Chapter 4

Evolution of conservation agriculture in winter rainfall areas

John Kirkegaard and Harm van Rees

Introduction

The southern Australian broad-acre agricultural region lies south of latitude 32°S with mainly winter rainfall in the south and west, grading to equi-seasonal in the northeast region extending into central NSW (Figure 1). The major point of contrast with systems to the north (Chapter 5) is that summers in the south are generally too dry and hot for reliable production of dryland summer crops, and most farms, though a diminishing number, retain livestock enterprises. As a result, the systems comprise annual winter crops either continuous, or phased with annual or perennial pastures (2-5 years) grazed by livestock. The soils in the vast majority of the zone are either naturally deficient or depleted in the major crop nutrients (P and N) (Isbell 2002), and average annual rainfall is generally low (<550 mm) and extremely variable by world standards. As a consequence, extensive agricultural production involves significant attention to the management of business risk, due to the probabilistic nature of the outcomes of most important management decisions.

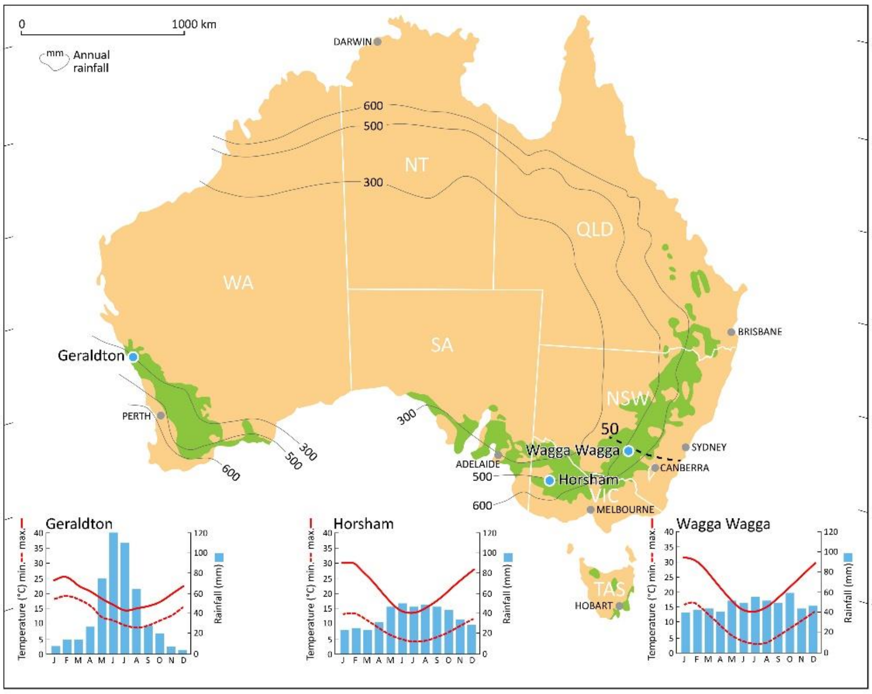

Figure 1. The distribution of broad-acre crop production in Australia (green). The southern mixed farming zones discussed in this chapter are those areas in south-eastern and Western Australia which receive 300-600 mm rainfall annually, with >50% falling during winter months (below dashed line). Patterns of rainfall and temperature are shown for three contrasting centres that represent diverse zones from which farm case studies for mixed farms and crop specialists have been prepared

The evolution of the farming system in southern Australia, from traditional mixed crop-livestock systems towards more intensive cropping, was already underway in 1987 when *Tillage – New Directions in Australia Agriculture* was published (Poole 1987). During the late 1980s the impact on the soil resource of more frequent tillage, shorter pasture and fallow periods, successive cereal crops and the expansion of cropping onto poorly structured soils was already apparent, and the impetus for the comprehensive review of crop establishment systems at the time. In the subsequent period, both the production (yield) and productivity (yield per unit input) growth in agriculture were exceptional at around 2% p.a. in the period prior to the millennium drought (2002 to 2010), which reflected both improved crop varieties and the adoption of a range of technological advances in production (Kirkegaard *et al*. 2011). The productivity gains resulted from the increased adoption of arguably the most sustainable practices since cropping had commenced, including reduced and no-till farming systems, improved weed control using herbicides, tactical and efficient application of fertiliser, adoption of broad-leaf rotation crops and better understanding and amelioration of soil constraints including soil acidity and sodicity (Kirkegaard *et al*. 2011).

The relative frequency of crops and pastures, and the rotations practised, vary greatly between regions and individual farms in southern Australia. Around 80% of the area cropped each year is sown to wheat and other cereals, but canola and a range of winter grain legumes are now common (ABARES 2018). The predominance of cereals across the cropping zone reflects their contribution to farm profits, reduced risk and ease of marketing. The choice of other broad-leaf crops to include in the crop sequence is often based on their benefits to following cereal crops (*e.g.* weed and disease control, N contribution), although they can also be profitable in their own right (Robertson *et al*. 2010, Angus *et al*. 2015). Long fallows (plant-free for 12-18 months) were traditionally used in some semi-arid areas to conserve water and N for following crops and while the area diminished with the adoption of no-till farming systems, they are now being reconsidered in areas experiencing a drying climate (Oliver *et al*. 2010, Cann *et al.* 2019). The area of perennial pastures, particularly of lucerne (*Medicago sativa*) has increased on non-alkaline soils at the expense of annual pastures such as subterranean clover (Angus *et al*. 2001), while on alkaline soils in the Mallee vetch has expanded at the expense of medic which suffered in the Millenium drought.

A strong focus in Australian broad-acre systems has been to capture, store and use rainfall as efficiently as possible to support crop growth, while managing inputs (including N) to achieve the water-limited productivity potential and quality requirements (Kirkegaard *et al*. 2014). Benchmarking production against potential to stimulate improvement has been a powerful tool at both the crop (French and Schultz 1984) and farm level (Cary 1994). Inadequate nitrogen supply remains one of the major current causes of yield gaps in southern Australian systems (Hochman *et al.* 2018) as N application can be risky in seasons with limited spring rainfall due to 'haying-off' (van Herwaarden *et al.* 1998). On average, N application rates are low (approx. 40 kg/ha N), but reliance on fertiliser N has increased as pasture area declined (Angus 2001).

The productivity of Australian broad-acre agriculture has been the subject of considerable review prompted by an apparent recent slow-down in productivity trends, and food security concerns in the face of climate change (Fischer 2009, Hochman *et al*. 2009, Keating and Carberry 2010, Robertson *et al*. 2016). The recent slowdown in productivity has been variously blamed on drought (Hochman *et al*. 2017), reduced research investment and decreasing impact of new technologies (Mullen 2010) but the maintenance of production in the face of a climate induced reduction in yield potential of 27% in the period 1990 to 2015 suggests significant uptake of new technologies on-farm continues (Hochman *et al*. 2018). The success of agriculture in the southern Australian cropping zone has not come without the emergence of environmental problems such as soil acidification, dryland salinity, compaction and herbicide resistance in weeds (Kirkegaard *et al*. 2011). Addressing these issues, while maintaining crop yields, is crucial for the future.

