Chapter 5

Evolution of conservation agriculture in summer rainfall areas

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Introduction

Over the last fifty years increases in grain yields have resulted from improvements in breeding, agronomy, soil and crop management, the cropping system, and their interactions. There is little doubt that the same drivers will be responsible for future yield gains. This suggests that identifying and adopting optimum combinations of agronomic management and cultivars that make best use of available resources *i.e.* soil water and fertility, and the seasonal conditions will continue to be the focus of research and development in the future.

Since the early 1900s wheat yields across Australia have shown periods of both rapid and slow rates of increase over time, attributed to synergistic gains from the introduction of legumes, pasture rotations, semi dwarf cultivars, and more diversified rotations that included legumes and canola as break crops (Angus 2001). Crop yield benefits from the adoption of residue retention and zero tillage have been elusive in Australia and elsewhere (Strong *et al*. 1996, Pittelkow *et al*. 2015). However, clear benefits from increased profits as a consequence of increased cropping intensities or reduced risks from conservation agriculture (CA) practices are evident when the comparison is made at the cropping system or whole farm level (Rodriguez *et al*. 2011).

CA is a farming system that promotes maintenance of permanent soil cover, minimum soil disturbance (*i.e*. no tillage), and diversification of plant species (FAO 2018, www.fao.org/conservation-agriculture/en/). In Australia, it has been promoted since mid-last century to conserve soil and water resources. Currently more than 84% of Australian farmers use some type of CA, including minimum soil disturbance, stubble retention, and/or rotations with legumes (Bellotti and Rochecouste 2014). The significant adoption of CA in Australia has been explained in response to biophysical, technological, and socio-economic drivers. Adoption across the continent has not been uniform with highest levels in Western Australia, and lowest in South Australia and Victoria. Adoption of CA in Australia's summer rainfall dominated environments, *i.e*. northern New South Wales and Queensland, has been in response to the need to manage soil and water erosion. Presently soil water retention to allow timely sowing of winter crop and early planting of summer crops as well as stabilising yields in a highly variable climate are key objectives of best management practices.

Biophysical drivers included the ubiquitous nature of Australia's fragile soils and their susceptibility to wind and water erosion, and the need to maximise the capture and use of rainfall for crop production (Serraj and Siddique 2012). Technological drivers included the introduction of glyphosate, crop disease resistance, controlled traffic, and direct seeding technologies (Llewellyn *et al*. 2012, see Chapter 2), while socio-economic drivers included cost and drudgery savings (Bellotti and Rochecouste 2014).

In this chapter we provide a re-assessment of the main drivers for the evolution of CA farming systems in the summer rainfall environments of Australia, the enabling technologies that are making it possible, and the needs for further research in view of the emergence of disruptive technologies, climate variability and change.

The environment and the farming system

Summer dominance of rainfall increases northwards of Dubbo in central New South Wales. Variants of CA dominate crop agronomy with the proportion of summer crops increasing northwards, particularly in the wetter eastern areas.

Climate in the region is characterised by unreliable rainfall, high evaporative demand (double that of rainfall in most months) and frequent intense summer storms (and associated runoff) with extended and unpredictable dry periods between rainfall events (Figure 1).

The unreliability of in-crop rainfall can make its capture as stored soil water challenging, but critical to reliable crop production. The variable nature of climate makes planting crops in the optimum window to minimise the risk of frosts and heat stress around anthesis difficult. In order to deal with such unreliable water supplies, fallowing to store water is an essential part of risk reduction. While climate change may become an issue for agronomists and farmers in coming decades, its impact is overshadowed by the challenges of dealing with seasonal variability in the short term. For example, rainfall varies from 50 to 200% of the average in any two seasons.

