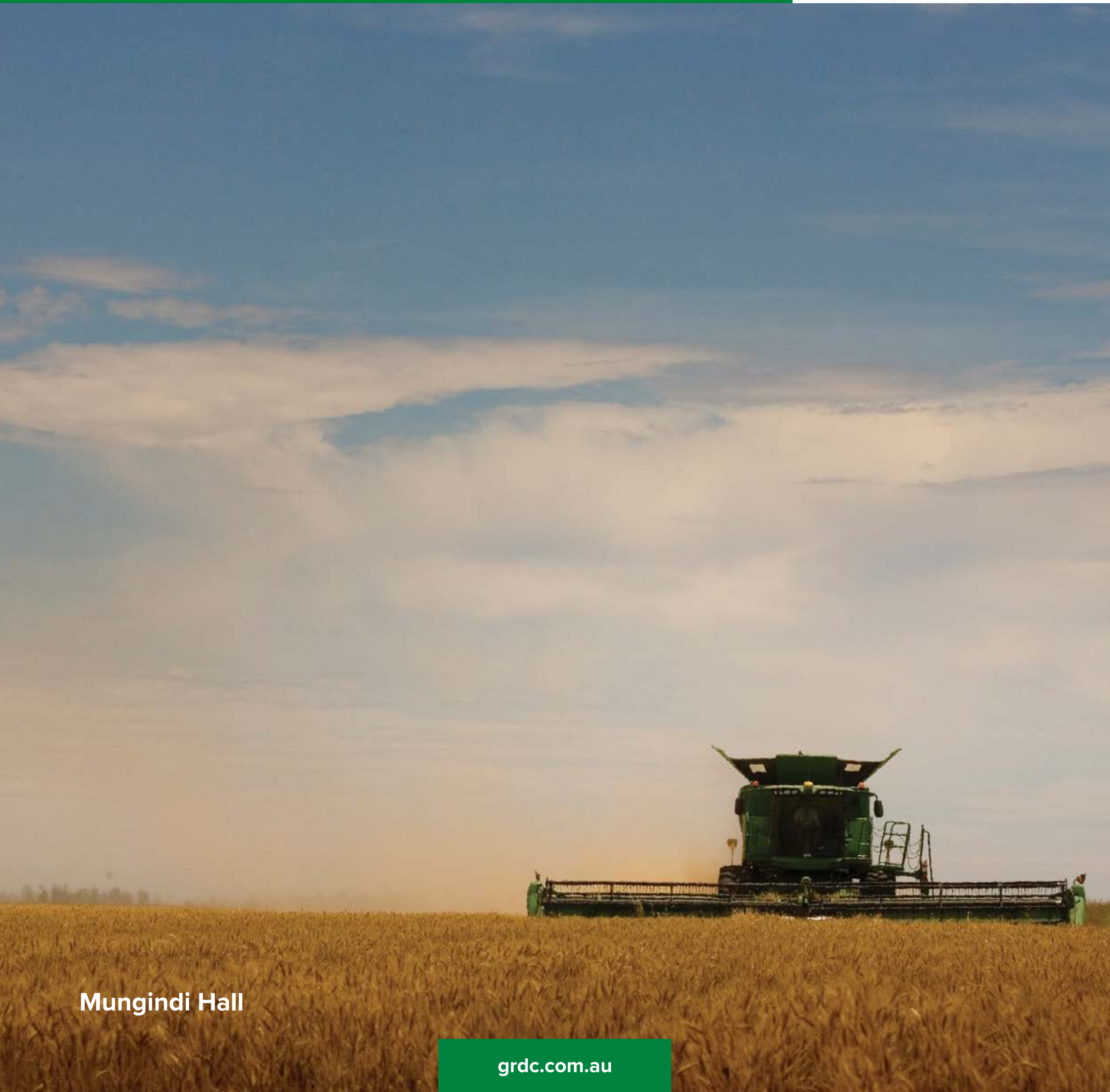
MUNGINDI
NEW SOUTH WALES
THURSDAY 5
MARCH 2020

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH



Mungindi Hall

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

GRDC 2020 Grains Research Update Welcome

If you are reading this, then chances are you have taken time out from an extraordinarily tough season in our very sunburnt country to hear the latest grains research, development and extension (RD&E) information.

Welcome.

We at the GRDC understand how very challenging the current situation is for growers, advisers, agronomists, researchers and those associated with the grains industry across New South Wales and Queensland.

Drought takes an enormous toll financially, emotionally and physically on those working and living through it daily. We trust that these GRDC Grains Research Updates will offer you new research information to help guide your on-farm decisions this season and to be best placed to take advantage of future seasons. We also hope the Updates provide a chance to connect with your peers and temporarily escape work pressures.

We would like to take this opportunity to thank our many research partners, who, like growers and advisers, have gone over and above in recent years to keep trials alive in rain-deprived environments.

Challenging seasons reinforce the importance of rigorous, innovative research that delivers genuine gains on-farm. For more than a quarter of a century the GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of the industry.

Sharing the results from this research is a key role of the annual Updates, which are the premier event on the northern grains industry calendar and bring together some of Australia's leading grains research scientists and expert consultants.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers.

For the past four years we have been doing that from regional offices across the country. Through the northern region offices in Wagga Wagga and Toowoomba and a team of staff committed to connecting with industry, we are now more closely linked to industry than ever.

Today, GRDC staff and GRDC Northern Panel members are at this Update to listen and engage with you. This is a vital forum for learning, sharing ideas and networking, all of which are critical to effect successful change and progress on-farm.

Regards,
Gillian Meppem
Senior Regional Manager North

GRDC Grains Research Update
MUNGINDI

Thursday 5 March 2020
Mungindi Hall, Wirrah Street, Mungindi

Registration: 8:30am for a 9am start, finish 3:00pm

	AGENDA	
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	
9:10 AM	**Climate change, production risk and frost**	Steven Crimp (ANU)
9:40 AM	**Maintaining wheat yield and quality under high temperatures -** status and prospects for improvement. How do current cultivars compare with what's coming?	Richard Trethowan (University of Sydney)
10:10 AM	**Sowing grain sorghum early** - reducing risk of water and heat stress at flowering and increasing chances of double cropping to chickpeas or of ratooning irrigated sorghum into a second harvest. Local trials at Mungindi	Loretta Serafin (NSW DPI)
10:35 AM	**Morning tea**	
11:05 AM	**Upgrading nutritional strategies to feed the farming system** - P & K placement, impact & economics over time. When should you start to worry about deep P reserves in soils that have not been cropped for as long? Impact of P and K on N placement.	Mike Bell (UQ)
11:30 AM	**Deep P application** - a grower experience	Tom Woods (Woods Pastoral)
11:40 AM	**Discussion session: Nutrition**	Mike Bell (UQ), Tom Woods (Woods Pastoral) and Bede O'Mara (Incitec Pivot)
12:00 PM	**Lunch**	
1:00 PM	**New technologies for the Australian grains industry** - observations from a four month Fulbright Fellowship study tour of the USA and Germany	Craig Baillie (USQ)
1:30 PM	**Modifying variety and sowing date with frost risk and slope** - how big are the potential gains and why?	Matt Gardner (AMPS Research)
2:00 PM	**Cover crops for fallow efficiency -** soil water, health, nutrition and crop performance	Andrew Erbacher (DAF Qld)
2:30 PM	**Discussion session: Dealing with the drought and planning for recovery**	Sam Heagney (South Bunarba Agriculture) and Tom Greentree (ATD Farming)
3:00 PM	**Close**	

Contents

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Changes in northern NSW farming system climate conditions - Mungindi

Steven Crimp and Mark Howden, Australian National University

Key words

Climate projections, production impacts, adaptation options

Take home messages

- Greenhouse gas (GHG) emissions continue to accumulate in the earth's atmosphere and drive warmer global temperatures. Warming of globally averaged air temperatures of just over 1°C since records began in 1850 has produced national, regional and local changes in environmental conditions. These changes have shifted debate from "Is climate change real?" to "What should we do about it?"
- Adapting agricultural practises will be required to respond to changing environmental conditions and will require all components of the agricultural value chain to work together in order to maintain resilient and profitable food systems.

Historical changes in climate?

Preliminary results suggest that 2019 is likely to be either the second or third warmest year on record, with globally annual averaged air temperatures now 1°C warmer than the long-term average calculated for the period 1961 to 1990. This warming is driven by increasing concentrations of all the major long-lived greenhouse gases in the atmosphere, with carbon dioxide (CO_2) concentrations rising from 208ppm prior to the industrial revolution, to 413.65 ppm as of 4 January 2020 (NOAA, 2020).

In Australia, warming in average temperature has resulted in 2019 being the warmest year on record (1.52°C above the 1961 to 1990 average of 21.8°C) (BoM, 2020). Average daytime maximum temperatures in 2019 of 30.69°C were 2.09°C above the 1961 to 1990 average. In December 2019 more than 40% of the entire country recorded maximum temperatures greater than the 97th percentile i.e. top 3% of temperatures. Examining the shift in the distributions of monthly day and night-time temperature shows that very high monthly maximum temperatures that occurred around 3% of the time in the past (1951–1980) now occur around 12% of the time (2003–2017) (BoM & CSIRO 2018). Very warm monthly minimum, or night-time, temperatures have shown a similar change from 2% of the time in the past (1951–1980) to 12% more recently. This shift in distributions towards hotter temperatures and more extreme high temperature conditions has occurred across all seasons, with the largest change being in spring (BoM & CSIRO, 2018).

In the Mungindi region over the period 1960 to 2019 (length of the temperature record), warming has occurred in both minimum (2.1°C) and maximum temperatures (2.3°C). For the period 1960 to 1991 an annual average maximum temperature of 29°C occurred, on average, 3% of the time. More recently (1992 to 2019) this temperature now occurs on average 13% of the time. Similarly mean annual minimum temperatures have warmed with the frequency of a minimum temperature of 14°C increasing from 6 to 27% of the time (Figure 1). As a consequence of this warming, the frequency of extreme minimum temperatures has declined, with temperatures of -4°C declining from 5% during 1960 to 1991 to 1% in the most recent period. Maximum temperature extremes have increased with temperatures greater than 47°C now occurring about 6% of the time, versus about 1% of the time during the period 1960 to 1991 (Figure 2).

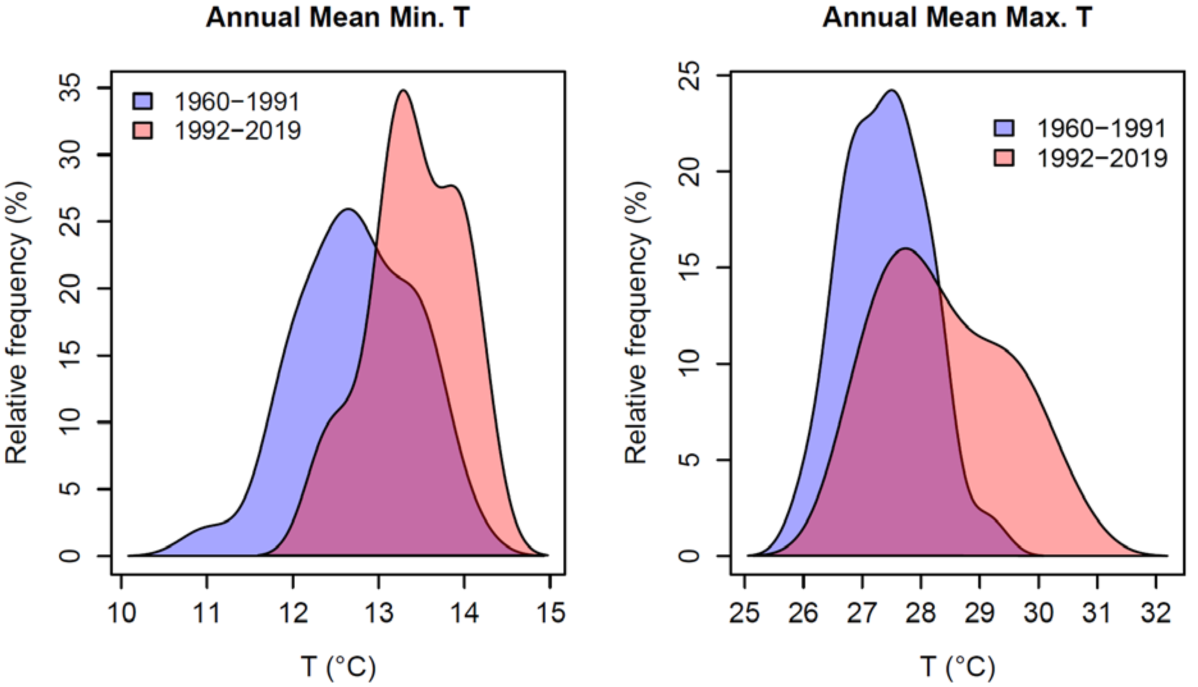

Figure 1. Probability distributions of annual mean maximum temperature (right) and annual mean minimum temperatures (left) for Mungindi for two periods, namely 1960 to 1991 and 1992 to 2019.