Numerous previous reviews and subsequent chapters in this book deal in detail with the various technological innovations that have underpinned the evolution of southern farming systems during the last 30 years, and the economic, environmental and social changes that influenced their adoption. As a consequence, following a brief summary of the science and innovation underpinning those changes, a large part of this chapter is devoted to case studies on commercial farms across three diverse regions of southern Australia (Figure 1). Using crop intensification as a theme, we contrast farms in three zones that have either retained mixed crop-livestock enterprises or moved to crop-only operations to capture a brief, but important record of systems evolution at the farm level.

Science underpinning change – lessons from long-term studies

Prior to 1987 when *Tillage* was published, a convergence of enabling factors in the 1970s formed the potential for the revolution foreseen by agronomists in that publication. These were:

- Government and public focus on improved natural resource management stimulated by reports and evidence of land degradation (*e.g*. dust storms in Melbourne in 1983);
- Economic drivers related to the diminishing terms of trade with the imperative to reduce fuel and other input usage; and
- Key enabling technologies (already the subject of considerable review in 1987) including herbicides for weed control, machinery developments to enable crop establishment with less tillage and retained stubble, and profitable broad-leaf break crops.

In his review of tillage practices for winter rainfall areas in that book, Poole (1987) wisely noted that "*….Even the most promising innovations will bring attendant problems which will require solution by science if the new systems are to be embraced by farmers"*

Building on this demonstrably accurate prophecy, and as background to the farm case studies from southern Australia later in this Chapter, we briefly consider the evolution of the three pillars of CA in southern Australia – reduced tillage, retained crop residues, and diverse rotations. These elements are intimately linked and interactive in farming systems, but for ease of discussion, we briefly consider developments in each separately.

Tillage

Comprehensive reviews of the evolution of reduced tillage systems in Australia can be found elsewhere (Llewellyn *et al*. 2012, see also Chapter 2). The general trend initially was towards a reduced number of cultivations prior to seeding, reduced soil disturbance with each pass, and ultimately to one pass at seeding (direct-drilling DD), and finally reduced soil disturbance using no-till (NT, tynes) or zero-till (ZT, discs) during the seeding process itself (Umbers 2017). The evolution of machinery technology and herbicide to facilitate the transition is discussed in Chapter 6 and 10 respectively. The economic benefits in reduced fuel, time, machinery wear and labour were obvious, as were the reductions in the risk of soil erosion and improved water conservation, but reliable crop establishment and the maintenance of yield were clearly desirable.

The significant benefits in crop yield potential of the earlier-sown, direct-drilled crops we acknowledge today were often not expressed in long-term agronomic experiments (Kirkegaard 1995). This was partly due to the common sowing dates used for all treatments in the experiments, especially where crop establishment in direct-drilled treatments matched those in cultivated treatments. In drier environments, or on structurally unstable and degraded soils, improvements in soil structure and water conservation may have translated into yield benefits, but benefits from RT or NT treatments in long-term experiments were rare in southern Australia up to the mid-1990s. Kirkegaard (1995) reviewed all of the data from 33 medium and long-term experiments in Australia (26 in southern Australia) and found the yield benefit of DD *vs* RT wheat across all regions ranged from -0.18 to +0.06 t/ha. Subsequent (Heenan *et al*. 2004) and more recently published long-term experiments (Armstrong *et al*. 2019) confirmed the small or even negative impacts of RT or NT treatments where common sowing dates were used. While the undisputed environmental, economic and timeliness benefits underpinned farm adoption (Llewellyn *et al*. 2012), it remained puzzling to many soil and plant scientists why improvements in most of the 'soil health' indicators demonstrated in RT and NT treatments (*e.g*. aggregate stability, earthworms, macro-porosity, microbial biomass) did not translate to improved yield (Watt *et al.* 2006, Kirkegaard *et al.* 2014).

Poor early crop vigour had always been a common feature under NT with complex interactive soil physical and biological interactions involved (Simpfendorfer *et al*. 2002), though much of that could be offset in practice by the earlier sowing opportunity. Interactions with the other components of the CA system (stubble retention and crop sequence) under different soils and climates also complicated attribution of effects to tillage alone (Flower *et al*. 2017). Kirkegaard and Hunt (2010) used simulation modelling to demonstrate the importance of the synergy between different agronomic innovations within the cropping system. For the Mallee farm considered, NT (not cultivating the soil and retaining stubble) generated only a small predicted average yield improvement if adopted alone (from 1.6 to 1.8 t/ha), but contributed to a large yield improvement (from 1.6 to 4.2 t/ha) as part of a package of synergistic innovations including improved rotation, summer fallow weed control and earlier sowing. The focus on 'non-disturbance' in NT systems often overlooked these true drivers of the yield benefits, but the cost savings and soil protection without yield penalty was a powerful driver for adoption (Llewellyn *et al*. 2012). Recently machinery costs have been scrutinised as a significant financial burden in risky environments (O'Callaghan 2014), and stepwise adoption and upgrading is a feature of many successful farms (see Case Studies below).

Increasingly dry autumns and the trend towards earlier sowing in recent years (Chapter 18) has provided new incentive for systems that can maintain surface soil water to capture early sowing opportunities (*e.g*. high stubble retention with disc seeding). At the same time, some strategic tillage may be required to deal with emerging issues such as herbicide resistant weeds, nutrient and pH stratification and compaction (Chapter 7). Adoption rates for 'one pass' tillage (ZT, NT and DD) between 2008 and 2016 have remained stable at 80 to 90% of cropped area (Umbers 2017) suggesting Australian tillage systems have matured towards pragmatic approaches tailored to specific conditions (Table 1).