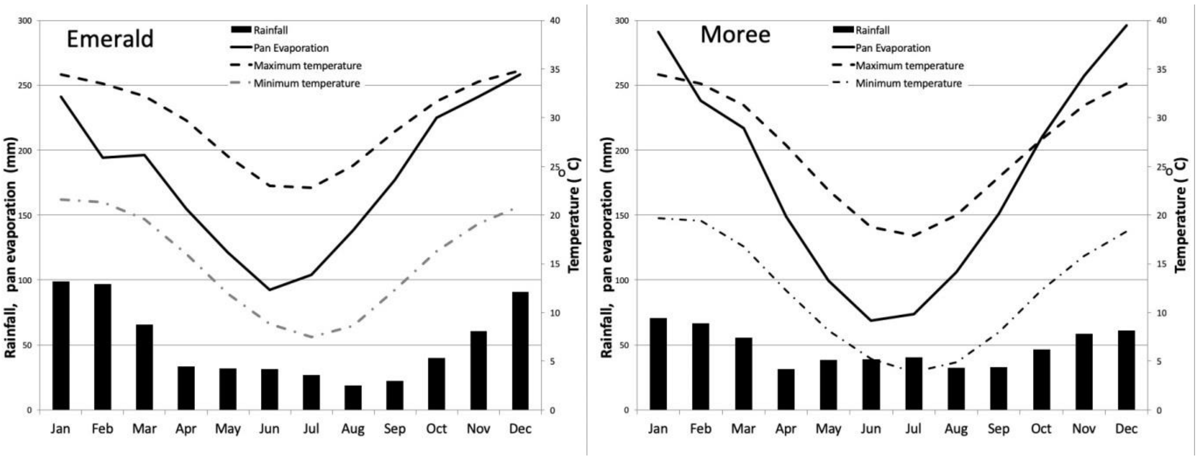

Figure 1. Average monthly rainfall, minimum and maximum temperature and evaporation potential for Emerald (AAR 600 mm, evaporation 2160 mm, Latitude 23.5° S) and Moree (AAR 595 mm, evaporation 2180 mm, Latitude 29.5° S)

Typical crop rotations are based around wheat (winter) or sorghum (summer). For example, wheat to chickpea or wheat, then a long fallow to sorghum or double crop to chickpea are common rotations in northern New South Wales and southern Queensland. Fallows of 12-15 months are also common during the transition between summer to winter crops (*e.g*. sorghum harvested in autumn, with wheat, chickpea or barley sown in winter the following year). In the drier western cropping areas, fallows may need to be 12-24 months for sufficient fallow water accumulation as fallow efficiencies of 15-25% require time and effective rainfall.

However, given the likelihood of heat stress and dry spells around flowering (Singh *et al*. 2015), there is increasing interest in winter sown sorghum. Winter sown sorghum crops aim to avoid the overlap between flowering and extreme high temperature days that cause flower sterility (Singh *et al.* 2015). Grain filling takes place at more favorable temperatures thereby reducing screenings and increasing yields. Crops can be harvested as soon as early January which allows the opportunity for the fields to be double cropped into chickpea after a short summer fallow.

Further north in Queensland, the importance of grain sorghum and other summer crops such as maize and mungbean increases together with the dominance of summer rainfall (Rodriguez and Sadras 2007). In response to the large variability of summer rainfall (ca. 30% coefficient of variation), northern cropping systems are highly opportunistic, in contrast to fixed rotations (Freebairn *et al*. 1997, Rodriguez *et al*. 2011). Further west, rainfall and soil quality decline significantly, reducing cropping intensities of predominantly mixed crop-livestock farming systems (Rodriguez *et al*. 2014), reflecting the need to spread risk with lower and more variable production.

Impact of conservation agriculture in the summer rainfall zone

Research conducted in the late 1970s and 1980s provided strong initial evidence to support the adoption of stubble retention in the summer rainfall zone and helped demonstrate the value of efficient fallows through improved water storage. Numerous studies in the region reported increases in water storage with crop residue cover in no-till (NT) systems compared with residue removed by tillage in conventional tillage (CT) systems (Marley and Littler 1989, Norwood 1994, Felton *et al*. 1995, Radford *et al.* 1995, O'Leary and Connor 1997a, Li *et al.* 2007, Thomas *et al*. 2007b).

More recently Thomas *et al.* (2007) reviewed results from 120 experiment years and showed that NT systems generally resulted in higher soil water storage in fallows due to better infiltration and possibly reduced evaporation associated with crop residues providing soil cover. Greater infiltration rates of NT soils was also attributed to an increase in macropores improving water movement into the soil profile (Chan and Mead 1988, McGarry 2000). Residue cover in NT systems also reduces wind speed and soil temperature, thereby helping to reduce water loss through evaporation (Jones *et al.* 1994, O'Leary and Connor 1997a).

The dependence of winter crops on starting soil water at three locations; Greenethorpe (southern NSW), Moree (northern NSW) and Dalby (southern Queensland) is shown in Figure 2 to demonstrate changes in the importance of fallows for different climates. For example, just to the south of the Northern region at Greenethorpe, 20% of a winter crops' water supply is provided through fallow moisture (proportion of the crops water supply derived from soil water at planting). This value increases to 60% for a winter crop at Dalby. Improved rainfall capture and reduced evaporation has shown significant yield and cropping system profits, particularly during the Millennium Drought that affected eastern and southern Australia during the early 2000s.

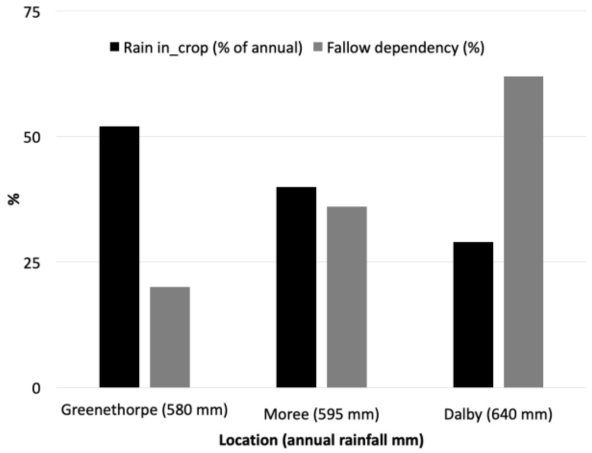

Figure 2. Percentage of in-crop rainfall and 'fallow dependency' (the proportion of the crop's water supply derived from soil water at planting) for winter crops at three locations.

