Chapter 3

Farms and farmers – conservation agriculture amid a changing farm sector

Ross Kingwell, Andrew Rice, Jim Pratley, Allan Mayfield and Harm van Rees

Introduction

Conservation agriculture (CA) in Australia had its beginnings in the early 1970s with the release by ICI of Spray.Seed®, comprising paraquat and diquat (Pratley and Rowell 1987). However, it was not until 1978 with the release of diclofop (Hoegrass®) for post-emergent ryegrass and wild oat control and then the safer, more effective glyphosate (Roundup®) in 1980 by Monsanto for seedbed vegetation control that the tools were in place for adoption of direct drilling (DD) of crops. Adoption of DD was fastest in Western Australia (WA) with its large areas of sandy soils suited to DD and its larger farms and crop areas that benefited from more timely sowing.

Adoption of DD during the 1980s was due largely to the increased cost of farm labour, machinery and fuel (Pratley and Cornish 1985) rather than due to perceived beneficial effects on soils. The initial cost of glyphosate was an impediment, particularly for summer rainfall regions where multiple applications to control weeds in fallows were needed. Early adoption of DD was not without its challenges. Careful management was required to make it work and there was a delayed realisation of its farming system ramifications.

DD and related conservation practices have greatly influenced the business of farming in Australia since the late 1980s. However, identifying the separate and particular impacts of CA on farm businesses is no simple task; especially when so many other changes have contemporaneously lessened, magnified or complemented the effects of conservation practices.

Other chapters in this book provide the technical detail and experimental evidence for the benefit of CA. Our task is not to duplicate their work but rather to reveal the socio-economic change in Australian agriculture and its farm sector that formed the backdrop of farmers' use of conservation practices. We conclude our chapter by reflecting on the current challenges and opportunities facing farmers regarding their use of conservation practices.

Many factors influence the nature of farming in Australia:

- Price trends in domestic and international agricultural commodity markets signal to farmers their need to increase or diminish production of agricultural commodities;
- Technology change typically lowers real costs of production and increases agricultural production;
- Changes in government policy and government support alter the incentives farmers face to engage in agricultural production;
- Periods of climate volatility and any underlying spatial shifts in climate patterns affect production risk, and ultimately the financial risk of farming and business expansion;
- Social attitudes and expectations, within and outside of farm communities, invariably affect the nature and outcomes of farm practices and the social attractiveness of farming;
- What economists call 'path dependencies' and 'asset specificity' affect options for farm businesses. A farm business's location, soil mix, machinery, finances, access to capital, workforce and management skill are its assets. Some of these assets which cannot be quickly altered, and their history of use, their path dependency, determines what business opportunities and directions can feasibly best serve the financial interests of the farm business; and
- Innovation and investment in farming systems and their related supply chains affect the relative affordability of various farm commodities and the appeal of those commodities in processed goods.

Some of the main changes in the nature of broadacre farming in Australia since the mid-1980s, and the main causes of those changes, are described briefly in the following paragraphs.

Key changes in Australian agriculture since the 1980s

Climate variability and an apparent change in climate has affected the nature and profitability of many farm businesses (Kingwell *et al*. 2013, Stephens 2017). The change in climate is most evident in southern Australia, especially in the south-west of WA. Figures 1a and 1b illustrate the southwards and coastal drift of observed climate patterns in Australia. In southern Australia many farmers observe longer, warmer autumns and a later onset of rains to commence the winter growing season. Farmers tend to experience fewer very wet winter days and observe a decline in winter rainfall. In response to these changes, farmers adapt.

Figure 1. Australian seasonal rainfall zones based on rainfall data (a) 1990-1999, and (b) 2000-2015 (source Stephens 2016, 2017)

There is a long list of farmer adaptations to climate variability and climate change (see Ash *et al*. 2000, Howden *et al.* 2003, Kingwell 2006). The partial list includes:

- reduction in downside risk of crop production (*e.g*. staggered planting times, erosion control, minimum soil disturbance crop establishment, crop residue retention, dry-sowing, crop and varietal portfolios, soil moisture measurement);
- reduction of downside risk of animal production (selection for heat tolerance, crop-grazing, fodder and grain storage);
- seasonally tailored planting (*e.g*. tactical selection of crop portfolios, crop sequences, fields, seeding rates, row spacing, timing and rates of application of nitrogenous fertilisers and crop protection chemicals); and
- diversification of revenue streams (*e.g*. off-farm income, spatial diversification)

Since the early 1990s, Australian broadacre farming has experienced a pronounced and enduring shift into grain production, resulting in large part from the collapse, until recently, in profitability of sheep production in the 1990s. Grain production became commercially more attractive following the folly of administrators of the Reserve Price Scheme for wool (Garnaut *et al*. 1993). Their actions triggered a prolonged collapse in wool prices that weakened the profitability of sheep production. In 1987, the national sheep population was 152 million; and by 2018 the population had shrunk to under 70 million (AWI 2018).