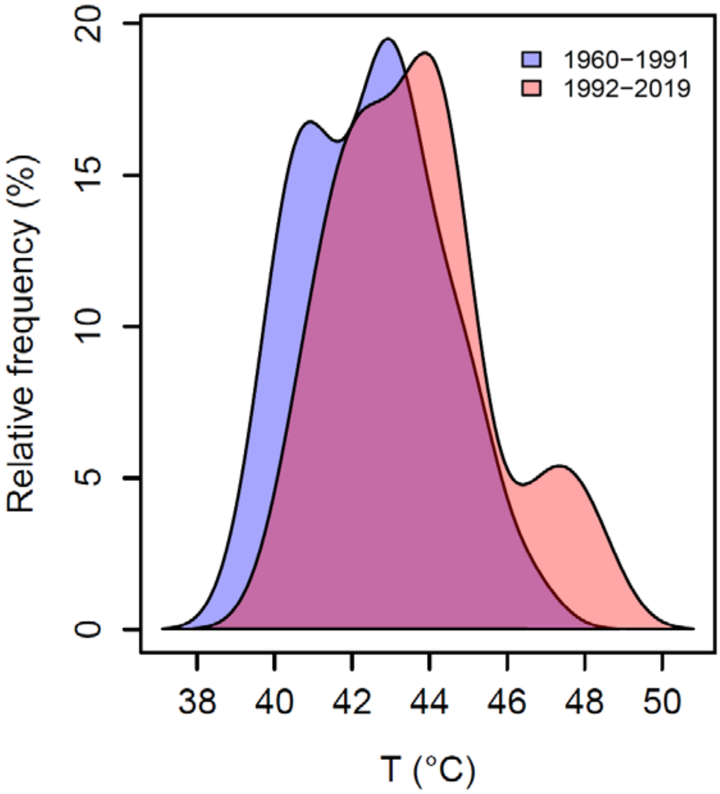

Figure 2. Probability distributions of daily maximum temperature extremes for Mungindi for two periods, namely 1960 to 1991 and 1992 to 2019.

The Mungindi rainfall record exhibits a declining trend, with an average 88mm less annual rainfall now than in the 1960s. A comparison of the annual rainfall between the period 1960 to 1991 and 1992 to 2019 (Figure 3) does show a slight change in the annual distribution of rainfall in the Mungindi region. The analysis highlights an increase in the occurrence of very low annual rainfall amounts less than 250mm in the most recent record as well as a decrease in the occurrence of annual rainfall amounts greater than 600mm (Figure 3).

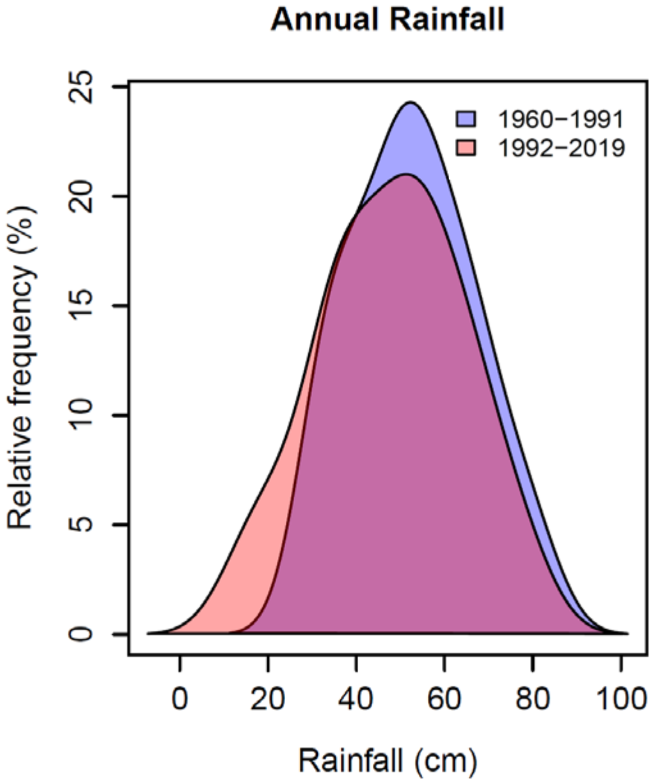

Figure 3. Probability distributions of annual rainfall amounts for Mungindi for two periods, namely 1960 to 1991 and 1992 to 2019.

The current acceleration of global warming is expected to continue based on future Greenhouse Gas (GHG) emissions trajectories. Previous studies have examined how the rates of record-breaking have changed in the US (Anderson *et al*., 2011), the UK (Kendon, 2014), and Australia (Lewis & King, 2015). These studies have found increased rates of hot temperature records and decreased record setting for cold temperatures in recent decades (King et al., 2015; King, 2017). Lewis and King (2015) found that from 2000 to 2014 there were 12 times as many hot record-breaking temperatures as cold records in Australia and attributed this to anthropogenic climate change. Recent BoM analyses has shown that from 1960-2018 the ratio of hot records to cold records set across Australia was 6:1 whereas from 1910-2018 the ratio was 9:1 (Blair Trewin pers Comm. 2020). In 2019 the ratio of hot to cold records broken at the state area average level was 34:0 (Blair Trewin pers Comm. 2020). Across the world, there were about five times more record-breaking monthly temperatures than would be expected without a long-term warming trend (Coumou et al., 2013) over the early 21st century.

During the 2018/19 Australian summer more than 206 individual location extreme temperature records were broken in just 90 days (Climate Council, 2019). Climate change has been found to not only increase the likelihood of breaking high temperature records (e.g. Lewis and Karoly, 2013), but record-breaking hot summers and years over previous decades are also attributable to anthropogenic climate change (King et al., 2016). More recent research by Mann et al. (2018) has shown that the synoptic features (large scale weather systems) responsible for prolonged heatwaves are on average 50% more prevalent under a business-as-usual GHG emissions trajectory.

In addition to record breaking temperatures, changes in rainfall patterns, sea levels, rates of glacial retreat and biological responses have also been detected consistent with expected climate change projections. This mounting evidence has led to scientific consensus that:

- Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that affect the climate system and these changes and resultant trends will continue for the foreseeable future; and
- There is at least 95% confidence that humans are the main cause of global warming since 1950, and most likely responsible for 100% of that temperature rise (IPCC, 2018) with a less than 1 in 100 000 chance that human activities are not responsible for the observed increase in global temperatures (Kokic et al., 2014).

These changes are already likely to have negatively impacted on Australian agriculture, acting as a major drag on yield growth with similar impacts on yield growth globally for the major crops (Porter et al., 2014).

A major issue in understanding historical and future climate change is how much are the various human-induced climate forcing's (greenhouse gas emissions, stratospheric ozone depletion, Asian aerosols, and landcover change) interact with components of natural variability (Watkins 2005, McKeon, 2006). Thus, it is important for successful climate adaptation that agricultural decision-makers keep informed of the evolving climate science and updated climate change scenarios. As scientific understanding improves and there is more confidence in emission scenarios, current and future uncertainties can be rapidly assessed in terms of decision making.

What is expected to happen in the future?

In response to the continued growth in atmospheric GHG concentrations, scientists estimate that global average temperatures could increase by up to 4.8^{o}C by the end of the present century, dependent on global population growth, technological advancement and economic growth (IPCC, 2013). To put this in context, the difference between our historical temperatures and those of the last ice age was only about 5^{o}C. So even though 4.8^{o}C does not sound like much, it signals a huge change in how the climate-ocean-land systems of the earth function and hence how agriculture will operate.

In Australia, national projections suggest additional warming of up to 1.3^{o}C of additional warming could be experienced by 2030 and up to 5.1^{o}C of warming could be experienced by 2090, with the greatest warming being in inland Australia and the lesser warming along the southern coast and Tasmania (CSIRO, 2015). Global studies indicate that a rule of thumb is that global potential crop production drops by 6% per degree warming (Porter et al., 2014). Whilst changes in rainfall are more uncertain, projections suggest drier conditions in the southern half of Australia, particularly in the south-west and during the cool season months of May to October, with as much as 20% less by 2030 and up to 50% less rainfall by 2090 in the south-western parts of Australia by 2090, respectively (CSIRO, 2015).

At a regional scale, projected change in climate for the New England and North West region (Mungindi represents a town in the centre of this study region) are summarised in Table 1. In addition to warmer temperatures, evaporation rates are likely to increase. By 2030 the median value of annual potential evaporation is projected to increase by 7 % under a high emissions scenario.

Table 1. Projected changes in temperature and rainfall for New England and North West region (Mungindi represents a town in the centre of this study region). Present average temperatures and rainfall are calculated for the period 1986 to 2005. The data contained in this table represents information compiled from the NSW Department of Planning and Environment.

Variable	Season	Historical mean (1986 to 2005)	2030	2070
Mean temperature change (°C change)	Annual	20.6°C	0.7 (0.4 to 1.0)	2.2 (1.8 to 2.6)
	Summer	27.5°C	0.9 (0.4 to 1.4)	2.4 (1.7 to 2.9)
	Autumn	20.8°C	0.7 (0.5 to 0.9)	2.2 (1.5 to 2.7)
	Winter	12.9°C	0.5 (0.3 to 0.7)	1.9 (1.4 to 2.4)
	Spring	21.1°C	0.8 (0.5 to 1.3)	2.3 (2.1 to 2.8)
Mean rainfall change (% change)	Annual	499mm	+1.6 (-12 to +15)	+7.7 (-10 to +25)
	Summer	179mm	-3.3 (-14 to +15)	+9.8 (-12 to +40)
	Autumn	111mm	+14.9 (-12 to +46)	+16.8 (+1.0 to +47)
	Winter	93mm	-7.6 (-29 to +16)	-0.7 (-29 to +30)
	Spring	118mm	+2.6 (-22 to +20)	-0.7 (-20 to +30)

Adapting to projected climate changes

Climate change is likely to pose a significant challenge for Australian agriculture. Of greatest concern are likely to be changes in water availability, and the change in frequency of climatic extremes (e.g. heatwaves, drought and floods).

Many of the actions required for adapting to climate change are extensions of those currently used for managing climate variability. For this reason, efforts to improve current levels of adaptation to climate variability will have positive benefits in addressing likely climate change impacts.