Marley and Littler (1989) showed average fallow efficiency values for four tillage treatments at a long-term trial near Warwick, Qld (Figure 3). An extra 9% of rainfall was captured when stubble was retained in NT systems, compared with cultivation and no stubble. Similarly, starting soil water measured over three years at three sites in northern NSW was 30 mm higher in NT with stubble compared with tilled and stubble burnt (Felton *et al*. 1995). However, in both these studies, wheat yields did not reflect these gains in starting soil water, indicating the complex dynamics between resource availability at the time of planting and the yield formation dynamics (Angus 2001, Pittelkow *et al.* 2015).

The full benefit of implementing NT is often not evident until later, in many instances greater than 5 years (Pittelkow *et al*. 2015). The reasons for this are mixed; for example, Radford and Thornton (2011) found that a yield penalty associated with aggressive tillage lasted three years after a NT regime was implemented over the whole trial (Table 1). It is notable that there were no yield differences between the three ‘stubble retained’ treatments and that crop type was varied depending on planting opportunities.

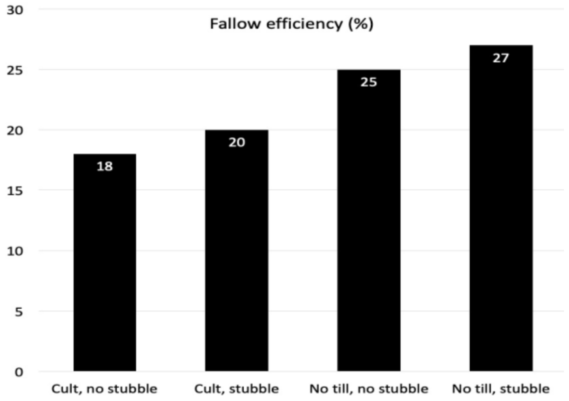

Figure 3. Average fallow efficiency (% of fallow rainfall stored in soil at planting) for four tillage/stubble treatments at the Hermitage Research Station near Warwick 1968-79 (11 years) (Marley and Littler 1989)

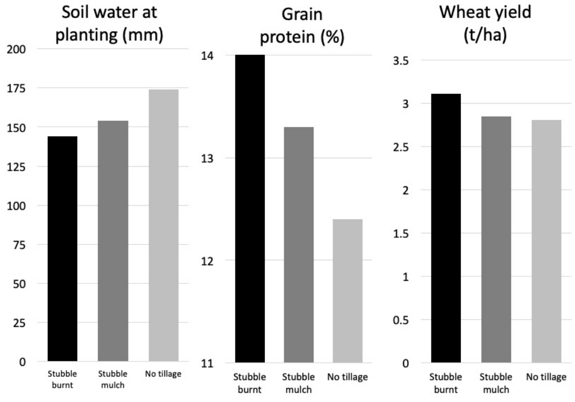

Figure 4. Average yield over 3 years for three fallow management strategies at Warialda, Croppa Creek and Breeza, 1986-88 (Felton *al et*. 1995). All treatments received basal fertiliser plus 50 kg/ha N

Table 1. Average grain yield (t/ha) over 20 years for four fallow management options and yield when all plots were managed for the subsequent 3 years (Radford and Thornton 2011)

Treatment	Mean Yield for 20 Years (t/ha)	Mean Yield for 3 years Post-treatment (t/ha)
Disc/scarifier tillage	2.15	1.43
Stubble mulch tillage	2.66	2.73
Reduced till	2.77	2.83
No-till	2.79	2.71

Drivers for the adoption of conservation agriculture practices

The combination of research, development and extension activities, together with a range of biophysical, socio, and economic drivers have led to the fast adoption of conservation farming practices across Australia’s summer rainfall areas. For example, in the span of ten years, the percentage of cropping land under NT increased from less than 5% in 1999 to 65% in 2010 (Llewellyn *et al*. 2012, Dang *et al.* 2018).

Biophysical drivers

As knowledge on the importance of capturing rainfall and retaining soil water developed, practices that promoted improved fallow efficiency allowed for earlier planting and increased the reliability of cropping (Rodriguez *et al*. 2011, Sadras *et al*. 2016). Today, soil conservation practices such as crop residue and NT are seen as crucial to manage dryland cropping (Belloti and Rochecouste 2014).