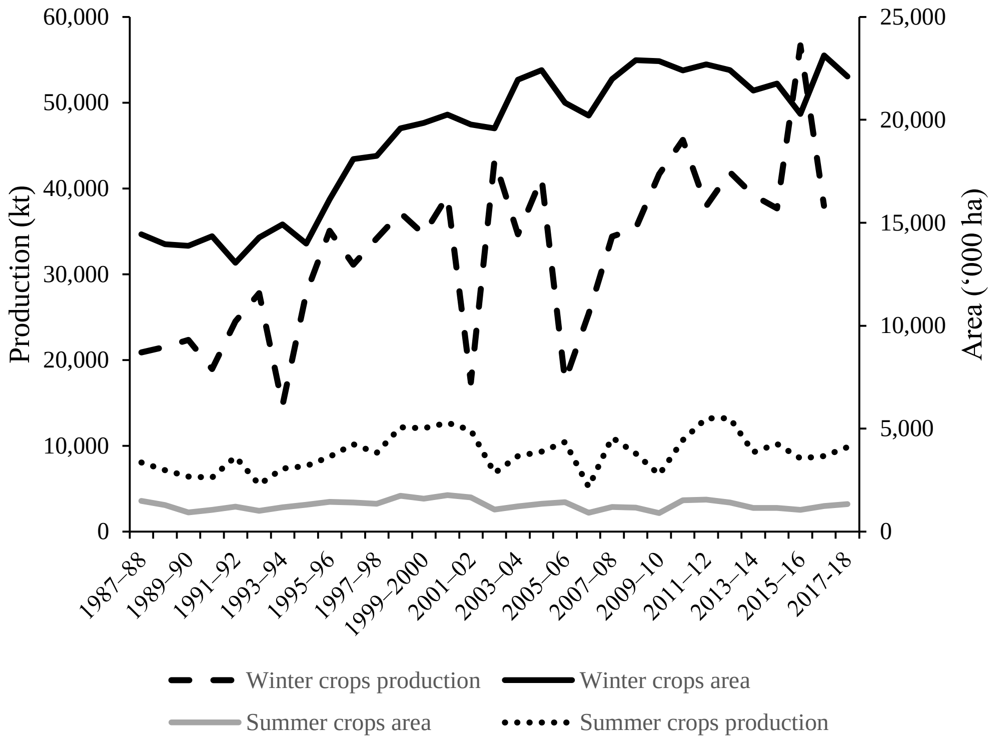

Figure 2. Changes in winter and summer crop production in Australia: 1987/8 to 2015/16 (Source: Based on Australian Commodity Statistics 2018)

Figure 2 shows the changes in the area planted to winter and summer crops in Australia and their respective production. A dominant and persistent change to winter cropping has occurred. Alternative crops to cereals such as canola and some pulses (*e.g.* lupin, faba beans and chickpeas), together with improved crop protection products, facilitated continuous cropping activity. Canola, barely grown in Australia in the late 1980s, has emerged over time as a major crop in all main grain-growing states, apart from Queensland (Figure 3). A four-year investigation (Harries *et al*. 2015) of farmers' crop use in WA showed that wheat, barley and canola, together, occupied 75% of the paddocks surveyed. Crop and pasture sequences had changed over the previous decade toward greater crop dominance and higher levels of inclusion of canola. Wheat remains the dominant crop, mostly followed by barley and then canola. These top three crops are sown often on over 80% of the total crop area in each state, except for Queensland and northern NSW with a greater area of summer crops.

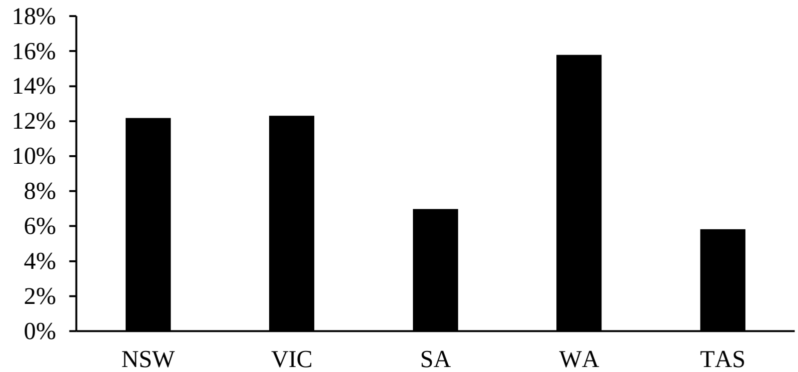

Figure 3. Percentage of the total area of crop sown to canola: 5-year average to 2017/18 (Source: Based on Australian Commodity Statistics 2018)

Farm size

Aside from the relative decline in the profitability of sheep and wool production, especially during the 1990s, many other factors encouraged the change to crop-dominant farming systems including mechanisation, labour-saving technologies, cost-effective herbicides, varietal improvement, and increases in farm size that delivered scale economies, especially to cropping. Further, in some states, the challenges to animal production of sequences of severe drought encouraged a swing into crop production. The increased focus of crop production, when combined with increases in farm sizes, transformed the asset base of broadacre farming (Figure 4).

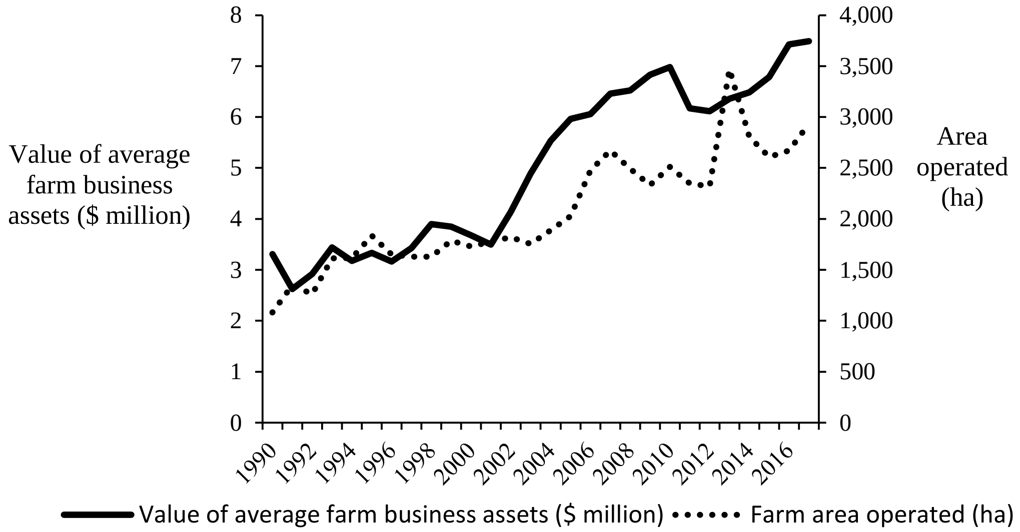

Figure 4. The average farm area operated and the value of farm business assets in the wheat and other crops industry in Australia (Source: ABARES Ag Surf data. All values are presented in constant 2017 dollar terms)

Average farm size increased markedly between 1990 and 2017, as implied by the change in area operated in Figure 4 and because the total number of wheat dominant and mixed enterprise farms declined by 40% over the period. By 2004, the largest 16% of farms accounted for around 75% of total industry output (Sheng *et al.* 2016). Larger farms generated social implications. Increasingly only the children of farmers or those with remarkable wealth were able to become sole owners and operators of a large farm business. Most others keen to engage directly in farming needed to do so via hobby or part-time farming, as farm equity partners, as farm managers or as farm workers.