Table 1. Evolution of the three current principles of conservation agriculture practice and suggested further principles (italics) needed to support sustainable intensification (from Giller *et al*. 2015)

CA principles (and related practices)	**Past (protective)**			**Present (prescriptive)**	**Future (pragmatic)**
1.Less tillage	multiple pass inversion deep	reduced pass less inversion	one pass (tine)	zero till (no disturbance)	strategic tillage
2.Retain residues	remove all early burn	later removal later burn	partial retention	full retention	managed thresholds
3. Rotation	monocultures	fallows	rotations	rotation	flexible sequences
Nutrient balance	*Exploitative Supplemental*			*None prescribed*	*Replacement*
Pest management	*Cultural Chemical*			*None prescribed*	*Integrated*

Stubble retention

The value of retaining crop residues to reduce wind and water erosion has been recognised in southern Australia since the 1920s, but by the late 1980s when *Tillage* was published, widespread adoption of stubble retention had barely commenced (Felton *et al*. 1987). The fundamental principles of water conservation were well advanced, yet the costs of stubble retention clearly outweighed the benefits at that stage, and research focused on managing crop residues to capture the benefits, while minimising constraints. The range of potential constraints in stubble-retained systems then included crop establishment, crop nutrition, and pest, weed and disease control and this has remained remarkably consistent over the subsequent 30 years (Scott *et al*. 2010, 2013). A recent 5 year research investment by the GRDC (2014-2018) to maintain profitability in stubble retained systems focused on many of the same issues, though significant improvement is clear given adoption rates of retained stubble through to planting are 60% nationally, and early stubble burning is now less than 4% of cropped area (Umbers

2017). A comprehensive account of the pathways to improved residue management is provided in Chapter 13, but a brief summary for southern Australia is provided here.

Steady improvements in machinery design, much of it involving innovative farmers, was critical to achieve adequate crop establishment in retained crop residues. These have included moving tyne ranks further apart, widening sowing rows, increasing break-out pressure, attaching clearing mechanisms to brush stubble aside, or moving to disc openers able to cut through heavier stubble. Matching harvest and post-harvest residue management to the seeding equipment available includes considerations of harvest height, and the level of residue spreading. In modern systems, harvest weed seed control (HWSC) for weed control often concentrates residues into rows for burning or onto wheel tracks for targeted spraying. The advent of satellite guidance and controlled traffic farming has facilitated inter-row sowing and further opportunities to establish crops in retained stubble.

Crop residues are invariably retained throughout most of the fire-prone summer in southern Australia as permits are required to burn, and they may be grazed on mixed farms to capitalise on spilt grain and new straw. A retained threshold of 2 to 3 t/ha minimises erosion and maximises water infiltration, while 4 to 5 t/ha of residue generally causes few problems for most current seeding equipment. Advances in post-harvest stubble management, new seeding technology and inter-row sowing have reduced the need for residue reduction, though circumstances invariably arise where pragmatic decisions to reduce weed, pest or disease-infested stubble loads make sense. Diversifying crops and practices provides the platform for success, and being flexible and pro-active to ensure stubble does not compromise timely and successful crop establishment is critical. Maintaining crop residues under continuous cropping is important as they are the major source of C input, though predicted increases in C-sequestration appear overstated (see Chapter 16). Maintaining more residue for longer near the surface in early autumn has become a focus for many farmers to capitalise on earlier and timely sowing, though dry sowing by calendar which can be problematic for weed control, is now also widespread in southern Australia (Chapter 18).

Crop diversity

Until the 1980s, southern Australia grew mainly cereals (mostly wheat, with some barley) in rotation with annual grass-legume pastures and fallow, with some areas of early-sown oats for sheep (Figure 2). In the two decades from the mid-1980s, crop area doubled (at the expense of pasture and fallow) and sheep numbers halved, and many farms or parts of farms are now continuously cropped (Kirkegaard *et al*. 2011). The degree of intensification and the main drivers (*e.g*. financial, social, logistic, bio-physical) vary between regions and with individual businesses (see Case Studies). The intensification of cropping was facilitated in part by the introduction in the 1960s and 70s of a range of legume and oilseed break crops, most notably lupins in Western Australia (Seymour *et al*. 2012), and canola across southern Australia in the 1990s (Kirkegaard *et al*. 2016). Lupins expanded in the 1980s to reach 1.2M ha prior to declining to 0.5 M ha in recent years, while canola is now the most widely grown break crop occupying 2.5 M ha in 2018 (Figure 2). The areas of other main pulse crops in southern Australia such as lentils, fababean and field pea are generally smaller (around 230,000 each in 2017) with smaller areas of chickpea (see Chapter 19). These are often soil-type dependant, but can be significant in specific regions; lentils, for example, are concentrated in the Wimmera of Victoria and York Peninsula of South Australia. The development of these crops all relied on publicly-funded R&D programs (Maatz *et al*. 2018), which still support most pulse development, while canola breeding is now largely privatised.

The area of broad-leaf break crops can suffer from significant variation from year to year as a result of unfavourable seasons (*i.e.* considered less resilient), market and price fluctuations and disease epidemics (*e.g.* blackleg in canola and Ascochyta in chickpea). The area of lupins peaked in 1999 and has declined significantly since, mainly due to low prices and cost of herbicide resistant grass weed control. In contrast, canola recovered from a halving of cropped area in the millennium drought to reach a current area of around 2.5 M ha. During the prolonged millennium drought (2002-2010), cereals intensified in some areas to occupy more than 95% of cropped area in southern Australia (Figure 2).

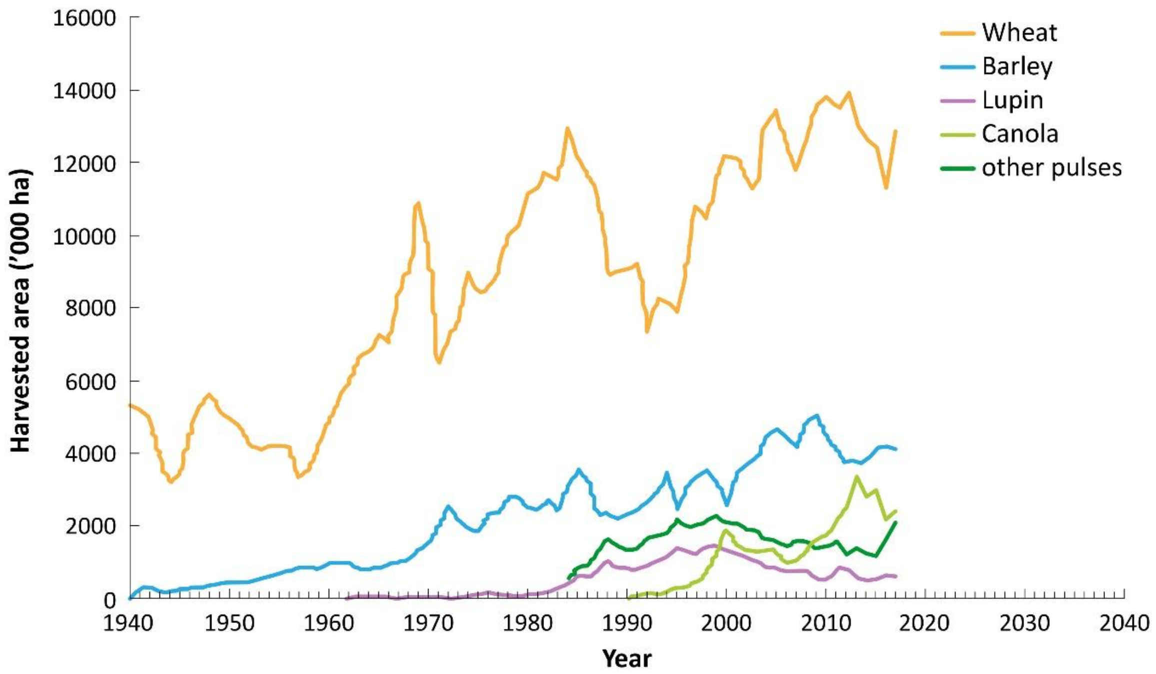

Figure 2. Area of different crops in Australia showing increasing area and diversity of broad-leaf break crops since the 1980s and the significant variability in the area of different break crops during the last 30 years.