Socio-economic drivers

Socio-economic factors that favoured the adoption of CA practices included the limited availability of labour in remote communities, land consolidation into larger farms, and the availability of drudgery and cost saving technologies such as auto-steer, controlled traffic and larger machinery. The CA practices and soil water retention brought increased opportunities to diversify crop rotations and double cropping. Whole farm simulation studies suggest that increased cropping frequency is possible with an opportunity cropping strategy combined with direct drill, controlled traffic systems (Chudleigh *et al*. 2002, Rodriguez *et al*. 2011, 2014). This increased cropping frequency is reliant on stored soil moisture to dictate rules for sowing.

Benefits are particularly notable in the more marginal environments where the ability to retain stubble *in situ* allowed for the expansion of cropping activities into previously sole grazing, or mixed cropping and grazing farms. The opportunity to increase the area under crop in recent years has been forgone as meat prices have increased and annual rainfall has been below average.

Soil organic carbon and biology

Soil organic carbon (SOC) levels of NT soils have frequently exceeded CT soils with a pronounced stratification of SOC in the top 0-0.15 m soil depth (Luo *et al*. 2010, Soane *et al.* 2012, and see Chapter 16). Results from experiments conducted in the summer rainfall region comparing CT with NT have been mixed, with some NT treatments reporting small increases in SOC stocks calculated on depth increments in the surface soil layers (Dalal *et al*. 2011), while others reported that NT management has little or no impact (Fettell and Gill 1995, Armstrong *et al*. 2003).

In the semi-arid sub-tropical environments of north-eastern Australia, many studies observed greater SOC concentrations under NT systems; however, this is primarily due to NT simply decreasing the rate of decline relative to CT management (Doran *et al*. 1998, Olson 2010, Chan *et al*. 2011, Page *et al*. 2013). The crops are grown following a fallow period in order to accumulate soil moisture and the crop biomass production is generally insufficient to lead to any overall gain in total SOC (Fettell and Gill 1995, Franzluebbers and Arshad 1997, Chan *et al.* 2003, Hoyle and Murphy 2006).

An analysis of 40 years of SOC data at the Hermitage, Queensland site showed that SOC stocks measured over time showed a decrease (0.29 Mg/ha/year to 0.3 m soil profile) across the experiment and more so in the top 0.1 m under stubble burnt (SB) and NT as compared with stubble retained (SR) and NT (Page *et al*. 2013).

Similar to SOC, several studies have reported greater soil biological activity in NT systems when compared with CT systems (Wildermuth *et al*. 1997, see Chapter 15) with greater abundance and diversity at the soil surface and with minimal difference at lower depths. This is attributed largely to a more favourable soil environment because of increased quantity and diversity of organic material, increased moisture, improvements in soil structure and, in some instances, a more favourable temperature (Wardle 1995, Lupwayi *et al*. 2001). Wardle (1995) showed that there was a wide range of responses between different species, although most organism groups had greater abundance or higher soil microbial biomass (SMB, defined as mass of living microbial tissues) in NT soil than in CT soil. Large organisms in general are more sensitive to tillage than smaller organisms due to longer life cycles, combined with physical disruption of the soil and habitat destruction (Wardle 1995). Earthworm populations have increased markedly in the region under NT, and are adversely affected by cultivation (Robertson *et al*. 1994).

Weeds in conservation agriculture systems

Prior to the advent of effective herbicides, tillage was the primary method of controlling weeds that interfered with the crop sowing operation and then competed with the emerging crop for limited available water and nutrients (Pratley *et al*. 1999). Tillage influences weed populations by the combined effect of mechanical destruction of weed seedlings and by changing the vertical distribution of weed seeds in soil (Peigné *et al*. 2007). Practices such as residue burning are also known to destroy weed seeds and decrease weed infestations (Heenan *et al*. 1990). In the absence of residue burning, NT has led to increases in the population of some weed species (Buhler *et al*. 1994, Chauhan *et al*. 2012, Lyon *et al*. 1998,) and reduction in others (Pratley 1995).

The weed flora in the summer rainfall areas of Australia have been documented in several field surveys (Felton *et al*. 1994, Osten *et al*. 2007, Rew *et al*. 2005, Walker *et al*. 2005, Werth *et al*. 2010, Wicks *et al*. 2000). Multiple studies have shown a significant shift in both weed population densities and species. Weeds with wind dispersed seeds and glyphosate-tolerant species have become more prevalent. Essentially a small number of species tend to dominate in NT cropping including the summer grasses, such as *Echinochloa* spp. and liverseed grass (*Urochloa panicoides),* and weeds with wind dispersed seeds, such as sowthistle (*Sonchus oleraceus)*, and increasingly windmill grass (*Chloris truncata)* and fleabane (*Conyza bonariensis).*

Alternative methods for weed control have emerged in response to the changing suite of weeds and resistance to herbicides. Strategic tillage and weed seeker technology have been combined with agronomic practices such as higher seeding rates and altering row orientation to improve crop competition with weeds and reduce weed seed set (Dang *et al.* 2018). These methods could be further exploited. Future options may include the use of microwave and robotic technology to increase the control of weeds. Desiccation of crops, primarily sorghum and chickpea using glyphosate as the sole or base active ingredient has become accepted practice to prevent further crop growth and use of soil water, as well as allowing late season weed control. Further information is available in Chapter 10.