The increase in the size and complexity of farm businesses (Kingwell 2011), when combined with farm families having fewer children who spend many years in education away from the farm, cause most farm businesses to increase their expenditure on purchased services (including farm labour). Use of permanent and casual labour, contractors (spraying, fencing, shearing, harvesting) and specialist services (*e.g.* grain marketing, agronomic advice, accountancy) are now common features of current farm businesses, especially cropping farms (Figure 5).

There is a positive relationship between farm size and total factor productivity. As well as outsourcing services, larger farms are better able to purchase new equipment and technology (Sheng and Chancellor 2018). Often these businesses benefit from their managers being well educated.

The increase in farm size and the commensurate decline in the farmer population, accompanied by the on-going urbanisation of Australia's population, continues to reduce the political and economic importance of the farm sector. Although farmers often draw an empathetic and sympathetic response from city consumers, the political reality is that most governments rise and fall on urban votes.

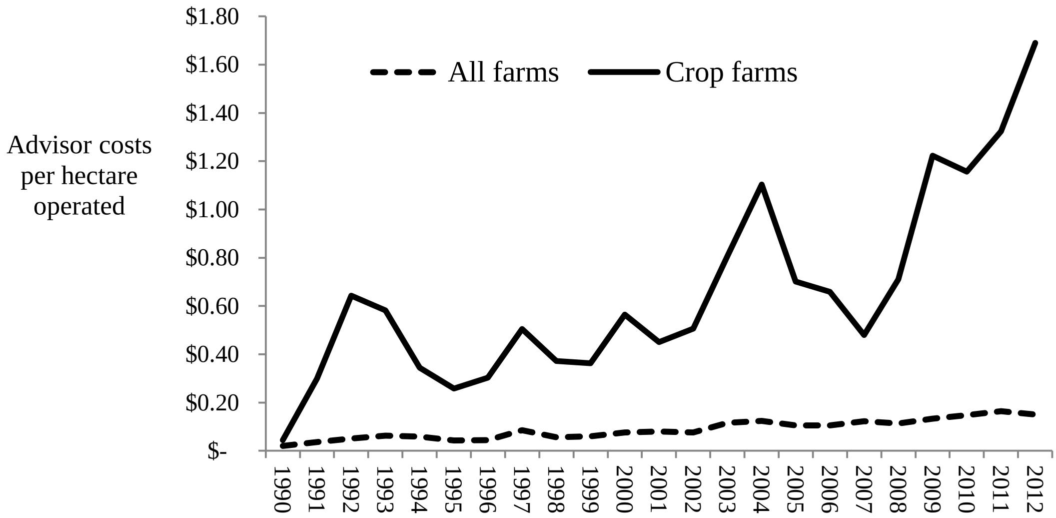

Figure 5. The increase in advisor costs for crop farms relative to all farms, 1990-2012
(Source: Keogh and Julian 2013)

Farm ownership

Although broadacre farming in Australia remains largely the province of family-owned and operated businesses, corporate farming is on the rise. Corporate and foreign ownership of Australian farmland attracts much media and political scrutiny. As at 30 June 2017, around 10% of the farmland in most mixed cropping and grazing regions of Australia were corporately-owned and at 30 June 2017, 13.6% (FIRB 2017) of Australian agricultural land was wholly or partly foreign-owned (with around half of the latter in majority Australian ownership). This compared with 5.9% of agricultural land being wholly or partly foreign-owned in 1984.

In general, there is little churn in cropping zone farmland ownership (Pritchard *et al.* 2012) which is typically around 4% per annum, suggesting most farmland is owned and operated over the long term. ABS (2018) indicates the average duration in farming is around 37 years. This longevity of familial ownership of farms gives rise to succession issues in farming being a potentially problematic business and social issue. However, farm families are having fewer children and provide their children with greater levels of education to facilitate some children pursuing careers outside of farming. However, ensuring within and across generational equity remains a general problem in farm succession.

When farmland is sold, the purchaser is usually another family farm business in the district or a corporate or family farm operation outside the district. Increasingly, family farms operate as a corporate business. Financial duress imposed by events such as the millennial drought provided investment opportunities for corporates.

Marketing arrangements

The institutional landscape has altered in conjunction with farming system and farm size changes.

- Firstly, Australia's National Competition Policy (Hilmer *et al*. 1993), actively applied after 1994, gradually, yet fundamentally, changed Australian agriculture. More than fifty statutory marketing or single desk marketing arrangements of agricultural commodities, including grains, were dismantled. For the grains industry, individual farmers became responsible for the production *and* marketing of their grains.
- Secondly, supply chain infrastructure shifted from being owned and operated by grower co-operatives into private ownership (GrainCorp, Viterra, Cargill), the exception being Cooperative Bulk Handling in WA. Most farmers, especially those in eastern states, increased

their investment in on-farm storage, in response to perceived marketing opportunities in the new deregulated environment.

- Thirdly, breeding of major crops was privatised and provision of advisory services shifted increasingly from the public sector into the private sector. Farmers increasingly received information electronically through mobile phones, portable computers and spread of the internet. As the volume of grain production grew, so did finances for grains R&D.

The need for access to real time information on markets has been accentuated by these changes and this is reflected in internet use. Gooday (2018) reports that, in 1998, 30% of farms owned a computer but 20 years later, that proportion was 90%. Broadacre farms report the major limitation of this technology to be internet access.

Education

Although the level of education in agriculture has been well below that of the general community, a phase of 'catch-up' has been underway since the 1980s, as Figure 6 shows. The data are skewed somewhat due to the different age distributions of the farm sector versus the general community, with farmers in 2017 having a greater average age of 57 (ABS 2018).