Examples of likely farm level adaptation options include:

- Enhancing the current implementation of zero tillage and other minimum disturbance techniques, retaining crop residues, extending fallows, changing row spacing, changing planting density, staggering planting times, traffic and erosion controls
- Alter planting decisions to be more opportunistic – more effectively taking into account environmental condition (e.g. soil moisture), climate (e.g. seasonal climate forecasting) and market conditions
- Expand routine record keeping of weather, production, degradation, pest and diseases, weed invasion
- Incorporating seasonal climate forecasts and climate change into farm enterprise plans

- Improve efficiency of water distribution systems (to reduce leakage and evaporation), irrigation practices and moisture monitoring
- Learning from farmers in currently more marginal areas
- Selection of varieties with appropriate thermal time and vernalisation requirements, heat shock resistance, drought tolerance, high protein levels, resistance to new pests and diseases and perhaps that set flowers in hot/windy conditions
- Enhance current consideration of decision support tools/training to access/interpret climate data and analyse alternative management options (e.g. APSIM, EverCrop).

There are also longer-term decisions at a family farm level - to sell up, to buy more land, where to invest. These are especially pertinent for farmers in low rainfall regions and it will increasingly be more difficult to find no-regret decisions if climate change progresses as anticipated (Hayman, 2005). These decisions, along with industry infrastructure (silos etc.) and industry support (drought policy) are hard decisions requiring full understanding of the likely future risks (Hayman, 2005).

The value of adaptation

In Australia a number of studies have examined the economic benefits of adaptation in the wheat industry at both national and regional scales under a range of likely future climate conditions. Hochman et al. (2017) highlighted that the adoption of new technology and management systems held actual yields fairly steady: without these advances, water-limited yield would have dropped by 27%. It was estimated that rainfall declines should have accounted for about three-quarters of the fall in simulated yield potential, whilst observed warming should have accounted for about a quarter of fall in yield potential.

Continued adaptation to climate change has been estimated to add an additional AU$500M per annum (Howden and Crimp, 2011) via the introduction of improved water-use efficiency options and may mitigate potential yield losses by up to 18% through broader scale adaptation (Ghahramani et al., 2015).

The results suggest a number of adaptation options exist to manage increased future downside risk, however the effectiveness of adaptation is driven by the extent of future change. Under conditions of large climate change, tactical adaptation will only have limited effectiveness and more extensive adaptation options, often defined as transformation adaptation, may be required.

Advisers have a key role to play in changing the nature of the climate change dialogue. In the space of about five years many grain growers and their advisers have moved from asking "What is climate change?" or "Is it real?" to "How do we manage for climate change?" and "What will the impact be on the grains industry?"

Advisers have a vital role to play in this dialogue, not only in assisting grain growers in reducing greenhouse gas emissions from on-farm activities, but also in developing information systems that growers can tap into in order to build farming systems that can cope with current climate variability and can adjust to ongoing climate changes.

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Maintaining wheat yield under high temperatures - how do current cultivars compare with what's coming?

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Keywords

Wheat, heat tolerance, genomic selection, phenotyping, pre-breeding

GRDC code

US00081

Take home message

- Recent Australian wheat cultivars are heat tolerant. However, new materials developed from diverse genetic backgrounds using field-based phenotyping and genomic selection suggest that levels of heat tolerance can be substantially improved.

Introduction

Periods of extreme high-temperature, particularly short periods of heat shock are a major threat to wheat yield and grain quality throughout much of the Australian wheat belt. Current projections of Australian climate change indicate that heat waves and temperature variability will become more frequent and more intense in the coming decades (CSIRO 2011, Climate Change in Australia. http://climatechangeinaustralia.com.au). It is vital that new wheat germplasm with improved high-temperature tolerance and molecular tags linked to this tolerance are developed and introduced into commercial breeding programs.

Genomic selection is a breeding method that requires a reference population of wheat lines that are phenotyped for the trait of interest and genotyped using many DNA markers distributed across the whole genome. Statistical methods are then used to estimate the effect of each DNA marker on the phenotype; the collection of all these DNA marker effects provides a prediction of genomic breeding value. This information can then be used to predict the phenotype of new plants that have known genotypes but not phenotypes. This allows early selection of plants/lines without phenotyping which decreases the breeding cycle leading to increased genetic gain.

Methods

A highly diverse set of agronomically adapted materials were assembled for phenotyping. These included thousands of new lines developed by the University of Sydney, including crosses with synthetic wheat, emmer wheat collected in warm areas, landraces, adapted germplasm with putative tolerance identified in hot wheat growing areas globally, Australian wheat cultivars and other sources of heat tolerance developed by others.

These materials were phenotyped for various traits; including yield, using a three-tiered strategy. Firstly, thousands of lines were evaluated in the field in replicated yield plots at Narrabri in northwestern NSW at different times of sowing. Later, sown materials were exposed to greater heat stress. Subsets of materials, based on performance in the previous year and estimated genetic values, were sown at sites in Western Australia (WA) and Victoria (Vic) to assess the transferability of traits. Each year, high performing lines were retained from the previous year, intolerant materials removed, and new materials added. Materials identified as heat tolerant in the times of sowing experiments were subsequently evaluated in the field during reproductive development using heat chambers to induce heat shock to confirm heat tolerance. Finally, those lines that maintained heat tolerance in the heat chambers were screened in temperature-controlled greenhouses to assess pollen viability under heat stress. Materials surviving all three stages of testing were considered highly heat tolerant.

All materials (>2000 lines) phenotyped in times of sowing experiments were genotyped using a 90K Single Nucleotide Polymorphism (SNP) platform and these formed the reference population for genomic selection from which all DNA marker effects were estimated. A prediction equation was developed and used to calculate genomic estimated breeding values (GEBVs) on selection candidates which were genotyped but not phenotyped. A genomic selection model that incorporated environmental covariates (for example; temperature, radiation and rainfall) directly was developed. This allowed the prediction of line performance under high temperature conditions. Environmental covariates were defined for each plot and growth development phase (vegetative, flowering and grain fill). An in-field validation of GEBV selected lines was then conducted by correlating GEBVs with field trial phenotypes. Various cycles of crosses were made among diverse lines with high GEBVs and progeny subsequently selected for high GEBV. These form the basis of our new elite heat tolerant materials.

Results

Extensive field-based phenotyping over a six-year period identified lines with superior adaptation to terminal heat stress (Figure 1). The tolerance of these materials was then confirmed in field-based heat chambers. The heat chambers were calibrated over a three-year period in replicated, triplicate plots (Table 1). Heat shock at anthesis significantly reduced yield compared to an ambient chamber and the uncovered plot. The ambient and uncovered plot were not significantly different from each other, and therefore, all future screening was conducted as paired plots (with and without heat chambers). The developed genotype-by-environment interaction genomic selection model increased genomic prediction accuracy for yield by up to 19%.

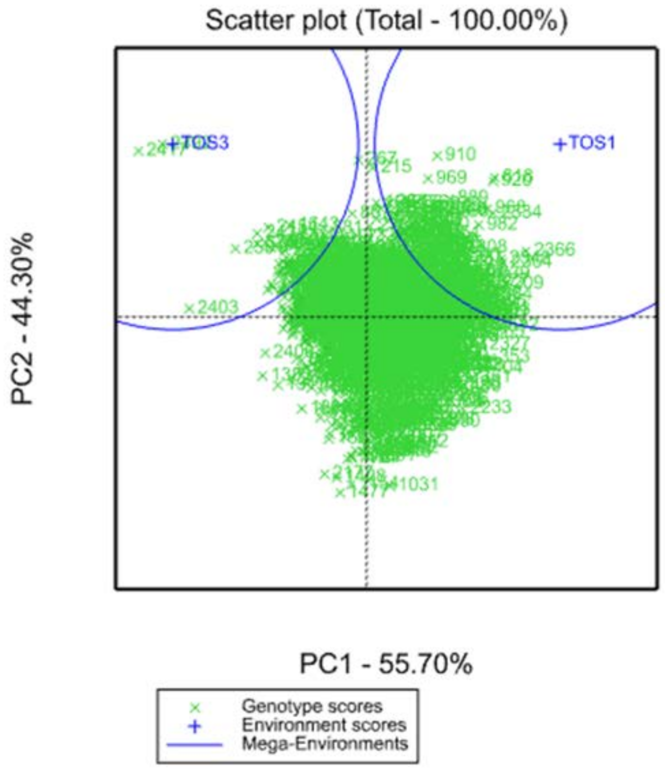


Figure 1. Genotype-by-environment interaction (GGE) biplot of yield in optimal (TOS1) and late (TOS3) sowing at Narrabri, 2013 to 2018.

Table 1. The impact of heat chambers on yield, kernel weight, kernel number and other traits, 2013 to 2015.

	Treatment			
	Ambient	Heated	No Chamber	Prob.
Yield (kg/ha)	2775 a	2248 b	2849 a	<0.001
TKW (g)	32.5	32.4	32	ns
Height (cm)	82.1	85.5	82.8	ns
Screenings%	4.09	4.89	5.13	ns
Grain number/10 spikes	49.3 a	43.8 b	48.74 a	<0.002

n.b. Means in the same row followed by different letters are significantly different.

The most heat tolerant Australian cultivars evaluated between 2013 to 2018 were the older varieties; Sunco, Annuello, Scoutⓟ, Sunstate and Langⓟ. These cultivars showed little difference in yield between times of sowing over years (Figure 2) but tended to have relatively low yield potential. However, the higher yielding, more recent varieties; EGA Gregoryⓟ, Suntopⓟ and Spitfireⓟ tended to have reduced heat tolerance. Several recently derived pre-breeding lines (PBI09C034-BC-DH38, PBI09C028-BC-DH56, PBI09C026-BC-DH5) have combined both high yield and heat tolerance.

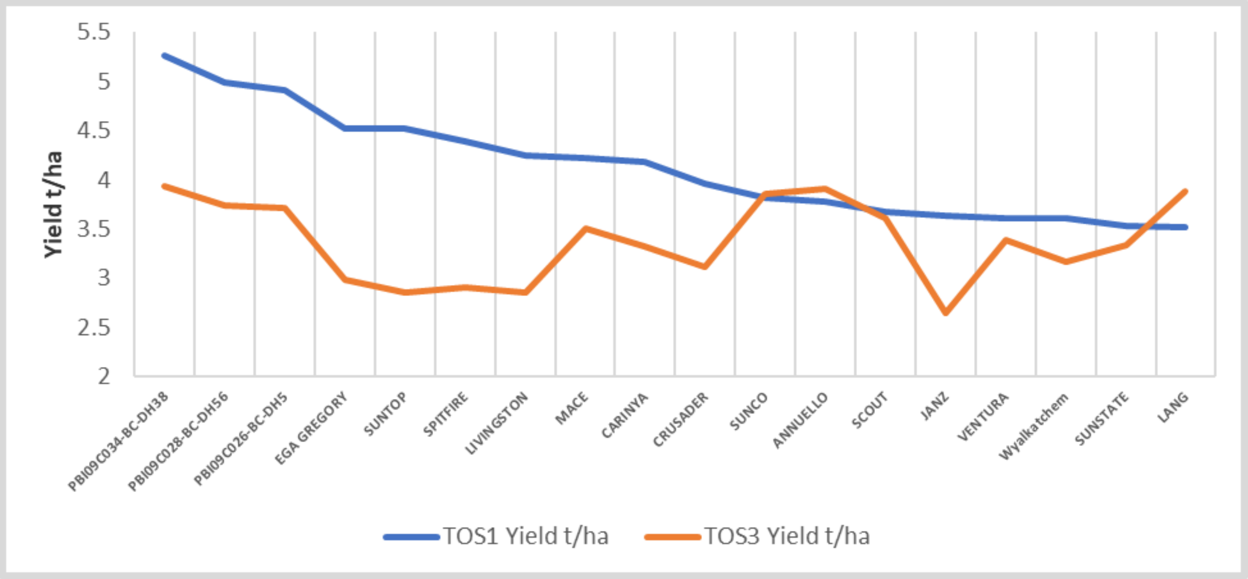


Figure 2. Yield at Narrabri (2013 to 2018) for heat tolerant lines and Australian cultivars for two different times of sowing (TOS1 and TOS2 are optimal and late sowing, respectively).

