some examples available at https://www.agric.wa.gov.au/tools are:

- **Wheat yield constraint calculator**: Simple water balance calculations with soil type considered. https://www.agric.wa.gov.au/grains-research-development/wheat-yield-constraint-calculator

- **MyPestGuide**: To identify pests. https://www.agric.wa.gov.au/plant-biosecurity/mypestguide-app
- **Wheat diagnostic tool**: A systematic tool to assess factors likely to limit yield. https://www.agric.wa.gov.au/wheat-diagnostic-tool
- **WA crop sequence calculator**: Rotation effects considered. https://www.agric.wa.gov.au/sowing/wa-crop-sequence-calculator
- **Flower power**: Wheat phenology; a tool to estimate when wheat varieties will flower from given sowing dates at a range of locations. Used to manage the risk of frost damage. https://www.agric.wa.gov.au/frost/flower-power
- **My paddock**: Compares the effect of different crop problems on the level of grain yield loss. https://www.agric.wa.gov.au/mypaddock
- **Seasonal climate information**: To assess the seasonal outlook during the year.https://www.agric.wa.gov.au/agseasons/seasonal-climate-information
- **Weather stations**: Contains current weather records for a range of stations in cropping areas. https://www.agric.wa.gov.au/weather-stations
- **Rainfall to date**: In-season. https://www.agric.wa.gov.au/climate-weather/rainfall-date

In addition to the crop models under development and testing, some models have been developed and used in pasture management (Bell and Allen 2000; Clark et al. 2000).

## *4.7 Diagnostic Research and Development*

There is recognition that crop and pasture yields that do not approach the rainfall-limited potential yield are likely limited by factors that are not easily identified by less than an objective trial-and-error process. The gap between actual or average grain yields and the rainfall-limited potential is likely greater in the wetter seasons (Anderson 1985, 2010).

Field diagnosis of the factors likely to limit production, as practised by advisors, agronomists and farmers at an informal and practical level, has been a part of system development. However, more formal and systematic diagnosis is developing. Objective field diagnosis using measurements and observations in a systematic manner have been developed by agronomists in Western Australia (www.agric.wa.gov.au/objtwr/imported assets/content/live/land/bn detect doug.pdf). Further, an experimental approach based on objective soil, plant and management measurements followed by field experiments and on-farm verification has been successfully trialled (Sharma and Anderson 2014; Anderson et al. 2014, 2016). Extension of the results from such field experiments can be achieved by either verification on similar soil types and/or the use of crop models.

# 5 Grazing and Pastoral Systems

Grazing animals, largely sheep and cattle, have comprised a major part of the dryland agricultural systems in Australia over the last 200+ years. Sheep numbers have declined from the peak of more than 170 million in 1970–1971 to less than 100 million in the mid-2000s in response to the declining price for wool and sheep meats. Cattle numbers continue to increase, reaching 28.5 million in 2005–2006 (data from Wolf 2009 derived from the Australian Bureau of Statistics). However, a mixture of crops and pastures in some form has been used to reduce the risks of both the weather and the markets. The proportion of each has varied according to economic conditions, but concerns for the long-term viability, or sustainability, of the systems has increased recently.

Dryland farming has been based on ley farming, a system that incorporates a short phase of self-regenerating, legume-based, annual pastures with cereal crops. However, the system has come under increasing pressure for change as the prices for animal products (largely wool and meat) have fallen (Reeves and Ewing 1993). This has resulted in much longer cropping phases ('phase farming') which has raised concerns regarding reduced soil fertility and perceptions of increased economic risk, even if the current profitability of crops exceeds that of pastures (Bell et al. 2014).

Recent innovations in the pastures and grazing area have included the revival of the use of dual-purpose crops (cereals and canola) for grazing and later recovery for grain harvest, and the introduction of perennial species to the crop/pasture sequence (Bell et al. 2014). Some of the concerns that confront farmers, and that perennial pastures may address, include dryland salinity associated with rising water tables, waterlogging and herbicide resistance.

In terms of the livestock component of the dryland system, economic pressures have resulted in an increase in the production of fat lambs for meat production from traditional wool (Merino) flocks (Kopke et al. 2008). This has come both from the use of meat-type sires over Merino ewes and from the development of dual-purpose Merino breeds.

# 6 Key Conclusions

## *6.1 Research Funding – Legislated, Voluntary and Private*

Various research and development corporations (RDCs) have been pivotal in supporting agricultural research for Australian dryland agricultural systems. Essentially, farmers pay a levy equivalent to a percentage (mostly 1 %) of the net farm gate value of their production. The resulting funds are matched by the federal government (fewer administration costs) and the combined funds are available for competitive grants for research, development and extension by government, universities and private organisations. In addition, various groups have engaged in research and development with more specific goals based on voluntary contributions.

Much, if not all, of the private research conducted by companies with interests in chemicals, plant breeding and fertilisers is conducted in other countries, with local verification.

As discussed above, there has been a partial withdrawal of public funds for agricultural research over the past decade or so. Various public–private research partnerships have been established in areas considered to have some component of public benefit.

### 6.2 Genetic Modification

Genetically-modified crops have been introduced to Australian dryland systems over the past two decades. The main type of modification has been for herbicide resistance, in addition to insect-resistant cotton cultivars. The use of herbicide-resistant crops has been controversial in some cases. Nevertheless, adoption of glyphosate-resistant canola, for example, has been widespread, even if problems with herbicide resistance in weeds such as annual ryegrass (*Lolium rigidum* Gaud.) have been encountered, requiring the development of integrated weed management systems.

The convenience and effectiveness of genetically-modified crops for weed or pest management have largely outweighed the possible hazards. However, there is some concern about the safety and efficacy of these cultivars as summarised from worldwide data (e.g. Antoniou et al. 2012).

### 6.3 Closing the Yield Gap

There is still a gap between average farm yields and the theoretical potential yield as limited by seasonal rainfall (Anderson et al. 2016). There is a need for objective, field investigations to determine the appropriate measures to address this yield deficit and to estimate the profitability of the various measures that may be required.

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