Although the break-crop value of broad-leaf legume and oilseed crops to the yield of subsequent wheat crops is recognised (Angus *et al.* 2015), the riskiness of break crops themselves has been a deterrent to adoption. But as closer to average seasonal rainfall returned after 2010, industry-wide initiatives (*e.g.* GRDC Crop Sequencing Initiative, 2011-2016) clearly demonstrated their value to manage grass weeds, nitrogen supply and disease. Including break crops in a 3 to 4 year crop sequence was as profitable, or more profitable, than continuous cereal rotations in most cases (McBeath *et al.* 2015) (www.farmlink.com.au/project/crop-sequencing). A wider range of better adapted and herbicide tolerant canola and pulse varieties (*e.g*. for grain, grazing, hay, brown manure) are now available. On average, across southern Australia from 2011 to 2016, around 30% of cereals were planted after canola, pulses or pasture legumes although this ranged from 40 to 50% in southern NSW, mid-north of southern Australia and WA Sandplain/Mallee, but as low as 17% in central NSW (Umbers 2017).

This brief background of the evolution of the key components of conservation farming systems, provides a backdrop to case studies of that evolution on commercial farms across southern Australia. Strategies to harmonise farm performance, maximise sustainable profit and ease of management are influenced by each farmer's economic, family and risk positions. The interplay of those factors has influenced whether farms have moved towards continuous cropping or retained a significant livestock enterprise. We chart the evolution of two commercial farms in each of three diverse regions of southern Australia (Figure 1) since 1990 to exemplify the way in which technological and socio-economic factors have influenced the farm business.

Farm case studies in three zones of southern Australia

Southern NSW – mixed farmers

Bernard (left) and Rob Hart (Hart Brothers)

- *Location:* Junee Reefs
  50 km north of Wagga Wagga, NSW
- *Mean annual rainfall:*
  525 mm, equi-seasonal
- *Soils:*
  Red Kandosols, pH 4.2-4.8 ($CaCl_2$),
  C 0.85%, N 0.09%

Enterprise description in 1990 The farm comprised 1,000 ha, with a 50:50 crop:livestock ratio. The business was managed by two brothers – Bernard (crop specialist) and Adrian (livestock). Major crops were wheat (4.0-4.5 t/ha), canola (1.8-2.0 t/ha) with smaller areas of lupin and field pea. Medium wool was produced from a self-replacing merino sheep flock. Lucerne-clover pastures were under-sown to wheat or canola in the last year of the crop phase and removed using herbicides in the spring prior to cropping. Pastures were rotationally grazing on a 4-field system supporting 15-20 DSE/ha with hay and silage produced in spring when feasible. Sequence was generally 3 years pasture, 3 years crop.

Major changes since 1990 Farm size increased by purchase and lease from 1000 ha in 1990 to 1900 ha 1996, to 2300 ha in 2006, and to 3800 ha in 2016. The partnership between the brothers was dissolved to allow succession with Bernard's son Rob becoming a partner. Leased blocks formed two compact operations in districts 50 km apart; most leased land is suitable for continuous cropping. The business now has an advisory board, and each enterprise is examined critically each year.

Livestock A move to two flocks (self-replacing merino flock and cross-bred flock for prime lamb production) during 1990-2000 was reversed due to low profit, the cross breed flock dispersed and the merino ewes joined to terminal rams for prime lamb production. Chicory was added to the lucerne-clover pasture mix in the early 2000s to help control 'red gut' in lambs. Lucerne survived the droughts during 2000-2009 but clover consistently failed and after 2003, pastures were established in late autumn without a cover crop. In 1998, falling livestock gross margins prompted a move to 80:20 until 2002, when drought increased cropping costs and improved livestock return and the ratio returned to 65:35 by 2008. The most profitable system (from 1992 to 2002) involved pasture spring growth either grazed or sprayed out prior to cropping or cut for silage or hay. This gave excellent long-term weed control (over 3 years) and residual N benefits from lucerne to the crops. In 2008 drought had reduced stock numbers to 1100 (wool only), and all sheep were sold (low profits, reduced family labour availability, and need for cash flow). Livestock returned to the business in 2012 with improved seasonal conditions, and opportunities presented by dual-purpose crops (especially winter canola), initially using agistment. It is currently a 3,000 breeding ewe and trading operation for meat and wool production. One property currently has 600 ha exclusively using summer (millet, sorghum, winter canola) and winter (winter canola, oats, rye corn, triticale, vetch, radish, turnip) forage mixes for livestock production, with lucerne-based pastures retained in frost prone areas.

Cropping Crop performance was benchmarked using the WUE (French and Schultz 1984) and between 1998 and 2005 for wheat averaged 17 kg/ha/mm (range 10-23) compared with the benchmark of 20 kg grain/ha/mm. In 2008 following the sale of the livestock, fences were removed to improve labour efficiency in cropping. In the period from 2008 to 2012, the operation was 100% cropping and Rob also grew the seed business. The cropping enterprise was 50:50 (break-crop:cereal) with around 50% wheat and barley, 35% canola, 15% legumes (field pea, lupin). Canola was not sown in dry years.

The tyne seeding system remained, but rows were widened from 22 to 32 cm with press wheels, and no nitrogen was added at sowing. Guidance and inter-row sowing were introduced with the aim of full stubble retention and crops were sown earlier (including dry sowing). In 2012 to 2014 work by local consultants on crop weed competition prompted a move back to 25 cm rows with a dual tyne parallelogram providing precision placement, urea upfront for extra yield and weed suppression.

The area of barley slowly increased with new varieties performing well in tough years (*e.g*. Hindmarsh, Latrobe, Spartacus and Planet). More crop monitoring was introduced, harvest weed seed control using windrow burning, and glyphosate spray-topped over canola gave excellent weed control.

Lentils were introduced in 2014 following on-farm research from 2012, and these replaced some of the field peas providing 2.8 t/ha yields @ $700/t in 2016. Clearfield® lentils (resistant to imizalidinone herbicides) also fitted well with Clearfield wheat, barley and canola all available.