A wider range of Australia cultivars, including many recent releases, was included in 2019 (Figure 3). Mustangⓟ, Scepterⓟ, Maceⓟ, Sunmateⓟ and Borlaugⓟ all showed relatively high levels of heat tolerance. Mustangⓟ and Scepterⓟ combined this with high yield. The pre-breeding lines PBIC15020-0C-60N-010N and PBIC15022-0C-6N-010N, developed using genomic selection, also combined high yield with heat tolerance. Unlike Mustangⓟ, these materials flowered later and did not escape the high temperatures during grain fill.

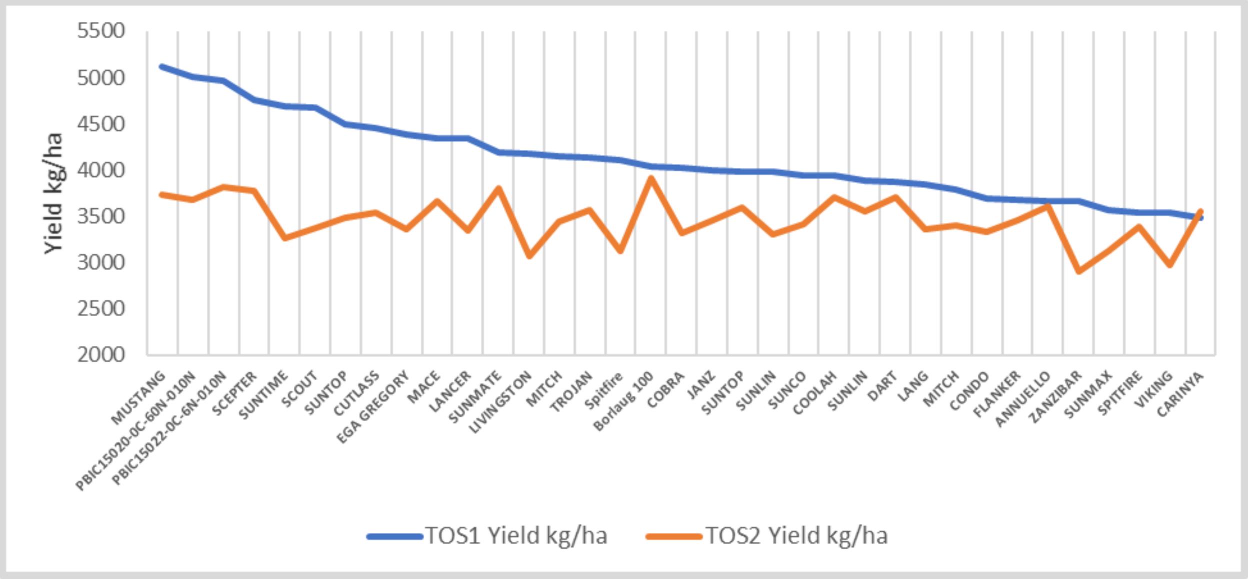
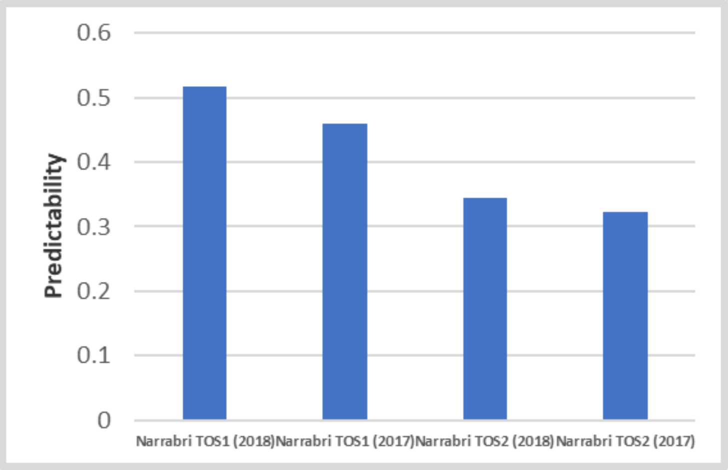


Figure 3. Yield of Australian cultivars and new heat tolerant lines at Narrabri, 2019 for two different times of sowing (TOS1 and TOS2 are optimal and late sowing, respectively).

An important aspect of this work was the transferability of the Narrabri results to other regions of Australia. Subsets of 200 lines, selected for high GEBV, were evaluated at Merredin and Horsham to validate the strategy. A training population was necessary to allow genomic prediction models to calculate GEBVs without the need for phenotyping at other sites. The accuracy of genomic prediction for yield, trained at Narrabri, was evaluated in 2017 and again in 2018 (Figure 4). When the 2018 data were included in the estimations of GEBVs, the predictability exceeded 0.5 for both early and late times of sowing.

A. Merredin



B. Horsham

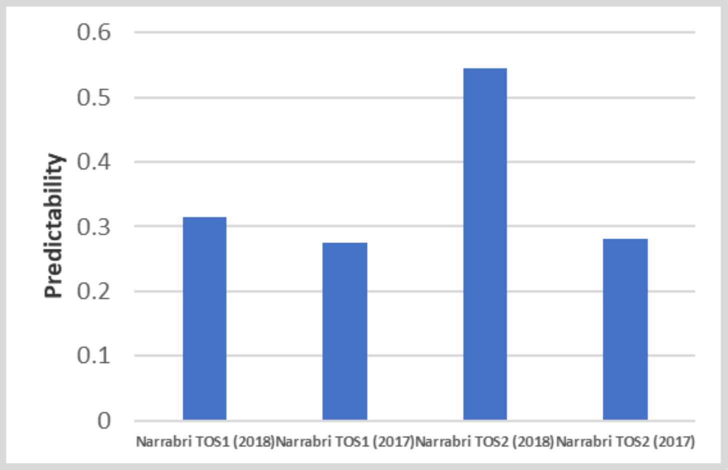


Figure 4. Accuracy of genomic prediction for yield trained at Narrabri (GEBVs calculated from five and six years of data) and validated at Merredin and Horsham in 2017 and 2018. TOS1 and TOS2 are optimal and late sowing, respectively.

Conclusion

Some recently released Australian cultivars have both the genetics of high yield and the genetics for heat tolerance. However, new pre-breeding materials developed using genomic selection offer commercial wheat breeders' new sources of diversity for both yield and heat tolerance that can be used to mitigate the effects of a warming environment. The strategy of selecting for heat tolerance at Narrabri for other regions of Australia was validated by the relatively high correlations between GEBVs and yield under heat stress at Merredin and Horsham.

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ф Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Sowing grain sorghum early: are we reducing risk and increasing opportunities?

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Key words

grain sorghum, cold tolerance, heat stress, flowering

GRDC code

Optimising sorghum agronomy project (UOQ 1808-001RTX)

Take home messages

- Grain sorghum can be sown earlier than traditionally recommended in north west NSW
- Sowing sorghum earlier than the traditional 16 – 18 °C soil temperature recommendation is possible without negatively impacting on crop establishment and grain yield. As soil temperatures decrease, plant establishment percentages and the time to emergence increase
- Defining the minimum soil temperature required is still tenuous as temperatures are variable in the late winter/early spring and the risk of mild and severe frosts is still present
- ’Winter’ sown sorghum achieves earlier flowering and harvest times and subsequently increases the fallow length to the next crop, allowing increased opportunity for double cropping.

Introduction

The traditional sowing window for grain sorghum in northern NSW has been challenged in recent years by increasing climate variability predisposing the crop to heat and moisture stress during the critical stages of flowering and grain filling. The impacts have been devastating; missed sowing opportunities, crop failure, reduced yields and grain quality with ultimately reduced returns to growers.

Similar to the changes we have seen in wheat sowing time, incremental changes to the time of sowing of sorghum crops is occurring. Traditionally, the recommendation was for soil temperatures to be 16-18°C and rising at 8 am for three days and also beyond the period of peak frost risk before we should contemplate planting grain sorghum. However, in recent years, particularly 2018-19, many crops were sown when soil temperatures were closer to 14°C, especially in the Moree region where a missed winter crop and continuing dry conditions were driving the need for cash flow.

Since 2017, GRDC, University of Queensland, NSW DPI and QDAF have partnered in a research program to test the boundaries of sowing sorghum earlier and measuring the impacts on plant establishment, crop development, grain yield and quality. Research trials have been conducted from Emerald in central Queensland, southern Qld, Moree and south to the Liverpool Plains in northern NSW.

This series of experiments were designed to deliver a data set to define how early sorghum can be planted in each of these environments and what are the potential benefits and risks from adopting this strategy of ’winter sown sorghum‘. The experiments considered both the actual sorghum crop as well as the follow-on impact on crop rotation intensity and even the possibility of ratooned sorghum.

This paper includes results relevant to the Mungindi region, including two trials established in 2019-20 at “Bullawarrie” and “Morialta” as well as results from a harvested trial at Moree in the 2018-19 season. Two other sites, not discussed here, were sown in the 2019-20 season at Moree and Breeza. Site details for the 2019-20 season are outlined in Table 1.

2019/20 season

Two trial sites were established in the 2019/20 season in the Mungindi region. Both of these sites were established using post sowing drip irrigation due to the lack of rainfall.

All of the sites established well, however due to the continuing drought conditions the trials did not survive beyond the vegetative stages.

The watering at establishment allowed collection of a good set of establishment data from both sites, however grain yield and in crop biomass data was not able to be collected.

Each of the trial sites included 2 times of sowing, with the first time of sowing (TOS) aimed to occur when soil temperatures reached 12°C. A total of 9 hybrids were included at each site sown at four different plant populations (Table 2).

Table 1. Site characteristics for three sorghum time of sowing trials sown during the 2018/19 and 2019/20 season

Time of sowing (TOS)	Sowing date	Soil temp. at 8am[#] (°C)	PAW Soil water[##] at sowing (mm) to 120 cm	In-crop rainfall[a] (mm)	PS[b] Irrigation* (mm)	PE Irrigation[b] (mm)*
2019-20						
"Bullawarrie" Mungindi, QLD (dryland)						
1	22nd & 23rd July	7.7 at sowing 9.3 average for following 7 days (Tinytag)	19 (pre water)	10	**33**	**33**
2	2nd & 3rd Sept	11.5 at sowing 14.1 average for following 7 days (Tinytag)	43 (post water)	10	**33**	**-**
"Morialta" Mungindi, NSW (dryland)						
1	30th July	9.8 at sowing 4.7 average for following 7 days	105 (pre water)	12	**33**	**33**
2	10th Sept	5.9 at sowing 6.4 average for following 7 days	227.12	12	**33**	**-**
2018-19						
"Ponjola" Moree, NSW (dryland)						
1	7 & 8 Aug	12.3	97.5	199.7	33*	-
2	11 & 12 Sept	17.1	112.8	153.2	-	-
3	27 Sept	18.9	115.7	153.2	-	-

[#] Average soil temperature (℃) at 8 am at sowing depth for seven days after sowing
[##] Soil water (mm, 0-1.2 m) at the time of sowing
** Bore water was applied post sowing using dripper lines to ensure even establishment due to dry seedbed moisture conditions. Additional in-crop watering was applied using the same method to try and prevent trial failure.*
[a] – in-crop rainfall current to 16th January 2020.
[b] - PS = post sowing, PE = post emergence

Table 2. Description of sowing dates, target populations, row spacing and hybrids treatments in 2018-19 and 2019-20.