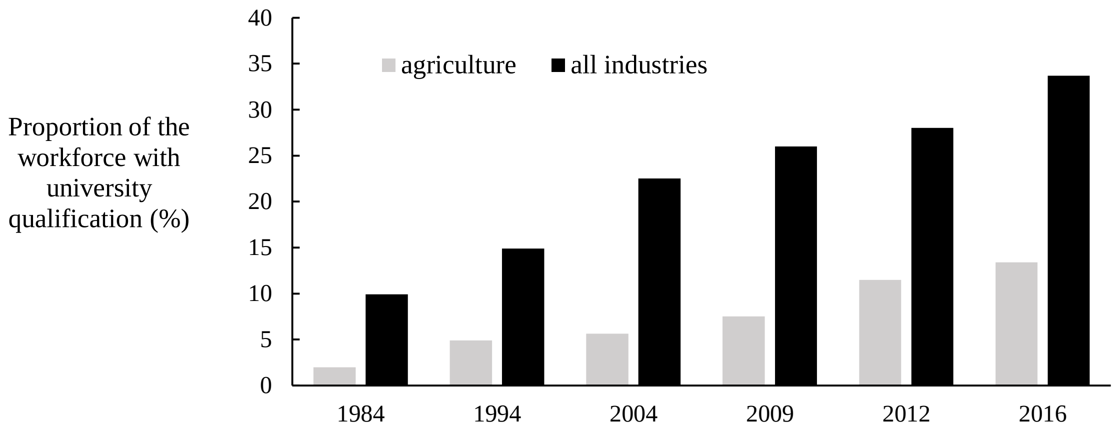

Figure 6. The trends in university education for the agriculture sector workforce in comparison with the Australian workforce (source: based on National Census data)

Further analysis specifically of the cropping industry provides clear trends of greater proportions of higher education attainment in its younger age groups and there being a smaller proportion without post-secondary qualification (Figure 7).

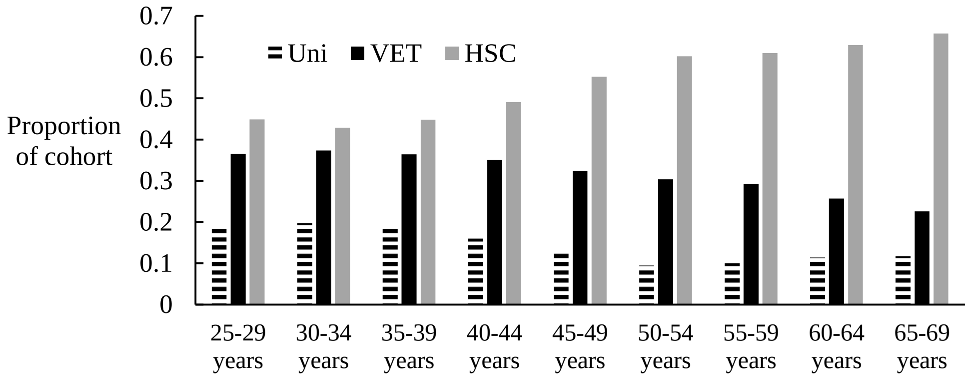

Figure 7. Highest education attainments (*i.e.* university, vocational education and training, or higher school certificate) by age cohort engaged in crop production in 2016 (Source: based on data from the National Census 2016)

During the period since the late 1980s there have been several changes in education provision and employment demands that influence farm production and management, additional to those mentioned earlier. These include:

- The closure of all professional public agriculture colleges in 1989 and their amalgamation with the university sector. Many vocational education and training (VET) level agricultural colleges also closed;
- Entry into the employment market for university graduates by distributors and resellers of agricultural goods and inputs;
- An increase in the leaving age from school from 15 to 17 years in most states in 2009;
- A decline in student numbers in agriculture from 1990 to 2012, due to the poor image of agriculture and ignorance of job and career opportunities in agriculture. However, university intake data show the number of students entering agriculture and related courses has increased each year since 2012 and, in 2016, is back at 2001 levels.

Conservation practices and farm businesses: an overview

The emergence and adoption of land and water conservation practices in Australia from the 1980s coincided with a rising community-wide sentiment regarding the need to care for rural landscapes. The National Landcare Program (NLP), initiated in 1989, encouraged farmers and other rural residents to share their knowledge, resources and their coordinated commitment to redress local or regional environmental issues (Lockie 2015). For over two decades, strong bipartisan political support for 'landcare' and sustainability issues persisted, allowing, for example, the national government's 'Caring for our Country' program to support the Grains R&D Corporation to conduct a national survey of growers regarding their farming practices (Kearns and Umbers 2010). The survey was repeated in 2012, 2015 and 2016 (*e.g.* Umbers 2017) and complemented ABS agricultural censuses that occasionally have reported on farmers' crop and soil management practices. The findings from these surveys reveal farmers' adoption of the following conservation practices.

Tillage

In the early 1980s, along the south coast of WA, severe wind erosion on cultivated sandy soils reinforced the need for improved land care and prompted interest in reduced tillage that was increasingly feasible due to new increasingly effective and affordable herbicides (Crabtree 1990). WA, with its sandier soils, rapidly became the leading state for adoption of reduced tillage (RT), direct drilling (DD) and no-till (NT) (see Table 1 in Kearns and Umbers (2010) and Chapter 2). Farmer adoption of NT began to plateau in the late 2000s in most states except for NSW. By 2016, NT was commonplace across Australia, with Umbers (2017) reporting that almost three-quarters of the national crop area relied on NT.

The widespread adoption of NT, even in WA where adoption was most rapid, was not without problems and dissent. Crabtree *et al*. (2018) provide an insight into the range of issues and personalities that affected farmer uptake of NT in WA from 1990 to 2010. These authors acknowledge the dominance of NT but also concede that occasional tillage remained necessary for various reasons, including to:

- fix non-wetting soils (Hall *et al*. 2010; Roper *et al*. 2015);
- raise the pH of highly acidic subsoils (Flower and Crabtree 2011);
- manage herbicide-resistant weeds (Derksen *et al*. 1995, Ashworth *et al*. 2014);
- remove soil compaction layers or 'hardpans' (Hanza and Anderson 2003) and
- level paddocks.