In 2017, a disc seeder was introduced on 16cm rows: it enabled faster sowing, maintained groundcover, managed stubble and rocks and saved the $20-30K cost of stubble burning. The farm is not yet fully controlled traffic as three base stations would be needed for full coverage with current cost prohibitive.

Future plans There is a current focus on soils and soil fertility, maintenance of soil cover, and understanding and overcoming subsoil constraints at depths below 40 cm. The new summer and winter forage options are opening the way to increase the potential livestock numbers to 5000 ewes (season and feed dependant) and perhaps reduce the cropped area by 500 ha. The strategy will be 'don't breed to keep, breed to sell' (*i.e*. from "mum to market"). The advisory board and the managers will maintain a focus on a business approach, on succession, and as in the past, adjust the business mix accordingly with a close eye on the latest research to continue adaptation.

Southern NSW – specialist croppers

Warwick and Di Holding

- *Location:* Yerong Creek
  40 km south of Wagga Wagga, NSW
- *Mean annual rainfall:*
  525 mm, equi-seasonal
- *Soils:*
  Red Chromosols and Sodosols,
  pH 4.4-4.9, total C 1.3 to 1.9%

Enterprise description in 1990 The 300 ha family farm was 100% arable with a 60:40 crop:livestock ratio. The main crops were wheat, lupin, canola, triticale. First-cross ewes for prime lambs were grazed on subterranean clover-annual ryegrass or lucerne-clover pastures, and there was a 40-sow piggery. The farm business was managed by Warwick's father, but was too small to support the next generation. Warwick earned off-farm income contract spraying and haymaking and leasing land to run sheep.

Major changes since 1990 Warwick and Di began a program of expansion through land purchase, leasing and share farming from 1995. By 2009, they were farming (wheat, canola and faba-bean) on 325 ha of their own land, 965 ha leased, 320 ha share-farmed, 1100 ha contract farming, all using controlled traffic. By 2018, with ongoing improvements to equipment and agronomy, the total area under management was 3,000 ha, all sown with a disc-seeder using CTF. The change from mixed cropping to continuous cropping was made due to concerns about surface soil damage by sheep, a personal preference for crops and the compromises in operational management and timing with livestock. The transition towards profitable and sustainable continuous cropping is described below.

Initial expansion of farming area and change to 100% cropping (1995-2002) Farming area was expanded with lease and share farming and a 40 ha 'home block' was purchased in 1997. All sheep were sold in 1998. Second hand machinery was purchased over this period to enable the expansion of the cropping program (wheat, oats, triticale, lupins and some canola).

Advances towards conservation farming (2002-2003) The total cropped area of 1,100 ha included more canola, and increased application of lime and gypsum. Crop failure in the 2002 drought prompted a change to soil management that conserved soil moisture. A new air-seeder with narrow points on 22 cm spacing was purchased: a prickle-chain allowed for 'up and back' seeding using global positioning system (GPS) guidance. Cutting and baling stubble reduced burning, and crop choice was based on disease and weed control with 2-3 year forward planning.

Precision farming (2004-2006) In 2004, Di and Warwick purchased a harvester with yield mapping capabilities and ±10 cm GPS autosteer which took control of harvest operations and began yield and elevation mapping. Concerns about soil compaction reinforced at a CTF conference provided the impetus for further modifications. In 2006, they adopted 12 m CTF on permanent wheel tracks with wheel centres spaced 3 m apart and ±2 cm autosteer for all operations. The sowing tyne spacing was widened from 22 to 30 cm and individual press wheels were added. They moved to block farming with each leased farm under the same crop for logistics, disease control and ease of management.

Continued 'fine tuning' of previous developments, with diversification (2007-2009) By 2007, sulphonyl urea herbicides were no longer used on cereals because of their carryover effect on canola. Stubble burning was confined to tactical weed control. Inter-row planting was introduced for cereals following cereals to reduce root disease. In 2008 they purchased 220 ha that was previously share-farmed. By 2009 they were farming 2600 ha all on controlled traffic.

Recovery from drought and floods (2010-2014) The long-term goal to buy more land was delayed by four years of drought (2006-09) and spring floods in 2010. Rising input costs were of greater concern than climate change which they believed they could adapt to. During this period, they were re-grouping financially. Drought had pushed the system to lower-risk continuous wheat, and pulses had dropped out. They slowly resumed their goal of sound rotations, with no wheat following wheat, and target crop proportions of pulses 25%, canola 25% and wheat 50%. This was achieved in 2017.

Improving weed control and timeliness of operations (2015-2017) Managing herbicide resistant weeds required numerous innovations during this period. The windrower changed from 9 m to 12 m with a sprayer added below the cutter bar for weed control at windrowing targeting seed set.

Windrow burning was adopted first by dropping the spreaders and then using a narrow chute – excellent on weeds, but hard to control the burns. A small self-propelled sprayer with high clearance dedicated to the break-crops was purchased in 2014 to improve the timeliness and logistics of spraying, especially fungicides and insecticides (*e.g.* sclerotinia/aphids in canola, heliothis in lupins).

In 2016, they commenced chaff lining (after tour of WA), and chaff-line sprayers were developed for use in the fallow (with non-selective herbicides) and in-crop (with selective herbicides – Warwick calls this 'weed-lining'). A second-hand disc-seeder was purchased in 2016 to improve crop establishment under marginal conditions enabling reliable sowing by the calendar (which has been practised since 2010), and all crops were sown with the disc seeder in 2018. The combination of stubble retention, reduced soil disturbance and lack of livestock provides more frequent opportunities for good early establishment of crops, as evident in the dry autumns of 2017 and 2018.

Novel approaches to maintain diversity, weed control and improve soil biology (2018 and beyond) Wide-row lupins (57 cm) were trialled to maintain/improve yield with an open canopy to enable shielded inter-row application of herbicides for control of late germinating broadleaves (prickly lettuce, sow thistle) and grasses (ryegrass, wild oats).

Companion cropping involving early sowing broadleaf species grown in normal wheat rows with winter wheat on wide-rows and the companion crop (broadleaves) sprayed out during spring. The aim is to stimulate soil biology, reduce monoculture, improve the productivity of challenging shallow soils, and perhaps allow a second wheat crop in the sequence. Numerous on-farm trials are conducted using yield maps in paddock replicated strip tests to fine-tune new ideas.

Future plans Di and Warwick see that the future will focus on improving the soil, especially sub-surface acidity. Overcoming high subsoil density and balancing micro-nutrients are ongoing challenges. They believe crop and soil management is where major gains can be made, rather than relying on new genetics.