Diseases in conservation agriculture systems

Reduced soil disturbance associated with residue retention in NT systems generally results in higher soil moisture and reduced temperature, which creates a more favourable environment for many plant pathogens and encourages disease persistence (Bockus and Shroyer 1998, Cook and Haglund 1991, Wildermuth *et al.* 1997,). Retained stubble residue retention also offers a food and inoculum source for many diseases. The most common soil- and residue-borne diseases in the Australian summer dominated rainfall region include: crown rot of cereals caused by *Fusarium pseudograminearum*; yellow spot of wheat caused by *Pyrenophora tritici-repentis*; net and spot forms of net blotch of barley (*Hordeum vulgare*) caused by *Pyrenophora teres* f. *teres and Pyrenophora teres* f. *maculata* Smedeg., respectively; ascochyta blight of chickpea (*Cicer arietinum*) caused by *Ascochyta rabiei*; and stalk diseases of sorghum (*Sorghum bicolor)* caused by *Fusarium moniliforme*. Root-lesion nematodes (*Pratylenchus thornei* and *Pratylenchus neglectus*) are also major pests and host on several crop species important in the region including wheat, chickpea and sorghum. Residue retention has been the main driver in increasing stubble borne diseases prompting increased focus on crop rotations and technologies such as inter-row sowing. Further information is available in Chapter 11.

Technologies that have enabled conservation agriculture

Over the last 30 years the level of technology has increased; tractors are a good example of the changes. Major changes to the internal and external design and functionality of tractors has made them more user friendly and automated as well as providing efficiency gains in the field. Tractor power has increased, wheel base sizes have expanded, more complex software and operating platforms to incorporate GPS technology have been widely adopted.

Sowing and spraying equipment have also changed in response to the requirements of farming operations with wider planters and improvements in seed placement and singulation. Precision planters are standard for summer crops, and some winter crops such as chickpea. Controlled traffic has reduced soil compaction, and overlaps creating savings in seed, fertiliser and herbicides (Tullberg 2010, see Chapter 6).

The introduction of GPS linked with Geographic Information Systems (GIS) has enabled capabilities such as auto steer, precision agriculture and variable rate technology. The use of real time Kinematic (RTK) navigation systems at a 2 cm level of accuracy has given producers the ability to collect and utilise more information about their fields and their crop performances. These systems have extended the working hours of operators as utilising auto steer extends the time which one employee can manage in a shift as well as the conditions in which tractors can be operated; for example, in low visibility such as at night or in fog. This technology has also elevated the skill set of producers; each tractor driver now requires advanced computing skills.

There has been a greater focus on reducing the ‘footprint’ of tractors across fields. The use of track machines and controlled traffic tramlines has helped to concentrate soil compaction to a smaller area of the field through reducing the area over which a tractor wheel passes. The next stage in technology innovations is the inclusion of remote sensing, many as independent platforms, but some also linked to tractors and spray rigs such as weed seekers and green seekers.

Planter improvements

Planting equipment has developed in complexity and adaptability to manage variable conditions. Capital investment in machinery is expensive and can have a significant influence on profitability (Vogt and Verrall 2018). However, crop establishment is critical to final crop yields. The focus of planter developments has been largely in seed placement and seed metering.

Use of precision planters has increased over the last 30 years, particularly for summer crops. The increase in hybrid varieties has increased seed costs leading to greater emphasis on planting less seed more precisely to keep establishment costs lower. Parallelogram planters with improved ability to follow soil contours and attention on reducing seed bounce and better placement has also become more important.

Seed singulation improvements have helped to ensure seed metering is more accurate and the occurrence of doubles or missed seeds is minimised. Through ensuring both seed spacing and singulation are optimised, even plant stands can be established to reduce intraspecific competition, improve crop evenness at maturity and assist in uniformity to aid management of weeds, pests and crop desiccation timing.

The combination of soil mapping, multi hybrid planters and connective software has now made it possible for farmers to plant more than one variety and apply more than one agronomy (*i.e*. plant population, nutrition) within a field on the go. This allows for zones within fields to be defined and optimum combinations of hybrids and agronomic management applied (Rodriguez *et al*. 2018).

The discussion on disc versus tyne implements continues with each system having its merits. Typically disc planters provide less soil disturbance but have less soil penetration capacity, limiting their usefulness in moisture seeking situations compared with a tyne. A tyne implement has better ability to ‘plant to moisture’ and establish a crop in otherwise too dry conditions and with more ‘soil throw’, which can be useful to incorporate herbicides for improved effectiveness.