Kirkegaard *et al*. (2014) point out that the impact of tillage systems on productivity involves a complex interaction between soil type, environment, yield potential and management system. For example, Armstrong *et al*. (2019) found tillage practice had little impact on productivity over 18 years at a site in Victoria where the soil had a naturally high structural stability.

No-till practices were typically part of a wider suite of changes in farm practices. It was the portfolio of changes in farm practices, rather than the sole uptake of NT that gradually transformed the nature of farming systems in Australia. Accompaniments to NT were the following changes in farm practices. Whenever adoption trends or figures are quoted in the following sub-sections the source is Umbers (2017).

Precision agriculture

Bramley and Trengove (2013) outline that precision agriculture (PA) also encompasses a range of technologies. These researchers review applications of PA to Australian agriculture, noting that PA is principally applied in the grains, winegrape, sugarcane, cotton and potato industries. One component of PA is controlled traffic farming (CTF) that has followed farmer adoption of NT (Tullberg *et al*. 2007, see Chapter 6)).

Currently around 30% of Australia's grain crops area is subject to CTF, with higher rates of adoption occurring in NSW and Qld. CTF requires alignment of farm machinery wheels such that they all follow the same path in paddocks, leaving large areas of soil un-trafficked and less prone to compaction that can be problematic, especially on clay soils. The increased size and weight of some farm machinery exacerbates soil compaction (Lamande and Schjonning 2011). Hamza and Anderson (2005) show that just one pass of machinery can negatively affect all soil characteristics and crop responses. Water infiltration rate is greater in un-trafficked soils (Chyba 2012) by as much as 400% (Chamen 2011). Kingwell and Fuchsbichler (2011) used whole-farm modelling to assess the profitability and role of CTF in different Australian farming systems. They found the most valuable aspect of CTF was its beneficial impact on the yield and quality of crops grown on soils most subject to compaction.

Adoption of autosteer, a component of CTF, occurred rapidly and is now a standard feature of most modern farm equipment. This technology currently is used on more than 85% of the cropped area nationally and over 90% of the crop area many regions of WA and SA. Of far less interest to farmers is variable rate technology (VRT), used on less than 7% of the national crop area. Robertson *et al*. (2012) examined VRT adoption across Australia and found the main constraints to adoption were technical issues with equipment and software, access to service provision and the incompatibility of equipment with existing farm operations.

Yield mapping, often a component of VRT, is used on about 35% of the nation's crop area. Yield mapping can involve simple monitoring of crop performance or the facilitation of crop input decisions, or as a crop diagnostic tool. McBratney *et al*. (2005) point out that although tools like yield mapping generate much data, an impediment to their utility is often the absence of accompanying decision-support systems. In other words, in order for farmers to make better decisions, the yield mapping data must be analysed and converted into information that unambiguously facilitates improved decisions from which the farm business will benefit. Robertson *et al*. (2012) also reported this lack in decision-support software.

The final technologies that form part of the suite of PA technologies (Jochinke *et al*. 2007) are remote sensing technologies such as electromagnetic sensing (most commonly being EM38 soil mapping and normalised difference vegetation index (NDVI) mapping of crop and pasture growth). EM38 soil mapping measures relative levels and depths of certain soil qualities. NDVI data helps identify plant growth and biomass levels (Abuzar *et al*. 2013). Nationally, adoption of these technologies is low, applied on only around 5% of the crop area.

Crop sequencing

The impact of crop sequences on yields of following wheat phases has been studied by Seymour *et al*. (2012) and more fully by Angus *et al*. (2015). Given the wheat dominance of farming systems in Australia it is important to know the nature and magnitude of yield effects in crop sequences. These researchers generally found that the uplift in wheat yields was greatest when the preceding crop was a pulse. In order of lessening impact was canola or linseed, followed by oats. The mean additional wheat yield after oats or oilseed break crops was independent of the yield level of the following wheat crop whereas the wheat yield response to legume break crops was not clearly independent of yield level. The yield of wheat after two successive break crops was 0.1-0.3 t/ha greater than after a single break crop.

In a sequence of wheat phases after a break crop the yield benefit decayed such that after the second consecutive wheat crop any yield increase was negligible in most situations.

Robertson *et al*. (2010) and Lawes and Renton (2015) showed that although inclusion of break crops improved farmers' potential profits, in practice farmer adoption of break crops was often less than might otherwise be expected. Harries *et al*. (2015) surveyed farmers' use of break crops over four years and concluded that crop and pasture sequences had changed, with canola as the preferred break crop. Most growers' motivations for selecting break crops involve weed management, disease management, crop nutrition and relative profitability as a cash crop.

Liming

Although rare up until the mid-2000s, apart from in southern NSW, the practice of liming has been rapidly adopted (Umbers 2017). The area of crop area limed and the rate of application of lime per hectare have both increased in the decade prior to 2016. The rationale for liming and the practicalities of how and when to lime (Gazey and Davies 2009) are now well known. The profitability of liming differs according to individual circumstances, with yield gaps due to acidity being more concentrated spatially in the high-rainfall regions of WA, Victoria and NSW (Orton *et al*. 2018). Cost benefit analyses of the amelioration of acidity, traffic hardpans, transient salinity and sodicity in various regions of WA reveal that addressing soil acidity is often the best option (Petersen 2017).

Other

Other accompaniments to no-tillage include soil water monitoring, fallowing and stubble management. Measurement of plant available water at planting is now commonplace in many parts of NSW and Qld. Umber's (2017) national survey of grain producers revealed that almost two-thirds of growers used some fallow in their crop sequences. Up to around 10% of crop area is fallowed, mostly to assist with weed control, and use of fallow is more popular in northern NSW and southern Qld. Stubble retention, through to sowing, occurs on approximately 60% of the nation's crop area whilst stubble burning now occurs on less than 10% of the crop area. Machinery improvements now facilitate management of larger stubble loads at seeding.