Northern Victoria – mixed farmers

John Ferrier and family

- *Location:* Birchip, NW Victoria
- *Mean annual rainfall:* 350 mm
- *Soils:*
  15% Birchip plains medium to heavy sodic clays;
  25% sandy loams over clay;
  65% shallow sandy clay loam over sodic clay;
  pH 8-9, total C 1.0-1.3%

Enterprise description in 1990 John and Robyn Ferrier and John's brother Peter and wife Sue farmed in partnership on an area of 2500 ha**,** with a 70:30% crop to livestock ratio over the whole farm area. The main crops sown were wheat, barley and field peas and long fallowing was still practised.

Self-sown medic was the main pasture, which at times was contract harvested and sown in paddocks low in medic, and the most common rotations were medic-medic-long fallow-wheat-barley (Birchip plains); medic-medic-long fallow-wheat-barley-field peas-wheat (sandy clay loams and sandy loams).

Stubbles were heavily grazed after harvest, paddocks were sprayed with glyphosate and cultivated several times prior to sowing (less cultivation on the sodic Birchip plains due to hard-setting).

Prior to sowing, trifluralin was applied and harrowed for incorporation, leaving the soil vulnerable and exposed to wind erosion. High protein wheat was often delivered at that time.

Changes in the farm operation In the late 1990s, John and Peter started to experiment with no-till and stubble retention and made their own direct drilling points. They were also members of Farm Management 500, a farm discussion group focused on financial management, led by private consultants. John was also an inaugural board member of the Birchip Cropping Group (BCG) established in 1993. Cropping information was obtained through discussion with a private agronomist who visited the farm 5 or 6 times annually, and crop yields were routinely benchmarked using WUE principles.

Changes to the farm business structure and operations Peter and Sue left the farm after the Millennium drought (2010) and John and Robyn have since increased the size of the farm to 5,300 ha.

John now farms with his son David and daughter-in-law De-Anne. The farm no longer employs an agronomist. However De-Anne has an agronomy background and together with skills of other family members and abilities to seek advice, they make their agronomy decisions ‘in-house’. Farm operations are carried out with two harvesters, one 18 m no-till seeder, a chaser bin, a mother bin, a self- propelled spray unit and 2 trucks. The farm also has 4000 t of on-farm storage.

Decisions to sell grain are based on decile pricing of the various commodities in October/November. For example, in 2017 chickpeas were priced at decile 10 and were all sold off the header whereas lentils were priced at decile 3 and stored on farm until at least a decile 5 price is reached.

Cropping Land is no longer long-fallowed or cultivated – all stubbles are retained and crops are planted with a no-till parallelogram seeder with precision seed placement on 30 cm row spacing. The seeder has three seed and fertiliser compartments enabling P and N rates to be blended whilst seeding.

The main crops grown are wheat, barley, canola, lentils, chickpeas and vetch (for grazing or hay). Medic in pastures did not survive the Millennium drought and is no longer planted (increased herbicide use also contributed to the demise of medic). Because there is now less medic N in the rotation, wheat protein has declined even though urea is now regularly used on cereals and canola.

The Millennium drought was a very difficult period on the farm with little or no grain produced in 2002, 2004, 2006 and 2008: 2016 was an excellent year with good rainfall and high prices, N fertiliser was applied twice during the season and the average wheat yield was 4.5 t/ha.

Crop computer simulations using APSIM was first used in 2001, in a Birchip Cropping Group (BCG) situation, and is now regularly used through ‘Yield Prophet‘ to make in-crop N decisions. Cereal and canola paddocks are deep soil tested for available soil water and mineral N content prior to sowing. Yield maps and NDVI are used to identify low and high yielding zones in the paddocks to use variable fertiliser application in the future.

Weed seeking technology is being investigated, especially for summer weed spraying.

Livestock The farm now runs a reduced sheep flock (80:20 livestock to crop ratio) consisting of 1500 breeding ewes (self-replacing Dohne flock, a South African meat merino). Depending on seasonal conditions John and David also trade lambs which are grazed on stubbles. After backgrounding with cereal grain (mainly oats) in the paddock, the lambs are fattened in a feedlot. Lambing is in June which is often a tight period for sheep feed (controlling weeds with herbicides inevitably leads to reduced stock feed), and vetch hay produced on the farm is used when feed is tight. A strict policy of 70% ground cover of stubble is maintained to reduce the risk of wind erosion.

Future plans John and his family are currently happy with the scale of the farm, the family operation, skill mix and machinery ownership. John regularly updates the farm’s financial position and is involved with benchmarking services provided by AgProfit™. John highly values his membership to organisations such as FM500 and BCG, primarily because of the contact with scientists from CSIRO, Department of Agriculture and private agronomists. John looks forward to sowing long coleoptile wheats currently being trialled by wheat breeders from CSIRO to improve germination and early growth in heavy stubbles. He hopes to pass on the responsibilities of actively maintaining and updating the financials to his son and daughter-in-law in the near future.

Victorian Mallee – specialist croppers

Roy and Joan Postlethwaite

- *Location:*
  South of Charlton, NW Victoria
- *Mean annual rainfall:*
  420 mm
- *Soils:*
  70% red brown earths (duplex);
  30% black self-mulching soils (vertosols)

Enterprise description in the early 1980s The farm comprised 800 ha and had been a traditional wheat-sheep enterprise, using cultivation to control weeds, and fallowing to conserve soil moisture.

In the late 1970s Roy experimented with a continuous cropping program on one paddock to see if he could use cropping rotations to improve soil fertility. The continual use of cultivation soon ruined the soil structure and by the 1982 drought (annual rainfall, 123 mm) it was obviously not going to work. Roy attended a local farmer meeting where direct-drilling in Canada was discussed. This, together with the dust storms in 1982/83, was the trigger to rethink the operation of the enterprise. Following the drought, livestock were sold, direct drilling with stubble retention commenced and gypsum was applied to the red soils. The original farm has now been continuously cropped using no-till for over 35 years.

Developments in the cropping enterprise No-till farming has evolved over the last 3 decades, with continuous adaptation of machinery and practices as conditions changed. The current 2100 ha operation is continuously cropped on red-soils with wheat, barley, canola, lupins and vetch/oaten hay; and wheat, barley, canola and pulse crops on the black soils. The crops are sown on 30 cm spacing with tine openers with press wheels, a triple bin seeder allows urea to be placed underneath the seed at sowing. Urea is also spread in-season dependent on soil moisture and the seasonal outlook. Sowing operations start in early April, dry if it has not rained, with vetch and oats for hay, followed by canola, cereals and other pulse crops. GPS guidance is used for all operations, but controlled traffic is not practised because it leaves paddocks too rough for hay machinery. Roy prefers to sow at a slight angle to the previous year to reduce problems with stubble residues.