Row spacing (skip row, wide row, twin row)

Varying row spacing is a management practice which is used to match the crop design better to the availability of resources or expected seasonal conditions. In winter cereals, wide row spacings (*e.g*. 50 cm) are used in marginal environments with narrow row spacings of 25-≤37.5 cm used in more favourable rainfall zones. Studies have demonstrated that yield decreases in winter cereals once row spacing moves wider than 30 cm (McMullen 2014). To gain efficiencies from investments in planters, many growers adopted the use of 37.5 cm winter crop row spacing and 75 cm summer crop row spacing, thus utilising this equipment for both winter and summer planting. Purchasing of precision planting equipment has become more typical for summer crops allowing adoption of more specialised row spacing suited to each crop in the rotation.

In summer broadacre cropping, the use of skip row technology has become common place in the marginal environments or where planting is proposed on fallows and soil moisture is lower than the ideal near full profile. Wide rows or skip rows provide an effective bigger soil mass and moisture supply during grain fill. Initially, single (plant two miss one row) or double skip (plant two, miss two rows) was favoured during 2000-2010, although wide rows (120-150 cm) have gained favour in recent years (Serafin and McMullen 2015).

Conversely, the need to maximise yields in more favourable environments has brought consideration of narrow row spacings (≤50 cm) or the use of twin rows. The need for additional planter units and the difficulty in managing high stubble loads have been challenges to adopting a narrow row planting design. In contrast, twin rows provide the ability to mitigate some of these issues.

Row placement: on row/ off previous crop row

The use of 2 cm RTK guidance systems and auto steer has meant the possibility of inter or on row sowing, *i.e.* planting in between the previous crops rows or planting back on the previous crop rows. Inter row sowing is an option for handling high stubble loads as well as disease management (*e.g.* crown rot) by minimising the contact which emerging seedlings have with previous crop residue. In contrast, sowing on the row of previous crop stubble allows seedlings to access old crop root channels and biopores which trap water better than the inter row area.

Adapting to heat and stress in the summer rainfall zone – looking forward

Across the summer dominant rainfall region, managing heat and moisture stress around flowering remains the focus of crop adaptation and systems agronomy. The main adaptation strategy farmers have to reduce yield loss is to avoid the overlap between stress events and flowering by targeting optimum flowering windows and managing canopy size. However, to fit the flowering of sorghum around a low risk window for heat and water stress for example, the crop would need to be sown into soil temperatures lower than the recommended 16°C, with a higher frost risk. Achieving rapid and uniform sorghum emergence is essential under these less ideal conditions; however it is a balancing act between the potential benefits of reduced stress around flowering and the higher risk of crop damage or loss due to frost damage at the early seedling stage.

These are some of the challenges farmers face to respond to an increasingly hotter and drier environment. Ongoing research has shown that sorghum crops sown into soil moisture as early as August take longer to emerge, though are harvested during mid to late December, potentially increasing cropping frequency and production. However, numerous questions require answers before widespread adoption of this practice.

Earlier summer crop establishment Present sowing recommendations indicate that sorghum “should be planted when the soil temperature at the intended seed depth is at least 16°C (preferably 18°C) for 3-4 consecutive days and the risk of frosts has passed” (Kneipp and Serafin 2006). However, initial results suggest that crops could be successfully established on colder soils (~12°C at planting depth) with good moisture and ground cover that reduces evaporative losses. Other factors likely to be important include seed quality, crop residue cover, soil moisture, soil type, and hybrid genetic differences.

Improved definition of frost risk Air temperature thresholds (intensity) and duration of damaging frosts in sorghum during early vegetative stages have not been clearly established. There is a need for better prediction of the likelihood of early frost damage so that early sowing decisions can be better informed. Other factors likely to affect frost damage include crop residue cover, soil moisture, soil type and hybrid.

Stresses around flowering, grain yields and risk of uneconomical crops There is a need to produce information on how alternative hybrid and agronomy combinations, including early sowings, change the frequency of stress environments around flowering, and how these changes impact on likely yields and risks of uneconomic crops across the region. This information needs to be packaged and delivered in a way that can be used to inform farmers’ decisions.

Cropping system benefits Initial simulations with APSIM show potential increases in the likelihood of double cropping a winter crop after a longer summer fallow. For example, a crop planted in early August at Warra Qld would take 100 days to reach flowering, and be harvested during mid or late December, leaving a longer fallow period into the next winter crop. The magnitude of the benefits and risks across the region need to be properly quantified following on from previous work in 1976 (Berndt and White 1976). Questions remain on how often this is likely to happen and the implications on subsequent crops, profits and risks.

What knowledge is missing for the future?