Current opportunities and challenges affecting conservation farming

Opportunities

Conservation farming and the plethora of its associated technologies currently offer farmers many advantages and further opportunities are emerging (Chandra 2018). The in-built intelligence in machinery allows farmers to more confidently rely on unskilled labour. Often, unskilled, casual labour (*e.g*. backpackers) is far cheaper and more available to farm businesses than skilled labour. Skilled labour in rural regions is relatively scarce and can be expensive, especially in states with buoyant mining sectors that attract workers away from the farm sector. In the near future, autonomous vehicles will further facilitate reliance on conservation farming (Pawel *et al*. 2018, Gan and Lee 2018) and help lessen costs in some parts of agricultural supply chains.

In the current period of low interest rates and relatively high equity levels of farm businesses, especially in states less affected by drought and associated production volatility, affording machinery upgrades and land leases or purchases to capture size economies facilitates faster adoption of evolving crop production technologies. Embedded in these machinery-based technologies will increasingly be data capture and data analysis systems that facilitate crop management (Fulton and Darr 2018). Spatially targeted use of inputs as accompaniments to conservation tillage will likely become sufficiently lucrative to be commonplace.

The incoming generation of farmers and farm managers will likely be more educated and potentially more skilled as business managers than previous generations. They will probably have greater competence in labour and information management, business analysis and grain marketing. Many will have wider social networks and will have spent time away from the family farm to develop skills and knowledge that complement farm management and ownership. Similarly, their family partners are likely to be better educated, further supporting farm business management and household decision-making. This greater human capital will facilitate the assessment and uptake of technologies and practices that will complement conservation farming.

Challenges

Although machinery intelligence provides opportunities, it also represents challenges, especially over who owns the data and the ability to transfer data across platforms. The Productivity Commission (2017) has considered rights to access digital information and potential impacts on competition. They concluded that this issue requires urgent attention by governments to maximise the economic gains potentially available from emerging digital technologies, and to reduce the risk of damage to competition. They have proposed a range of measures including a new comprehensive data right for consumers and small businesses.

Studies by Harries *et al*. (2015) and Armstrong *et al*. (2019) found no evidence that the observed sequences of crops, underpinned by conservation farming, were fundamentally unsustainable. Hence, conservation farming in the future may be resilient to most biological challenges. Other challenges, however, may unmask the sustainability of some aspects of conservation farming. The social requirement to not use certain chemicals or employ particular practices may challenge conservation farming. A swathe of social issues may in general weaken the social attractiveness of large-scale conservation farming. Issues of rural de-population, lack of diversity in rural employment, family stress, availability and affordability of education and health services in rural regions may be among the more challenging issues facing farm families. Often in farming it is not solely the biological challenges that inhibit success but rather the failure to appropriately respond to the social and economic challenges of farming.

Conservation farming has encouraged farm businesses to become more crop dominant and larger in physical and financial size. A challenge associated with these trends is that the businesses in some regions are potentially very exposed to financial damage from unforeseen prolonged drought. Drought can have long-term business consequences if the farmer's capacity to finance cropping and livestock operations during recovery is impeded (Lawes and Kingwell 2012). Kingwell (2002) observed when examining the structure of crop-dominant farming systems in Australia: ‘‘a switch into more cropping means a more capital-intensive business with greater demands for working capital. With such a business structure, a few poor seasons, especially if coupled with poor prices, can rapidly cripple a farm business‘‘. The prospect of subdued grain prices, or sustained downward pressure on grain prices, is a likely prospect over the next decade in Australia due mostly to the large volumes of affordable grains produced in the Black Sea region and in South America (Kingwell 2019). An associated challenge, as farms increase in size, are diseconomies of size when, in spite of technology and information aids, the farm manager and staff eventually are impeded in their ability to fully manage the business and its operations. Contrarily, greater crop dominance, supported by ever higher yielding crop varieties, reduces the unit costs of the bulk handling of grain thereby facilitating the competitive pricing of grain to end users. However, due to climate-induced production volatility, crop supply chains must be highly flexible to accommodate a range of sizes of grain harvests.

Increased crop dominance, supported by conservation farming, has also led to greater reliance on crop protection products. In addition, stubble retention and removal of cultivation is generating its own set of emerging issues in pest, weed and disease control. When coupled with rising direct costs (*e.g*. seed, fertiliser and crop protection products) of crop production, ensuring crop production remains profitable in the face of climate variability is a mounting challenge.

Broadacre farms are becoming larger and fewer. They are increasingly reliant on a range of professional services and external sources of innovation and research services. A challenge to these farm businesses and their service providers is how to ensure they have ongoing access to well-trained competent and affordable service providers. Answering this challenge is no simple task. Agricultural education in universities has historically been the foundation of many professional services provided to farmers.

However, in many universities, agriculture no longer has separate faculty status (Barlow *et al*. 2016) and undergraduate courses that solely focus on Australian agricultural science or agribusiness management are increasingly rare. These trends reduce the likelihood of readily available, competent personnel well versed in Australian agriculture to serve the advisory and research needs of Australian broadacre farmers. Hence, securing the future provision of competent support services to Australian farm businesses may in some regions become increasingly difficult. Such personnel are most likely to be educated in those institutions with rural campuses (Pratley and Crawley 2018).

Furthermore, many state governments have reduced support for their agricultural agencies and associated research. These agencies were often the training grounds for advisory services to farmers. Reduced training and restricted initial employment opportunities in these agencies may adversely affect the quality and quantity of future service provision to farm businesses. Moreover, infrastructure, education and social service provision in rural regions is often a poor cousin to urban investments. This reduces the attractiveness of employment in the agricultural services sector. To the extent that development and uptake of technologies and practices complementary to conservation farming depend on availability of reputable advisory and research providers, then the broadacre farm sector may not be served as well in the future.