Time of sowing (TOS)	Target plant population (pl/m^2)	Row spacing (m)	Hybrids
2019-20			
"Bullawarrie" Mungindi, QLD (dryland)			
1	3	1.5 m solid	A66, A75, Agitator, Cracka, HGS114, MR Taurus, MR Buster, Sentinel IG
2	6		
	9		
	12		
"Morialta" Mungindi, NSW (dryland)			
1	3	1.5 m solid	A66, A75, Agitator, Cracka, HGS114, MR Taurus, MR Bazley, MR Buster, Sentinel IG
2	6		
	9		
	12		
2018-19			
"Ponjola" Moree, NSW (dryland)			
1	3	1.0 m solid	MR Buster, MR Apollo, MR Taurus, Agitator, Cracka, HGS114, A66, G33
2	6		
	9		
3	12		

Results and discussion

"Bullawarrie" Mungindi – 2019/20

There was quite a bit of fluctuation in soil temperatures in the weeks following TOS 1 (Figure 1). This was also accompanied by some cold temperatures which did not result in plant death. Some minor signs of frosting were noted.

The first plant counts were recorded 22 days after sowing from TOS 1 (22 July). Plant counts were then conducted each week until the trial succumbed to the drought. No rainfall fell for 3 months following sowing.

TOS 2 was quicker to emerge, with the first plant counts occurring 15 days after sowing. Time of sowing had a significant impact on plant establishment. TOS 2 had better establishment than TOS 1 (Figure 2).

With the exception of the lowest population of 3 plants/m^2, there was a significant difference in establishment between the different target plant populations (Figure 2). An incremental increase in the rate of seed sown in TOS 1 was required to achieve similar establishment as with a lower seed rate in TOS 2. There was also difference between the establishment of hybrids, with the variety Agitator having the lowest plant populations (data not shown).

Plants continued to emerge over the weeks following sowing and then started to die due to the lack of moisture. The maximum emergence was recorded at the second plant count which was either 25 or 31 days after sowing (TOS 1 or 2 respectively).

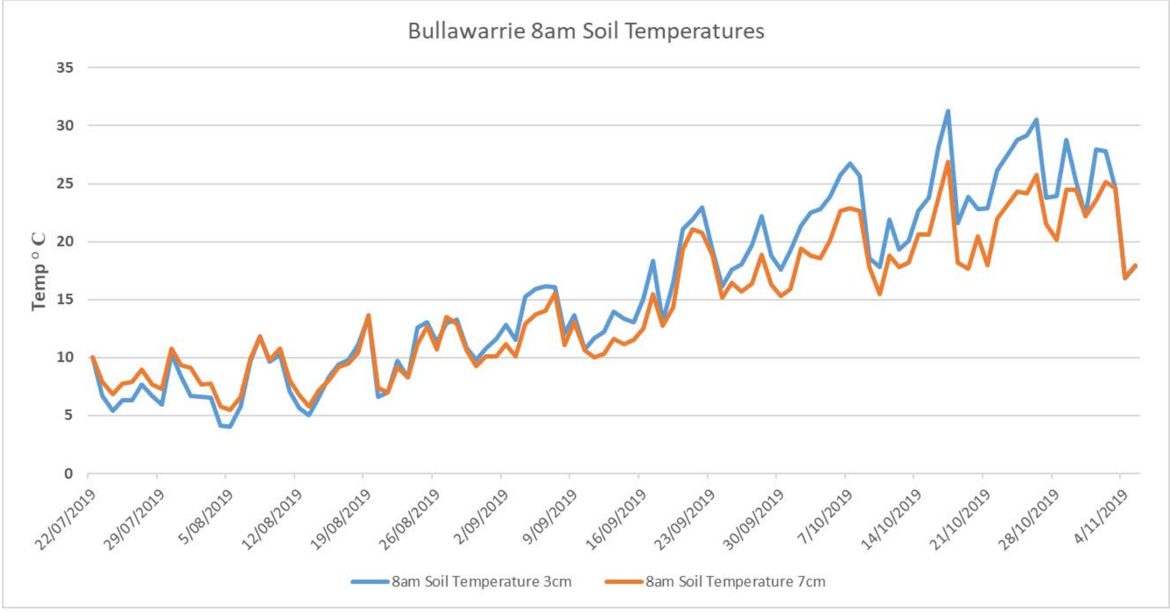

Figure 1. Soil temperatures around sowing at "Bullawarrie" - 2019

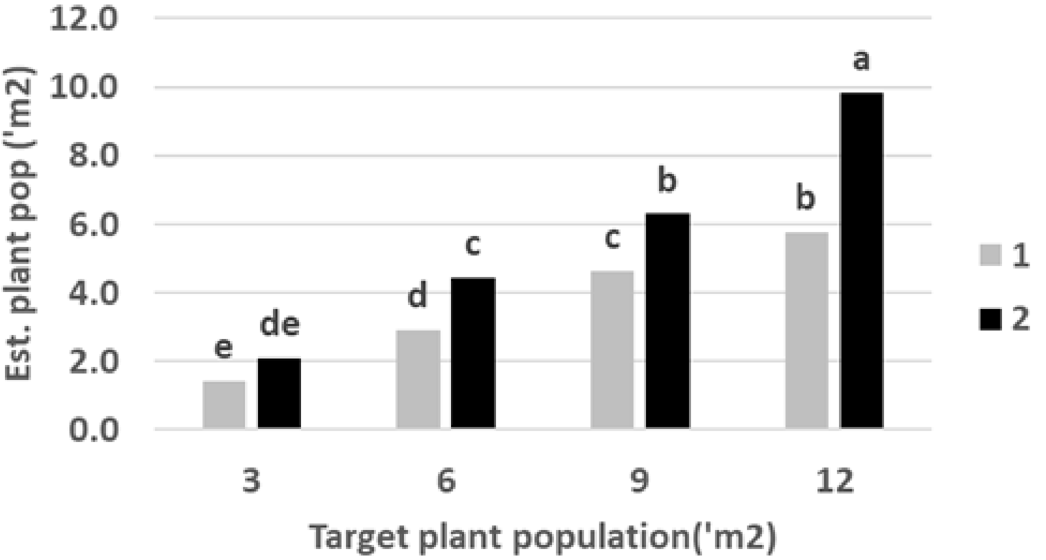

Figure 2. Sorghum plant establishment at different target plant populations (averaged across hybrids) at "Bullawarrie" - 2019/20 for time of sowing dates 1 and 2

"Morialta" Mungindi – 2019/20

The first plant emergence counts were recorded 29 days after TOS 1 (30 July). This was longer than the time taken for emergence at "Bullawarrie" due to a cold snap and declining soil temperatures below the 12°C which had been targeted (data not shown).

Except with the lowest target plant population of 3 plants/m^2, establishment from TOS 1 was statistically comparable to the higher target population at TOS 2 (Figure 3). For example, the TOS 1, 12 plants/m^2 treatment was the same as 9 plants/m^2 at TOS 2.

Therefore, while TOS 1 still achieved a commercial plant population, the establishment losses were higher from sowing at much colder temperatures (4.7°C for the 7 days following sowing) than waiting and sowing at TOS 2 (6.4°C for the 7 days following sowing; Table 1).

Plants continued to emerge over the weeks following sowing and then started to die due to the lack of moisture. No plant deaths were recorded as a result of frost at this site (data not shown). Maximum emergence was recorded at the second plant count which was either 37 or 20 days after sowing (TOS 1 or 2 respectively).

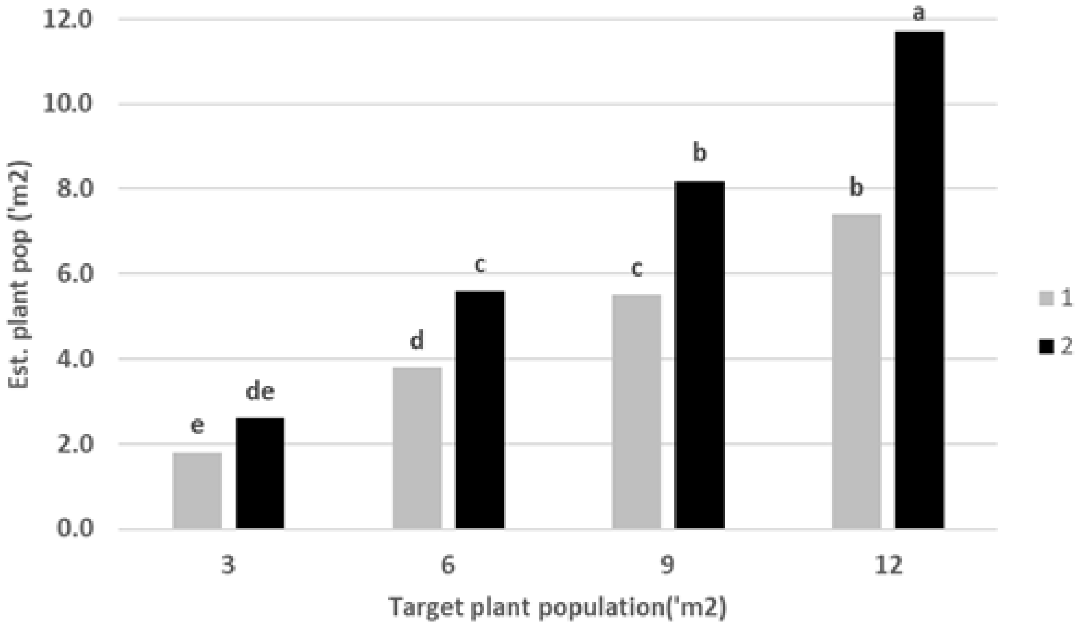

Figure 3. Sorghum plant establishment at different target plant populations (averaged across hybrids) at "Morialta" - 2019/20 for time of sowing 1 and 2

2018/19 season

"Ponjola" Moree – 2018/19

Plant establishment

The first time of sowing (TOS) occurred under dry seedbed conditions. To help ensure even establishment at the desired soil temperature, a total of 33 mm of water was applied one-week post sowing using dripper lines. The first establishment counts which recorded plants emerging were taken on the 31st August, 3 weeks post sowing and 2 weeks post watering. Plants emerged slower under TOS 1 than TOS 2 and TOS 3 which had more even and quicker establishment.

There was no impact of time of sowing on any of the final established plant populations, except the 12 plants/m^2 treatment which established more plants at later TOS (Table 3).

Table 3. Impact of time of sowing time on mean plant establishment (plants/m^2 established) versus target population at "Ponjola"

Target plant population (plants/m^2)	TOS 1 (7 August)	TOS 2 (11 Sept)	TOS 3 (27 Sept)
3	2.44 f	2.63 f	2.77 f
6	5.22 e	5.23 e	5.34 e
9	7.60 d	8.32 cd	8.35 cd
12	8.94 c	10.80 b	11.83 a
L.s.d: 1.02, P<0.05			

There was an interaction between TOS and hybrid. Comparing across times of sowing, Agitator had the poorest establishment at nearly all TOS. TOS 2 and TOS 3 had improved establishment for nearly all hybrids when compared to TOS 1, however differences were not always statistically significant (data not shown).

Did sowing earlier impact on flowering?

There was a significant impact of sowing time, population and hybrid on the number of days taken to reach 50% flowering.

Sowing timing had a significant impact on days to flowering; the earlier we sowed, the longer the time taken to reach flowering. TOS 1 took an average of 106 days to reach 50% flowering, which reduced to 82 days for TOS 2 and 75 days for TOS 3.

Delaying sowing from TOS 1 to TOS 2 (a period of 4 weeks); reduced the time to 50% flowering by 24 days. The days to flowering difference between TOS 2 and TOS 3 was much smaller, only 7 days, even though there was a 16-day difference in sowing time.