Although the adoption of CA has progressed steadily, further adoption appears to be hindered by several issues:

- the increase in herbicide-resistant weed species;
- the build-up of soil- and stubble-borne diseases;
- the stratification of organic matter and nutrients in the top layers of the soil, and the depletion of subsoil layers *i.e.* particularly phosphorus and potassium;
- the build-up of soil insects, and the limited number of management options to control insects that have a below-ground pupal stage (*e.g. Helicoverpa spp.*); and
- the environmental and health concerns about the effects of herbicides on- and off-site.

The importance of crop rotation and disease ‘break crops‘ is accepted, although the role of soil biology on soil processes is poorly understood beyond ‘soil organic matter is good’. Cover crops have shown possibilities but there has been little follow up until recently to explore where this practice fits into farming systems (Erbacher *et al*. 2019). While this area may be considered high risk, future improvements in system performance will be harder to find.

Weed control remains a high cost component of grain production and herbicide resistance presents a growing threat to CA. Herbicides are valuable management tools and their efficacy needs to be maintained, suggesting the need to combine multiple weed control strategies, including strategic tillage.

Future productivity gains across Australia’s summer rainfall dominant cropping systems are likely to continue to accumulate from improvements in farmers’ capacity to identify optimum combinations of crops and varieties (Genotype), agronomic management (Management), cropping systems (Cropping System) and whole farm management strategies across its diverse climate and soil environments (E). Large benefits are expected to arise from improvements in our capacity to characterise expected seasonal conditions in our variable climate.

Farm case studies in northern NSW and Queensland

Northern NSW

Darryl (left) and Sara Bartelen

> *“Optimising the full potential of your soil is the key to farming in northern NSW“*

- *Location:* “Krui Plains” 60 km north of Moree, NSW
- *Mean annual rainfall:* 552 mm
- *Soils:* Grey vertosol

Darryl and Sara Bartelen brought fresh ideas and a lot of enthusiasm to implement conservation farming practices when they took over operations from Sara’s parents at “Krui Plains” north of Moree 24 years ago. Today, the 4,300 ha cropping and steer backgrounding family farm operates under the management of Darryl, Sara, their daughter Catie and one full time employee.

In the mid-1990s, Darryl commenced implementing changes to the conventional farming practices that had included multiple tillage operations, round and round paddock traffic and grazing sheep. Sheep were replaced with a steer backgrounding enterprise where grazing was mainly confined to the non-cropped area and weeds were controlled by herbicides.

Darryl watched and listened to neighbours, agronomists, leading district growers and his father-in-law to glean information to improve the efficiency of the farm. Initially it was the simple step of spraying fallows for weed control instead of cultivating.

The dawn of the dry new decade in 2001 convinced him to try NT. He converted an old John Shearer trash worker into a no till planter and in 2001 sowed their first no till crop to improve moisture storage and reduce soil erosion, following the wet seasons in the late 1990s. The modified planter was used for all winter crops until 2013 when they purchased a 12 m disc planter. The disc planter soon proved unsuitable in their conditions; insufficient penetration excluded moisture seeking, and excessive stubble pinning occurred in heavy stubbles. Darryl reverted to their modified planter until 2017 when he purchased an 18 m tyned parallelogram planter on 37.5 cm row spacings. Their summer crops had benefited from the purchase of a precision planter in 2005.

“Krui Plains Pastoral Co” maintains a rotation of wheat /chickpea/barley/sorghum, with a 25% split in area between these four crops. Their crop rotation has changed little over time, except addition of barley in 2002 to expand feed grain market and reduced yield impact of crown rot. Opportunistic crops such as mungbean, sunflower and corn have been grown but they have returned to their core grain crops.

Currently they use 12 and 18 m planters and 12 m headers, all with a common 3 m wheelbase on a controlled traffic guidance system with 2 cm accuracy. A strong focus on conserving and retaining moisture means fallow weeds are controlled. Weeds are controlled in a timely manner using a WEEDit™, purchased in 2014, and a self-propelled 36 m spray rig purchased in 2017.

No-till has resulted in herbicide resistance and a new suite of weeds *e.g.* windmill grass. Glyphosate-resistant barnyard grass (species) evolved as a challenge but is now under control through using a multi-pronged approach of herbicides and crop rotation.

Darryl and Sara are conscious of the need to measure impacts of the changes they make. They use a mix of productivity, economic and sustainability indicators to monitor the impact of their decisions. For example, on a productivity basis, long term average wheat yields have lifted from 1.5 to 2.7 t/ha. From an economic viewpoint the WEEDit™ has reduced their chemical costs by $50,000/year and improved their sustainability by reducing the area sprayed in fields on average to 10%, extending the useful life of herbicide chemistry

In the most recent 2018-2019 drought, Darryl felt he had set up the farm to be in the best position to succeed, basing decisions on the amount of stored soil moisture and striving to improve efficiency of all aspects of their cropping operation.