References

Abuzar M, Whitfield D, McAllister A, Lamb G, Sheffield K, O'Connell M (2013) Satellite remote sensing of crop water use in an irrigation area of south-east Australia. 2013 IEEE International Geoscience and Remote Sensing Symposium – IGARSS, Melbourne, VIC, 2013, pp 3269-327

Angus JF, Kirkegaard JA, Hunt JR, Ryan MH, Ohlander L, Peoples MB (2015) Break crops and rotations for wheat. *Crop and Pasture Science* **66**, 523-552

Armstrong RD, Perris R, Munn M, Dunsford K, Robertson F, Hollaway GJ, O'Leary GJ (2019) Effects of long-term rotation and tillage practice on grain yield and protein of wheat and soil fertility on a Vertosol in a medium-rainfall temperate environment. *Crop and Pasture Science* **70**, 1-15

Ash AJ, O'Reagan P, McKeon P and Stafford-Smith M (2000) Managing climate variability in grazing enterprises: a case study of Dalrymple Shire, north-eastern Australia. In (Eds. G.L. Hammer, N. Nichols and C. Mitchell) "Application of Seasonal Climate Forecasting in Agricultural and Natural Ecosystems" pp 253-270 (Dordrecht: Kluwer)

Ashworth MB, Walsh MJ, Flower KC Powles SB (2014) Identification of the first glyphosate-resistant wild radish (*Raphanus raphanistrum L*.) populations. *Pest Management Science* **70**, 1432-1436

Australian Bureau of Statistics (2018) Agricultural Commodities, Australia, 2016-17. Catalogue 7121.0 www.abs.gov.au/ausstats/abs@.nsf/latestProducts/7121.0Media%20Release12016-17?OpenDocument

AWI (2018) Sheep numbers by State. www.wool.com/market-intelligence/sheep-numbers-by-state/

Barlow S, Kingwell R, Pratley J, Keating B (2016) Innovation in Australia's agrifood systems: Are Australian universities ready for the next challenge? *Farm Policy Journal* **13**, 15-24

Bramley R, Trengove S (2013) Precision agriculture in Australia: present status and recent developments. *Engenharia Agrícola* **33**, 575-588

Chamen T (2011) The effects of low and controlled traffic systems on soil physical properties, yields and the profitability of cereal crops on a range of soil types. PhD thesis. Cranfield University, School of Applied Sciences

Chandra, R (2018) FarmBeats: Automating data aggregation. *Farm Policy Journal* **15**, 7-16

Chyba J (2012) The influence of traffic intensity and soil texture on soil water infiltration rate. MSc diss. Harper Adams University, Department of Engineering

Crabtree WL (1990) Toward better minimum tillage for south-coastal sandplain soils. Department of Agriculture Western Australia. Division of Resource Management. Technical Report 111

Crabtree WL, Flower K, Bligh K, Siddique K, Fogarty J (2018) Revolutionary no-tillage adoption in Western Australia from 1990-2010, Working Paper, School of Agriculture and Environment, University of Western Australia

Derksen D, Thomas A, Lafond G, Loeppky H and Swanton C (1995) Impact of post-emergence herbicides on weed community diversity within conservation-tillage systems. *Weed Research* **35**, 311-320

Edwards J, Umbers A and Wentworth S (2012) Farm Practices Survey Report 2012 (Grains R&D Corporation, Kingston, ACT)

Flower KC, Crabtree WL (2011) Soil pH change after surface application of lime related to the levels of soil disturbance caused by no-tillage seeding machinery. *Field Crops Research* **121**, 75-87