In TOS 1, the slowest hybrid to reach 50% flowering was MR-Apollo at 115 days, and the quickest was Agitator at 99 days, a spread of 16 days over the eight hybrids examined. In contrast by TOS 3, MR-Apollo flowered in 81 days, while Agitator was 70 days, a difference of 11 days. Agitator was consistently the quickest and MR-Apollo consistently the slowest of the hybrids tested to reach 50% flowering (Figure 4).

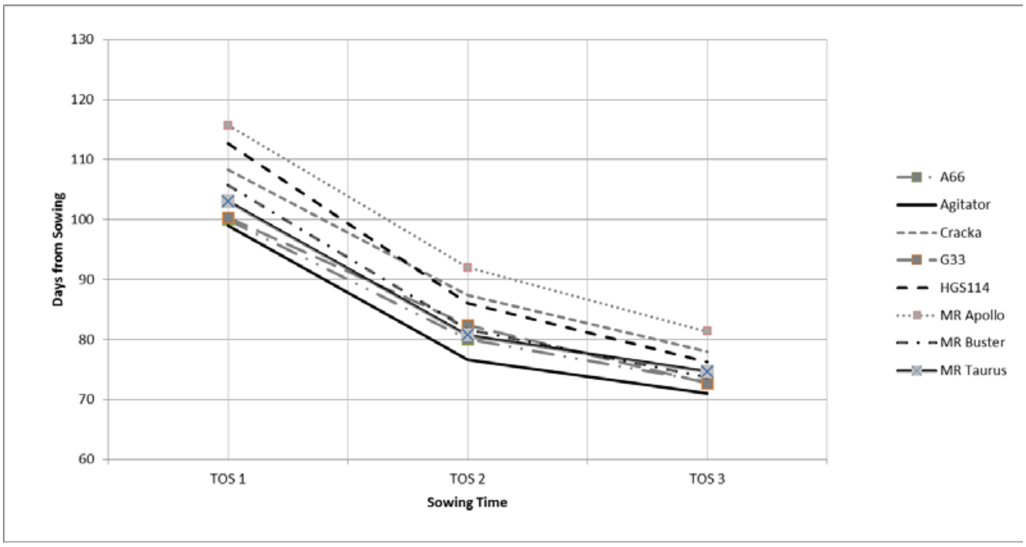

Figure 4. Days to 50% flowering at "Ponjola" for 6 plants/m^2 target population.

TOS 1 moved the flowering window for all hybrids forward by around three weeks compared to sowing at the recommended soil temperature (TOS 3). This meant flowering was completed prior to the onset of very high temperatures at the beginning of December (Figure 5).

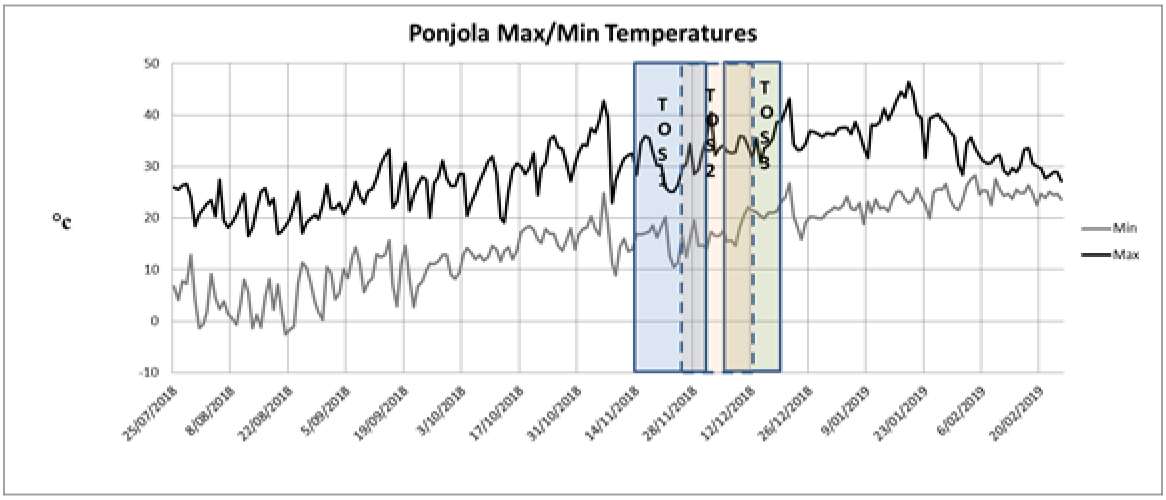

Figure 5. The flowering windows for TOS 1, TOS 2 and TOS 3 at "Ponjola" Moree in 2018-19

What was the impact on grain yield and quality?

The site mean yield was 1.78 t/ha at “Ponjola” in 2018-19. There was a significant interaction between time of sowing and hybrid yield (Figure 6). Plant population did not have a significant impact on grain yield. TOS 1 was the highest yielding at 2.14 t/ha. There was no significant difference in yields achieved between TOS 2 and TOS 3 being 1.51 and 1.68 t/ha respectively.

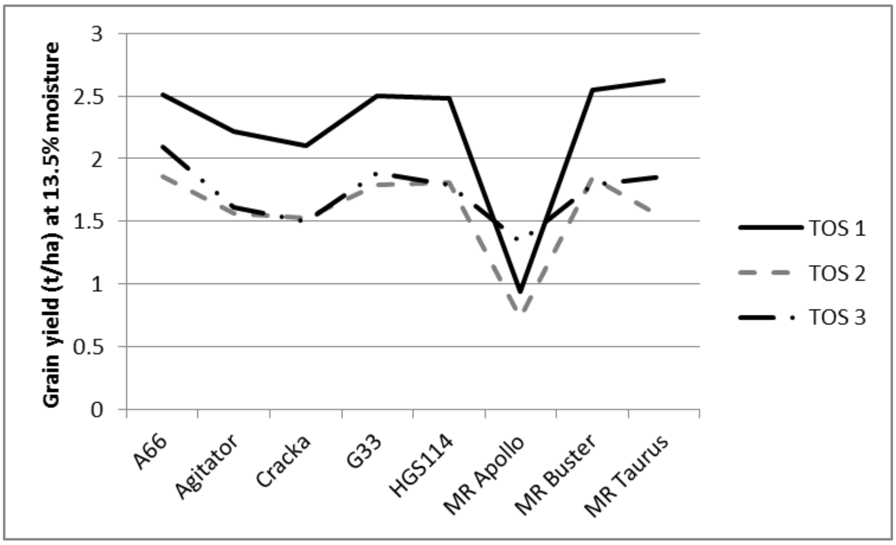

Figure 6. Grain yield at three times of sowing (TOS) at "Ponjola" Moree in 2018-19

Grain protein achieved was significantly less at TOS 1 (10.7%) compared to the TOS 2 and TOS 3 planting times at 11.1% and 11.2% respectively. However, all grain proteins were still at an acceptable level to show that nitrogen was not limiting yield.

Screenings were impacted by TOS, population and hybrid. TOS 1 had significantly lower screenings at 10.0% compared to TOS 2 at 16.6% and TOS 3 at 17.9%. The hybrid interaction was also significant, with Agitator averaging the lowest screenings at 10.5%, while G33 and MR-Buster had the highest between 18-19%. The 12 plants/m^2 target population was the only treatment to show significantly higher screenings at 15.9%, while all other target plant populations were between 14-15%, when averaged across hybrids and sowing times. This means that only TOS 1 met the sorghum 1 standards for screenings.

Test weights were generally low. No hybrid averaged the required test weight to achieve grade 1 sorghum (>71 kg/hL). The only treatment to achieve sorghum 1 was Cracka at TOS 3 with 71.3kg/hL (data not shown).

Conclusions

While only one season of establishment data has been collected in the Mungindi region, the conclusions reached are in line with the previous season's data at other sites in northern NSW. It is possible to establish 'winter sown sorghum' at lower than recommended soil temperatures, as long as there is acceptance that reduced establishment percentages and slower emergence will result. Reduced establishment can be compensated for by increasing the sowing rate.

Sowing earlier moved the flowering and grain fill periods forward in experiments conducted near Moree. This has also allowed some avoidance of additional heat at flowering and grain filling, as well as completion and harvest of the crop without the need for drying. The earlier sowing times have also provided higher yields in most previous seasons.

There is still an inherent risk of frost (either killing or mild) from sowing earlier than traditionally recommended. The exact details of how cold the temperature needs to be to cause significant plant death still remains undefined.

The earlier sowing time of sorghum also provides an opportunity for greater cropping intensity in the system as harvest is brought forward, thus allowing the fallow recharge period to commence earlier than normal. This increases the chances of planting a double crop such as chickpea into a profile with more plant available soil water compared to a traditional sorghum sowing time.

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Nutritional strategies to support productive farming systems

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Key words

fertilisers, placement, blends, recovery efficiency, application strategies

GRDC codes

UQ00063, UQ000666, UQ00078, UQ00082

Take home messages

- A critical success factor for cropping systems that rely heavily on stored soil water is co-location of plant nutrients with moist soil and active roots
- Our current fertiliser management practices need refinement, with low efficiency of fertiliser recovery often associated with nutrients and water being in different parts of the soil profile
- There needs to be greater consideration of placement and timing of fertiliser applications to improve fertiliser nutrient recovery
- Declining native fertility reserves means more complex fertilizer combinations will be needed to meet crop demands.

Introduction

This paper is based on a series of observations made in recent years from the projects listed above, as well as others made by Richard Daniel and the NGA team in their work on fertiliser N application strategies for winter crops. Collectively, the findings from this research, backed by the underlying regional trends in soil fertility and the drivers for successful rainfed cropping in our region, provide some useful insights into what are likely to be the critical success factors for future fertiliser management programs.

Do we have successful fertility management systems?

To maximise the chance of achieving effective use of available moisture, an effective fertiliser management strategy needs to consider all of the 4R's (right product, in the right place, at the right time and at the right rate – Johnson and Bruulsema 2014). While everyone pays lip service to these 4R's, our real thinking is often driven by considerations about only one – rate. We spend a lot of time agonising over rate, because rate is clearly an important part of the economics of growing the crop. Rate is also an important consideration in terms of soil fertility maintenance (i.e. replacing what we remove in grain). In many cases the rate we can afford is not always the rate we need to apply to optimise productivity, much less balance nutrient removal, but we still spend a lot of time thinking about it.

Because of that, we find that the thinking about the other 3R's tends to be much more superficial. Occasionally we might have a try at something a bit different, but in many cases we tend to keep doing what we have always done, and put the same products in the same place at the same time each year. Meanwhile, our background soil fertility reserves have fallen and our crops are becoming increasingly reliant on off-farm sources of fertility (fertilisers, manures etc.) to sustain productivity. It is this increasing reliance on fertilisers, especially N, P and (increasingly) K, that is allowing us to really see the inefficiency in current use practices. The impact of these inefficiencies in terms of lost productivity can often dwarf any of the considerations of rate, and are highlighting challenges for productivity and profitability in the long term.

We will now cover some examples of inefficiencies that are apparent in what has been considered as best practice for both N and P, and how the emergence of K infertility is adding further complexity to fertiliser best practice.

Management of fertiliser N

In the case of N in winter cereals, the recent comprehensive analysis of a series of N experiments from 2014-2017 by Daniel et al. (2018) highlighted the poor winter crop recovery of fertiliser N applied in the traditional application window (the months leading up to sowing, or at sowing itself). Fertiliser N recovered in grain averaged only 15% for applications of 50 kg N/ha and 9% for 100 kg N/ha. On average, 65% of the applied N was still in the soil as mineral N at the end of the crop season, while an only 15% was in the crop (grain and stubble). The fate of the other 20% of applied N could not be determined. Some of the soil and stubble N will carry over until the next season, but it means that you need <u>last</u> year's residual fertiliser to get you through <u>this</u> year. If you had a big year last year (little residual N) or lost a lot of the N carryover during a wet season, the current crop will suffer.