Challenges to the continuous cropping system On red soils the main problem is herbicide resistant ryegrass which was first recognised as a serious problem on the farm in the 1990s with full resistance to the Group A (fops and dims) herbicides. BCG had large scale herbicide resistance trials on the farm in 1998 and confirmed ryegrass resistance to fop and dim (Group A), glyphosate (Group M) and trifluralin (Group D) herbicides. A field day attended by over 400 farmers demonstrated the benefits of the double knockdown approach to ryegrass control (glyphosate followed by paraquat a few days later). Resistant ryegrass is now successfully managed through the incorporation of hay in the rotation. The farm has storage for 5000 bales of hay, which is sold into the export market and the dairy industry. The current rotation on red soils is 2 years of oaten or vetch hay, followed by canola, wheat and lastly barley. However, the rotation is flexible and lupins are also grown if there is too much hay. Ryegrass is not such a problem on black soils, but some of the black soil paddocks do have banks of red soil and resistant ryegrass is slowly establishing. The rotation on black soils is chickpeas, followed by canola, wheat and then barley. Lentils have occasionally been sown but are not preferred because of difficulties with harvest. Oaten hay is now also starting to be grown on the black soils. Roy has kept paddock records since 1965 and uses these to make decisions in operations, fertiliser applications, and rotating herbicide group mode of action.

The farm employs an agronomist for advice on fertiliser and herbicide decisions. Two labourers (friends) work on the farm on a casual basis during the seeding and harvest seasons.

Future plans. Roy and Joan are in their early 70s and all operations are still done by Roy with Joan helping during hay making. Farming is in their blood and they love the lifestyle, work and challenges. They have strong feelings about good land stewardship and though Roy has a huge workload they would buy more land at the right price and location. Currently the succession plan does not involve children coming home to farm.

Western Australian Northern Sandplains – mixed farmer

John Scotney

- *Location:*
  Badgingarra, WA
- *Mean annual rainfall:*
  550 mm, winter dominant
- *Soils:*
  Gravel 50%; sand over gravel 35%;
  Yellow sandplain 10%; heavy clay 5%

Enterprise description in 1992 The original farm was 1200 ha with a 40:60 crop: livestock ratio. The cropping phase was a wheat-lupin rotation, managed using minimum tillage with one full cut pass at sowing. Wheat and lupin yield generally averaged 2-3 t/ha. The livestock operation was run on sub clover-based pastures with a sheep trading operation for meat, and a merino-based breeding component with a total flock size of 8000.

Major changes since 1992 The farm size has grown to 4,400 ha with new purchases and is currently 75:25 crop: livestock operation. The major crop sequence is canola-wheat-barley phased with two-year subterranean clover-based pasture. The initial challenges through the 1990s were water-logging in the cropping phase especially in lupins on some unsuitable (water-log prone) soils, causing bare patches with subsequent wind erosion. Leaf (septoria) and root diseases were also a problem in the cereal phase primarily due to grassy weeds in the pastures acting as hosts.

No-till farming, canola and fungicides (1992-2002) The development and adoption of no-till farming (John Ryan's DBS) and the introduction of triazine-tolerant (TT) canola in 1995, together with the adoption of an effective fungicide regime to control root and leaf diseases, all led to an increase in yields through the 1990s. Septoria was a particular constraint which was initially addressed with foliar fungicides, but seed and fertiliser treatments are now used in conjunction with foliar applications to manage fungal disease. Lupins were dropped from the rotation in the mid-1990s and replaced with TT canola primarily for improved grass weed and radish control and increased profit. During the period in the late 1990s, productivity and profitability increased, with typically 3-4 t/ha cereal yield and 2 t/ha canola yield. Improved water use efficiency in dry and average years often fell away in wetter years.

Crop expansion in the drought (2002-2010) After 2002, rainfall declined, especially the early autumn rains, and the decline was around 100 mm in annual rainfall from 550 to 450 mm. This meant cropping was more profitable and certainly less stressful than livestock, especially in the very dry years of 2006/2007. The farm area expanded with new purchases during this period in 1998 (4,860 ha), 2002 (608 ha) and 2006 (932 ha).

Addressing soil constraints During the 2000s various soil constraints emerged on the no-till cropping country and over time have been addressed. Since the early 2000s non-wetting soils emerged as an increasing challenge initially on sandy soils but progressing to gravel soils and have been managed using several techniques including claying, spading, deep ploughing and delving and incorporation of clay. In collaboration with the West Midland Grower Group and DPIRD scientists (Dr Steve Davies) they have evaluated and adopted the most effective amelioration techniques for each soil type. Soil acidification has been addressed through application and incorporation of lime sand through this period.

Subsoil compaction also emerged and is being addressed by ripping and controlled traffic. This in turn caused erosion issues due to water harvesting into wheel tracks and a disturbed subsoil. Yield responses to soil improvements have been around 20% but vary significantly with seasonal conditions. Crop agronomy has changed, particularly with the more aggressive techniques *i.e*. mouldboard ploughing. In 2016, land area was 1200 ha. Stock numbers expanded in line with land purchases at a 70:30 ratio but stock numbers have not expanded with the latest land purchase increasing the cropping area.

Livestock enterprise changes Livestock numbers have remained fairly consistent across the years though John did experiment with higher stocking rates in 2004/2005, but the dry years of 2006/2007 caused a return to previous levels. The flock shifted from a merino based flock to a Dohne based flock with a late spring lambing, driven by higher prime lamb prices and the relatively poor wool prices through this period. This may change again to a more wool focussed breeding base if the current (2018) high wool prices are sustained. A purchase of 1215 ha in 2016 was for crop only, and the farm is currently running 70:30 crop: livestock ratio.

Future plans John is likely to be expanding the area of controlled traffic farming especially on ameliorated soils to preserve the soil benefits and will be investigating more specific VRT using new satellite and imaging techniques. He will also be continuing his experimentation with new, more productive pasture species which he sees as a driver of the system. He has experimented with biserulla, serradella, newer subterranean clovers, Tedera, and is especially seeking hard-seeded varieties that can be grazed heavily in the pasture phase and persist through the cropping phase.

Western Australian Northern Sandplains – specialist cropper

Brian and Tracey McAlpine

- *Location:*
  20 km west of Maya, WA
- *Mean annual rainfall:*
  340 mm, winter dominant
- *Soils:*
  Yellow tamma-tussock sandplain (OM 0.2%);
  Pockets of gravel, red clay, salmon gum loam

Enterprise description in 1990 The McAlpines farmed 4,000 arable ha with 70:30 crop: livestock ratio. Wheat was the main crop (50% of farm area with average yields of 1.4 t/ha) with an increasing use of lupins (20%) in a very profitable wheat-lupin rotation. Crops were spread evenly around the farm for sheep grazing of stubble in summer. Sheep were run for wool and meat production on poor pastures made up of capeweed, annual ryegrass and wild radish (DSE<1/ha).