In future Darryl predicts continued challenges with conservation farming, such as controlling multiple herbicide resistant weeds and an increasingly hot, dry and variable climate. For future weed control, he envisages a multipronged attack; expanding herbicide chemistry groups used, the WEEDit™, possibly an autonomous weed chipper and using new “green on green” variable rate spray rigs.

The Bartelen’s are already scanning the horizon for the next efficiency improvement, recently engaging the services of a company to utilise the plethora of data they have collected through yield maps and remote imagery since 2003. This information will be verified and zones of crop performance established across their property. This zoning will be used to implement a variable rate program, initially for fertiliser, but ultimately for crop inputs such as seeding rates, variety choice and even crop selection.

Central Queensland

Paul Murphy

"Combining conservation agriculture and organic production in central Queensland"

- *Location:* "Kevricia" 40 km north of Emerald, Qld
- *Mean annual rainfall:* 600 mm
- *Soils:* Brigalow Yellow wood

Paul Murphy is an organic grain producer who manages the family farm "Kevricia", in Central Queensland, with his wife Cherry and two adult children. The property consists of 1400 ha dryland crops and 500 ha of native pastures. Paul began managing the property in the early 1980s alongside his parents, who had cleared and developed the farm. A decade later, Paul and his wife took ownership of the property with the aim of supplying produce in response to the growing social demand of reducing chemical inputs. This led Paul to obtain organic certification for the farm and to utilise 'natural' means of soil and crop enhancement and a residue-free end product. The Murphy farm business focuses on selling organic cereals and pulses for niche markets, and their 'chemical free' products attract premium prices. Typically, yields of organic farming systems are lower than conventional practices, but this is currently offset by significant price premiums.

Driven by the vagaries of the Central Queensland climate, the cropping program is highly opportunistic. Organic management practices use rotations that comprise five years of cropping followed by two years of green manuring and field revegetation by legumes and grasses. The crop sequence and intensity are driven by planting opportunities (*i.e.* availability of soil moisture) and field history. Other influencing factors include the selling prices of multiple cropping alternatives including a range of speciality wheats, chickpeas and linseed in winter, and mungbeans, sunflower, sorghum, soybean and corn in summer. A key component is the green manuring with *Dolichos lablab*, Sesbania, and naturalised grasses during the revegetation periods, as well as stubble retention during the cropping phase. Opportunistic 'cash crops' only take place following cultivation with full soil moisture profiles. Weeds are the predominant constraint and are managed using strategic tillage and crop rotations.

During the 1980s, "Kevricia" was managed under conventional tillage with no chemical usage. Under Paul's ownership, organic crops have been produced using minimum strategic tillage. Strategic tillage and weed control continue to be evolving issues. Nowadays the farm is managed through control traffic on 18 m rows for the tillage and planting operations. However, harvesting is unable to follow the tram tracking system due to operational constraints. Critical to success has been identifying optimum soil moisture levels for any tillage operation. Maintaining crop and stubble cover, building soil organic matter and improving soil structure to increase rainfall harvesting have been key elements to prosperity. Crop nutrition is managed with the contribution from green manures and native legume species, in combination with composts and animal-based manures. The effects of green manuring and the revegetation periods can be observed for up to five years depending on conditions, and determine the length of the cropping and revegetation phases. Paul is also experimenting with the use of organic and inorganic soil amendments based on basalt rock dust to enhance soil structure and fertility.

An important driver for change on the management of the farm has been the observation of soil constraints, particularly compacted soil layers that have produced smaller rooting systems that result in poor rainfall infiltration. Improvements include the adoption of reduced tillage to preserve soil structure, reduce erosion and increase rainfall infiltration through larger root systems. The adoption of controlled traffic has helped to reduce compaction and increase efficiencies. Despite higher profits from selling differentiated produce in niche markets at higher prices, weed control remains the most important and difficult challenge.

The focus of the business remains to increase returns on assets. Driven by the lack of specifically adapted hybrids to perform reliably in the hot, dry conditions of the Central Queensland cropping region of ca. 160,000 ha, Paul has been heavily involved with the creation and growth of Radicle Seeds Australia™, a farmer-owned sorghum and maize breeding company. This helps to diversify sources of income. The Company's objective is to fill the space of smaller higher value seed markets, and to provide value propositions to clients and regional communities.

The main challenge for dryland cropping in Central Queensland is the trend towards increases in the intensity of management and rotation systems, and a reduction in the frequency of rainfall events. This together with hot summers makes the maintenance of crop and stubble cover paramount to the reliability, profitability and sustainability of crop production. Labour constraints and the need for strategic and localised tillage in organic systems leads Paul's cropping system towards the adoption of robotic technologies for weed control. Paul also looks to future developments on the availability of autonomous precision planting and field management systems that automatically changes genetics (*i.e.* hybrid type) and management (*i.e.* agronomy and nutrition) on the go across contrasting management zones, or that mechanically take weeds while retaining stubble where it needs to be.

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