The poor winter crop recovery of applied N in the year of application mirrored that reported for summer sorghum in the NANORP research program reported by Bell, Schwenke and Lester (2016), with the use of ^{15}N tracers enabling a more precise quantification of the fate of N applied prior to planting. Data from the Queensland sites in commercial fields are shown in Figure 1 for the 40 and 80 kg N rates across three growing seasons. Fertiliser N in grain averaged 27% and 23% of the applied N for the 40 and 80N rates, respectively, while total crop uptake averaged only 37% and 32% for the same N rates. What is noticeable in this figure is the variable N losses (presumably via denitrification) and the residual N in the soil, which may or may not be available for a subsequent crop in the rotation, depending on the fallow conditions. Schwenke and Haig (2019) reported good carryover of fertiliser applied for the 2013/14 sorghum crop for recovery by the 2014/15 season under favourable fallow conditions, while extensive loss of residual soil N after summer crops was experienced over large areas during the wet 2016 winter fallow.

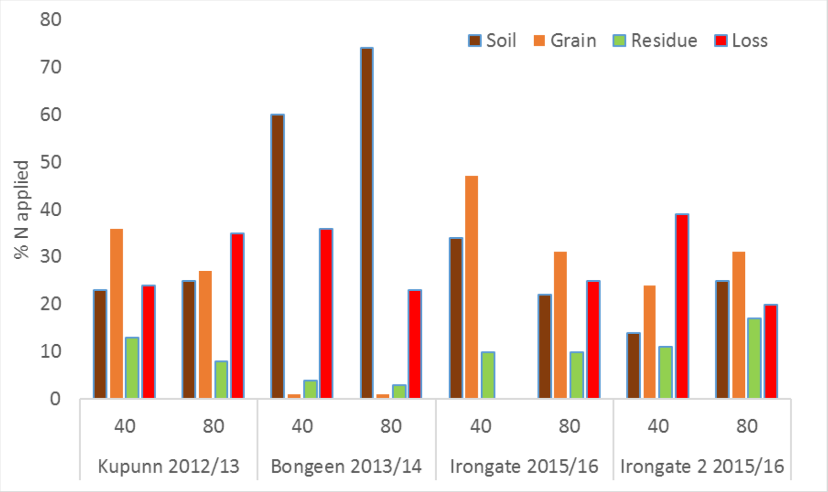


Figure 1. Partitioning of fertiliser N between soil, plant and environmental loss pools for summer sorghum crops grown on the Darling Downs in UQ00066 from 2012 – 2016.

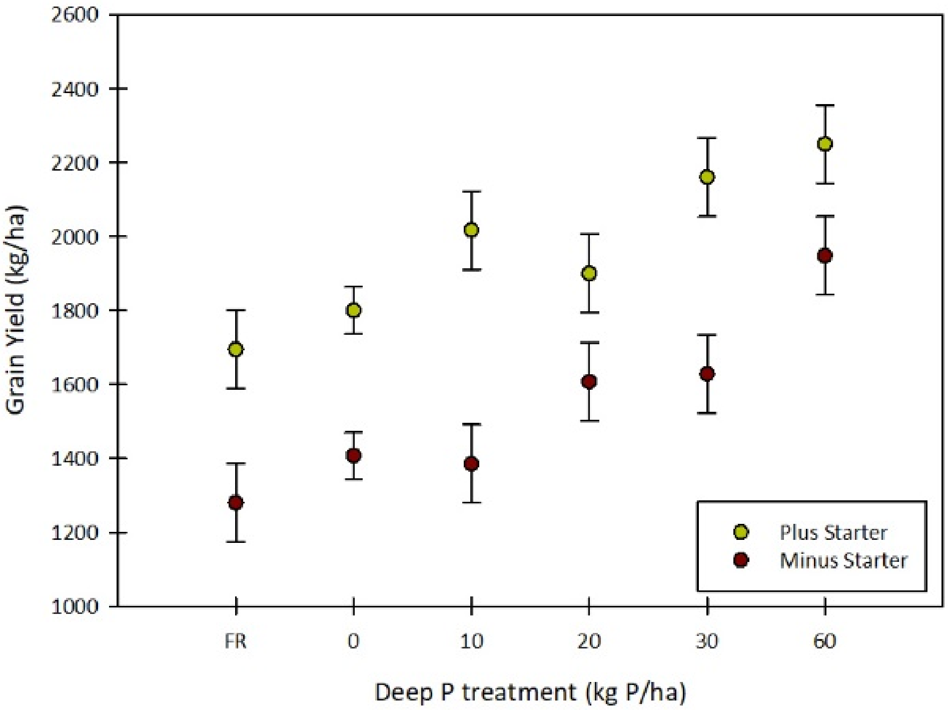
All studies have shown there can be significant amounts of residual N in the soil at the end of the growing season. Large amounts of that N are often found in quite shallow parts of the soil profile (i.e. the 0-10cm and possibly 10-20cm layers) and still strongly centred on the fertiliser bands, despite what were often significant falls of rain in-crop (i.e. 200-300mm). Even after a subsequent fallow, the Daniel et al. (2018) paper reported that 50-60% of the mineral N residual from fertiliser applied in the previous season was still in the top 45cm, with as much as half of this still in the 0-15cm layer. This largely surface-stratified residual N would have contributed to the quite muted (although still significant) grain yield response to the residual N in those studies.

Interestingly, findings from both the summer sorghum and winter cereal research suggest that crops recover mineral N that is distributed through the soil profile with much greater efficiency than fertiliser applied at or near sowing. In both seasons, 70-80% of the mineral N in the soil profile was recovered in the crop biomass, compared to recoveries of applied fertiliser that were commonly less than half that. The distribution of that N relative to soil water is likely to have played a major role in this greater recovery efficiency.

Management of fertiliser P

The substantial responses to deep P bands across the northern region where subsoil P is low have been detailed in a number of recent publications (Lester et al. 2019b, Sands et al. 2018), with these responses typically additive to any responses to starter P fertiliser (the traditional P fertiliser application method – e.g. Figure 2a, b). There has unfortunately been no direct measurement of P unequivocally taken from either deep or starter P bands due to the lack of suitable tracer technology, especially when we consider residual benefits over 4-5 years. However, simple differences in biomass P uptake in a single season suggest that the quantum of P accumulated from deep bands (3-5 kg P/ha) is substantially greater than that from starter P alone (1-1.5 kg P/ha) in all bar exceptionally dry seasons.

a)



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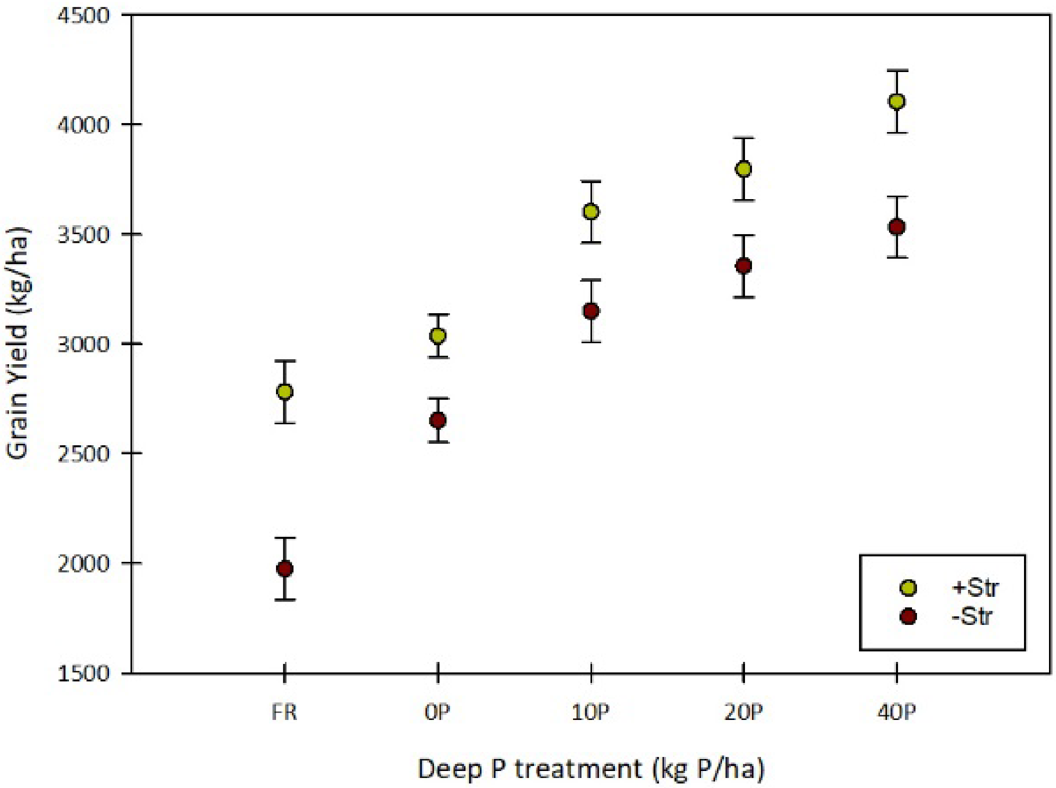


Figure 2. Response to different rates of deep P with and without applications of starter P fertiliser in (a) a wheat crop at Condamine in 2018 wheat, and (b) a sorghum crop at Dysart in 2018/19 grain yield for deep-placed P treatments (kg P/ha) with or without starter application. The vertical bars represent the standard error for each mean. (Lester et al. 2019a).

Perhaps one of the most significant findings from the deep P research has been the relative consistency of P acquisition from deep bands, despite significant variability in seasonal conditions. Research results from sites in Central Qld (CQ) often provide the best examples of this, due to the extremely low subsoil P reserves in some of those situations – if the crop cannot access the deep P bands, there is not much to find anywhere else in the subsoil! Interestingly, this type of profile P distribution is consistent with the lack of grain yield responses to starter P that were recorded over a number of years of trials in CQ and that contributed to reluctance to use starter P in some situations. Early growth responses that were consistent with the crop obtaining an extra 1-1.5 kg P/ha from the starter application were observed, but a lack of available profile P to grow biomass and fill grains limited any resulting yield responses.

The inability to acquire P from a depleted subsoil places greater importance on access to P in the topsoil, which means that seasonal rainfall distribution can have a huge impact on crop P status. This is illustrated for a site near Clermont in Figure 3 (a, b), in which the growing season conditions and crop P acquisition by successive crops of sorghum and chickpea are compared. From a yield perspective, deep P increased crop yield by 1100 kg and 960 kg for the sorghum and chickpea crops, relative to the untreated Farmer Reference treatment, and by 720 kg and 970 kg/ha for the same crops relative to the 0P treatment that received ripping and other background nutrients. The similar size of yield responses in the two crops represented quite different relative yield increases (40-60% in the sorghum, versus about 300% in the chickpeas), and obviously had hugely different impacts economically, given the price differential between sorghum and chickpea grain. However, from a nutrient use efficiency perspective it is interesting to note that the apparent P acquisition from the deep P bands was similar (3.3 kg P/ha in the sorghum and 2.7 kg P/ha in the chickpeas – Figure 3b)) despite the vastly different in-season rainfall (Figure 3a).