Foreign Investment Review Board (2016-17) Annual Report. Commonwealth of Australia ISSN 0155-0802
Fulton, J, Darr, M (2018) GPS, GIS, guidance, and variable-rate technologies for conservation management. In (Eds. J Delgado, G Sassenrath, T Mueller) "Precision Conservation: Geospatial Techniques for Agricultural and Natural Resources Conservation" pp 65-81 Agronomy Monographs 59 American Society of Agronomy and Crop Science Society of America, Inc.
Gan, H, Lee, W (2018) Development of a navigation system for a smart farm. IFAC-PapersOnLine **51**, 1-4
Garnaut R, Bennett S, Price R (1993) Wool: Structuring for global realities. Report of the Wool Industry Review Committee to the Minister for Primary Industries and Energy, 232pp
Gazey C, Davies S (2009) Soil acidity: A guide for WA farmers and consultants. Bulletin 4784 (Department of Agriculture and Food: WA)
Gooday P (2018) Farm performance: Latest trends and issues affecting ICT use on farms. Outlook 2018. www.agriculture.gov.au/abares/outlook/program/gooday
Hall DJM, Jones HR, Crabtree WL, Daniels TL (2010) Claying and deep ripping can increase crop yields and profits on water repellent sands with marginal fertility in southern Western Australia. *Australian Journal of Soil Research* **48**, 178-187
Hamza MA, Anderson WK (2003) Responses of soil properties and grain yields to deep ripping and gypsum application in a compacted loamy sand soil contrasted with a sandy clay loam soil in Western Australia. *Australian Journal of Agricultural Research* **54**, 273-282
Hamza MA, Anderson WK (2005) Soil compaction in cropping systems. A review of the nature, causes and possible solutions. *Soil and Tillage Research* **82**, 121-145
Harries M, Anderson GC, Hüberli D (2015) Crop sequences in Western Australia: what are they and are they sustainable? Findings of a four-year survey. *Crop and Pasture Science* **66**, 634-647
Hilmer F, Rayner M, Taperell G (1993) "National Competition Policy" (Australian Government Publishing Service: Canberra)
Howden M, Ash A, Barlow S *et al*. (2003) An overview of the adaptive capacity of the Australian agricultural sector to climate change – options, costs and benefits. (CSIRO Sustainable Ecosystems, Canberra)
Jochinke DC, Noonon BJ, Waschsmann NG Norton RM (2007) The adoption of precision agriculture in an Australian broadacre cropping system – challenges and opportunities. *Field Crops Research* **104**, 68-76
Kearns S, Umbers A (2010) 2010 GRDC Farm Practices Baseline Report www.grdc.com.au/__data/assets/pdf_file/0022/209740/grdc-farm-practices-baseline-full-report-july-2010.pdf
Keogh M, Julian C (2014) Optimising future extension systems in the Australian grains industry: Part 1. (Australian Farm Institute, Sydney)
Kingwell R, Anderton L, Islam N *et al.* (2013) Broadacre farmers adapting to a changing climate. Final Report to National Climate Change Adaptation Research Facility, Gold Coast www.nccarf.edu.au/publications/broadacre-farmers-adapting-changing-climate
Kingwell R (2002) Issues for Farm Management in the 21st Century: A View from the West. *Agribusiness Review* **10**, Paper 6. ISSN 1442-6951
Kingwell R (2006) Climate change in Australia: agricultural impacts and adaptation. *Australian Agribusiness Review*, Paper 1, **14**, 30. ISSN 1442-6951
Kingwell R (2011) Managing complexity in modern farming. *Australian Journal of Agricultural and Resource Economics* **55**, 12-34
Kingwell R (2019) International grain supply chains: issues and implications for Australia. *AARES Annual Conference* Melbourne Convention and Exhibition Centre
Kingwell R, Fuchsbichler A (2011) The whole-farm benefits of controlled traffic farming: An Australian appraisal. *Agricultural Systems* **104**: 513-521
Kirkegaard JA, Conyers MK, Hunt JR *et al*. (2014) Sense and nonsense in conservation agriculture: principles, pragmatism and productivity in Australian mixed farming systems. *Agriculture, Ecosystems and Environment* **187**, 133-145
Lamande M, Schjonning P (2011) Transmission of vertical stress in a real soil profile: Part II: Effect of tyres size, inflation pressure and wheel load. *Soil and Tillage Research* **114**, 71-77
Lawes RA, Kingwell RS (2012) A longitudinal examination of business performance indicators for drought-affected farms. *Agricultural Systems* **106**, 94-101
Lawes R, Renton M. (2015) Gaining insight into the risks, returns and value of perfect knowledge for crop sequences by comparing optimal sequences with those proposed by agronomists. *Crop and Pasture Science* **66**, 622-633
Lockie S (2015) Australia's agricultural future: the social and political context. Report to SAF07 – Australia's Agricultural Future Project (Australian Council of Learned Academies: Melbourne)
McBratney A, Whelan B, Ancev T, Bouma J (2005) Future directions of precision agriculture. *Precision Agriculture* **6**, 7-23

Orton T, Mallawaarachchi T, Pringle M *et al*. (2018) Quantifying the economic impact of soil constraints on Australian agriculture: A case-study of wheat. *Land Degradation and Development* (early view)
Pawel, K, Miroslaw, Z, Marek *et al*. (2018) Evaluation of the use of autonomous driving systems and identification of spatial diversity of selected soil parameters. *Applications of Electromagnetics in Modern Techniques and Medicine (PTZE)*, Racławice pp 121-124
Petersen E (2017) Economic analysis of the impacts and management of subsoil constraints. Report for the Grains Research and Development Corporation funded project: DAW00242 Subsoil constraints – understanding and management.
Pratley JE, Cornish PS (1985) Conservation farming – a crop establishment alternative or a whole farm system? *Proceedings of 3rd Australian Agronomy Conf*erence Hobart, 95-111
Pratley JE, Rowell DL (1987) From the First Fleet – Evolution of Australian Farming Systems. In (Eds. PS Cornish, JE Pratley) "Tillage – New Directions in Australian Agriculture" (Inkata Press: Melbourne)
Pratley J and Crawley N (2018) Graduate destinations in agriculture. *Agricultural Science* **29/30**, 6-15
Pritchard B, Neave M, Hickey D, Troy L (2012) Rural Land in Australia: A framework for the measurement and analysis of nationwide patterns of ownership change, aggregation and fragmentation. RIRDC Publication No. 12/038
Productivity Commission (2017) Data Availability and Use: Overview and Recommendations, Report No. 82, Canberra.
Renton M, Lawes R, Metcalf T, Robertson M (2015) Considering long-term ecological effects on future land-use options when making tactical break-crop decisions in cropping systems. *Crop and Pasture Science* **66**, 610-621
Robertson MJ, Lawes RA, Bathgate A *et al.* (2010) Determinants of the proportion of break crops on Western Australian broadacre farms. *Crop and Pasture Science* **61**, 203-213
Robertson MJ, Llewellyn RS, Mandel R *et al.* (2012) Adoption of variable rate fertiliser application in the Australian grains industry: status, issues and prospects. *Precision Agriculture* **13**, 181-199
Roper MM, Davies SL, Blackwell PS *et al*. (2015) Management options for water-repellent soils in Australian dryland agriculture. *Soil Research* **53**, 786-806
Seymour M, Kirkegaard JA, Peoples MB *et al*. (2012) Break-crop benefits to wheat in Western Australia – insights from over three decades of research. *Crop and Pasture Science* **63**, 1-16
Sheng Y, Davidson A, Fuglie K, Zhang D (2016) Input substitution, productivity performance and farm size. *Australian Journal of Agricultural and Resource Economics* **60**, 327-347
Sheng Y, Chancellor W (2018) Exploring the relationship between farm size and productivity: Evidence from the Australian grains industry. *Food Policy* doi.org/10.1016/j.foodpol.2018.03.012
Stephens D (2016) South-west Western Australia is losing its Mediterranean climate. GRDC Research Updates, Perth
Stephens D (2017) Australia's changing climate: Implications for wheat production. Guest blog for AEGIC. www.grainsinnovation.org/blog/2017/10/2/australias-changing-climate-implications-for-wheat-production
Tullberg JN, Yule DF and McGarry D (2007) Controlled traffic farming – from research to adoption in Australia. *Soil and Tillage Research* **97**, 272-281
Umbers A (2017) Farm Practices Survey Report 2016 (Grains Research & Development Corporation: Canberra)