Major changes since 1990 Wheat production methods changed from cultivation to no-till by 1993 but this led to increased weeds. These were managed by intensive cropping with lupins and then triazine-tolerant (TT) canola. An interest in long-term soil health also encouraged a move to continuous cropping due to structural damage caused to the soil by livestock, and the potential to increase soil organic matter under continuous crop, no-till farming. In 1997, a gross margin analysis of paddock returns revealed low return for stock and all stock were sold.

Cropping Sowing methods changed progressively from full cultivation to direct-drilling with wide points, then inverted T points, and finally to knife points. Deep ripping, green manure, potash and lime addition were used to lift soil fertility and crop yields. Controlled traffic was introduced in 2005 as information on the benefits became available. By 2008 there were concerns about the future of controlled traffic, as it restricted machinery purchase (scale and axle stress) to keep to the width, with tramlines becoming eroded by rainfall and crop residue concentrated in the same spots. The farm area expanded with purchase of new land (937 ha in 1999; 1,466 ha in 2002; 1,836 ha in 2006). By 2005, the area under crop peaked at 6,900 ha under wheat, barley, oats, lupin and canola. Lupin and canola crops failed in the droughts of 2006 and 2007 and, although it was thought herbicide resistance could be managed, good profits from these crops were required to achieve it.

Livestock enterprise. The drought caused a trend back to livestock, as did herbicide resistant weeds and emerging salinity problems in the region which required deep-rooted perennial pasture species in the system. In 2006, after considering other livestock diversification options, Brian and Tracy introduced a ‘back-grounding’ cattle enterprise. This involved agisting cattle for around 6 months (winter/spring) from surrounding pastoral stations, with payment based on live-weight gain during the period. This involved no upfront purchase costs, no animal husbandry requirements and no summer feeding requirements – in contrast to the significant labour requirement of sheep enterprises when labour supply was limited by the regional mining boom. After 1997 the farm had no infrastructure for cattle, so 500 ha of arable land with intractable weed problems were partitioned into 100 ha paddocks using electric fences and troughed water. Oat fodder crops and annual pastures provided cattle feed.

In 2008, 93% of the farm was cropped and 7% was available for back-grounding cattle, actual proportions depending on feed availability. Ian ceased all backgrounding of cattle in 2010, following the live-export crisis as it became too risky. Ian became a CBH Director in 2010 which considerably increased his off-farm commitments. He established an export oaten hay enterprise for around 3 years specifically to deal with the herbicide resistant weed problems on the farm, but it was difficult to source labour and this was discontinued. The introduction of GM Roundup Ready™ canola has replaced TT canola, and barley has increased in area especially on salt-affected land, while the area of lupins has diminished due to poor performance.

Soil amelioration In recent years, the whole farm was mapped to a depth of 30 cm for pH, and he has used deep ripping to 30 cm with inclusion plates across the whole farm in a program that will repeat every 5 years. He has seen big paybacks in the dry spring seasons. He has moved from windrow burning to chaff cart for last 4 years and has now moved to chaff deck to concentrate and control weed seed banks. Currently saline land (~300 ha) is being reclaimed with deep ripping and gypsum for both surface and subsurface drainage control and cropped to barley.

Operational efficiency By 2016, the WUE of the major crops had plateaued near the perceived potential with few opportunities to increase productivity, and the focus switched to reducing costs and increasing scale. In 2016, one farm (1,200 ha) of least productive land was sold off to reduce the total crop area to 5,810 ha, which allowed the sowing program to be managed by ‘1 tractor unit’. The purchase of the widest seeding equipment on the market (Morris single 26.2 m bar) allows the whole farm to be sown on time with one seeder. If necessary 80% of the farm will be sown dry with the remaining sown after the autumn break. The seeder uses tynes and press wheels on 30 cm rows, and he has moved back to granular urea rather than liquid fertiliser at seeding.

Future plans Weeds are the biggest ongoing challenge, together with isolation and community decline – the farm is going well but housing will likely move to towns. Large expensive machines with large repair bills and depreciation are an issue. They will not buy more land, as successive droughts (2006/07) destroyed confidence in growing the business in the region. They have pursued balancing their personal wealth rather than having all the risk in the farm. They will continue to seek improvements and modifications to add further efficiencies to the system while protecting the resource base.

Summary

The farm case studies reinforce many of the national trends in the evolution of southern Australian farming systems over the last 30 years described earlier in the chapter, and elsewhere in this book. Equally they illustrate the diversity of individual farm enterprise response to the external drivers for change. All of the farms have increased significantly in size with the average increase of 220% for the mixed farms, 380% for the specialist crop farms but a range from 73 to 900%. It is interesting that the largest farm (6,900 ha) recently downsized, citing machinery and labour efficiency as the driver. The diversity of both crop and livestock enterprises increased in all cases from one or two main crops dominated by cereals and self-replacing wool flocks, to combinations of five or six cereal, oilseed and pulse crop options and to dual-purpose flocks, prime lamb and beef production as well as feedlots, livestock trading and agistment. The mixed farms, and even some crop specialists demonstrated the flexibility of reversible integration to adjust the crop-livestock ratio on farm according to seasonal, market and family (labour circumstances) – one farm moving between 50:50, 80:20, 65:35 and 100:0 across the 30 year period. The cropping systems on both specialist crop and mixed farms have all transitioned towards earlier sowing systems with no-till or zero-till, retained residues, controlled traffic and an increasing adoption of, or at least interest in, various precision technologies. Herbicide resistance weed management and managing soil constraints were consistently cited as ongoing issues and opportunities on most farms.

Despite these consistent trends that mirror those at national scale, the case studies also illustrate the importance of personal preference as well as family circumstances in enterprise selection and management, the value of off-farm activities, and the impacts of sudden change on individual farms when land or large equipment items are purchased, or livestock are sold. The changes were sometimes the result of long-term planning but were often triggered by changes in price, droughts, government policy or new family circumstances. Even within this relatively small set of farms, subject to similar macro-economic and climatic trends, there is enormous diversity in the specific response and fine-tuning of enterprises that needs to be acknowledged.

Interestingly there was unanimous optimism among the growers for the future with succession planning in place, a focus on sound business decisions and specific technological options for continued improvement and fine-tuning of the farming system proposed. These mostly revolved around overcoming soil constraints, better management of weeds, capitalising on new satellite and other precision technology, as well as a focus on managing personal wealth with both off-farm investments and sound farm business decisions. If they existed, concerns over the much discussed issues of rising energy and input costs, the potential impacts of climate change and slowing productivity trends were not offered voluntarily by these growers as concerns for the future. This may simply signify that these issues are considered to be a manageable extension of the negative terms of trade and climate variability that has been an accepted feature of dryland farming for this generation of Australian farmers over the last 30 years.

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