What is dramatically different, and what is driving the much larger relative yield response in the chickpea crop, was the inability to access P without deep P bands in that growing season. Crop P contents in the Farmer Reference and 0P treatments averaged 2.9 kg P/ha in the sorghum crop but only 0.6 kg P/ha in the chickpeas. This difference was driven by the combination of deep sowing and extremely dry topsoils encountered in the 2018 winter season. The chickpea crop was planted below the 0-10cm layer, and there was never enough in-season rainfall to encourage later root growth and P recovery from that layer. Despite available moisture in the subsoil, there was not much P available to support growth and yield. In contrast, the sorghum crop was planted into the relatively P-rich top 10cm layer, which was then rewet regularly over a significant proportion of the vegetative phase. This allowed better P acquisition from the background soil, but the deep P bands were still able to supplement this and provide an additional yield benefit.

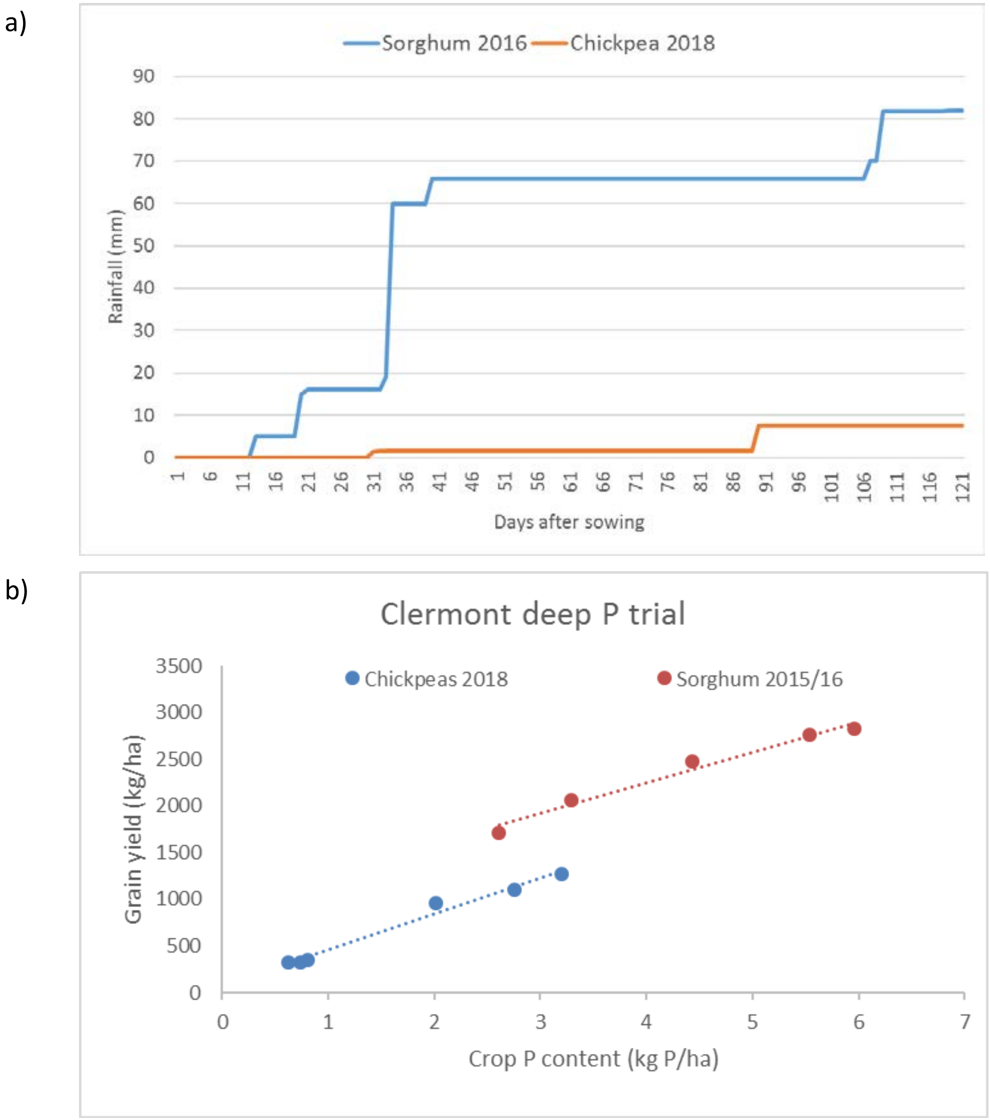


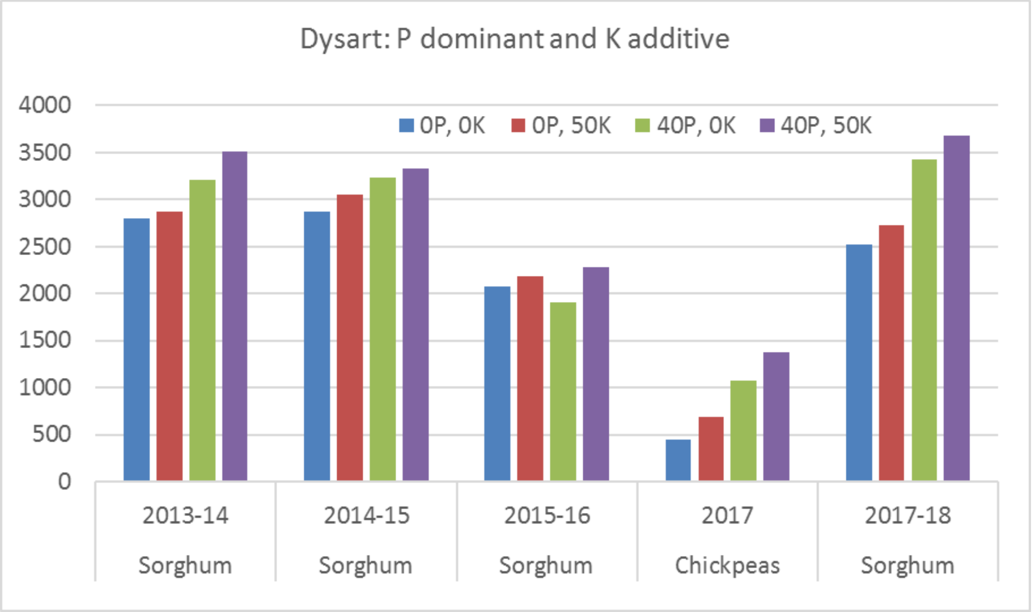
Figure 3. (a) Cumulative in-crop rainfall and (b) the relationship between crop P content and grain yield for consecutive crops of sorghum (2015/16) and chickpea (2018) grown at a site near Clermont, in Central Queensland (Sands et al., 2019).

Choice of product to address multiple nutrient limitations

As native fertility has been eroded by negative nutrient budgets and/or inappropriate placement, there are an increasing number of instances of complex nutrient limitations that require compound fertilisers to address multiple constraints, with the relative severity of each constraint changing from season to season. Perhaps the best example has been the emergence of widespread examples of K deficiency in recent (drier) seasons, but which can 'disappear' in more favourable ones. This is an example of the impact of increasingly depleted and more stratified K reserves, and is an issue that adds complexity to fertility management programs. Soil testing benchmarks for subsoil nutrients are improving as a result of current programs, but at best they are only likely to ring alarm bells for the different constraints, rather than predict the relative importance of each in future (uncertain) seasonal conditions. Examples provided in Figure 4, again from sites in CQ, show fields where subsoil P and K would both be considered limiting to productivity, but the responses to deep placed P and K have varied with crop and seasonal conditions. Assuming enough N is applied, the site at Dysart shows a dominant P constraint which is evident in most seasons, and a smaller K limitation that is only visible once the P constraint has been overcome. The Gindie site, on the other hand, has limitations of both P and K, but the relative importance of each constraint seems to depend on the crop choice and/or seasonal conditions. In both cases, the appropriate agronomic response would be to apply both nutrients, but the relative economic returns of adding K to the fertiliser program (as opposed to higher/more frequent P additions) would be different.

The emergence of multiple constraints such as those shown in Figure 4 require a greater understanding of the implications of co-location of different products, especially in concentrated bands applied at high(er) rates, less frequently. There is evidence that effective utilisation of banded K, at least in Vertosols, is dependent on co-location with a nutrient like P to encourage root proliferation around the K source (Figure 5 – Bell et al., 2017). However, there is also evidence that there can be negative interactions between P and K applied together in concentrated bands that can reduce the availability of both nutrients. There is an existing investment (UQ00086) exploring the reactions that occur in bands containing N, P and K, and the implications of changing the products and the in-band concentrations on nutrient availability.

a)



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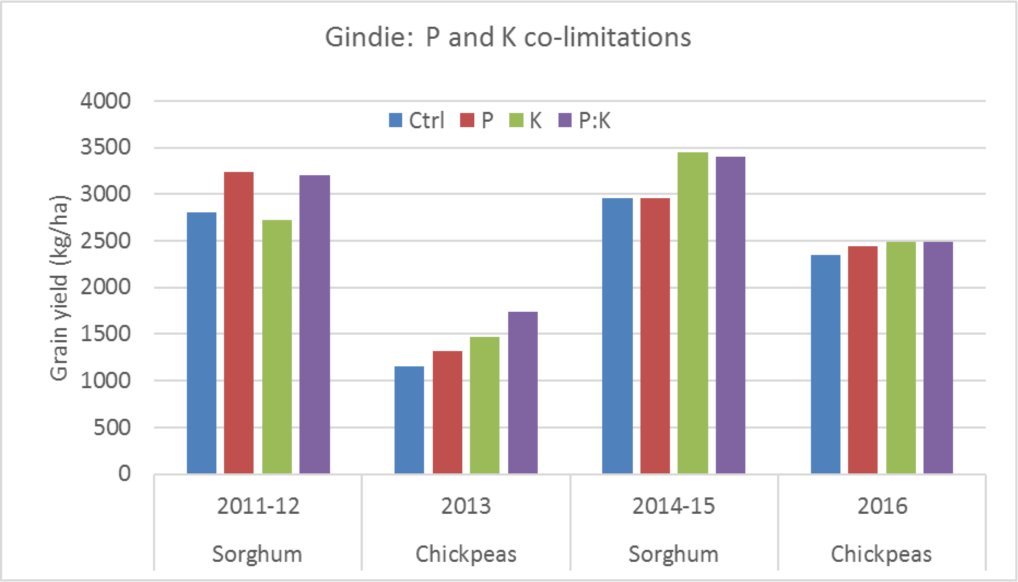

Figure 4. Examples of combinations of P and K limitations to crop performance at (a) Dysart and (b) Gindie, and the response to deep banded applications of those nutrients alone, or in combination.

What are the key farming systems characteristics complicating nutrient management?

The changing nutrient demands in dryland grains systems, especially on Vertosols, are driven by the combination of nutrient removal that has not been balanced by nutrient addition (especially in subsoil layers), and the reliance of our cropping systems on stored soil water for long (and in some cases all) of the growing season. Crops need access to adequate supplies of water and nutrients to perform, and while crop roots can acquire water from a soil layer with little to no nutrient, they certainly can't acquire nutrients from soil layers with little or no available moisture. The co-location of water, nutrients and active crop roots enable successful crop production. Historically our cropping systems have been successful because (i) soils originally had moderate or higher reserves of organic and inorganic nutrients; (ii) there were sufficient reserves of those nutrients at depth so the crop could still perform when the topsoil was dry; and (iii) our modern farming systems are now much better at capturing water in the soil profile for later crop use.

Our soils are becoming increasingly characterised by low organic matter, with reserves of P and K that are concentrated in shallow topsoil layers and depleted at depth. Our typical fertiliser management program applies all nutrients into those topsoil layers, with the immobile ones like P and K staying there, and the mobile nutrients like N applied late in the fallow or at planting, when there is no wetting front to move the N deeper into the subsoil layers. Without that wetting front, even mobile nutrients like N are not able to move far enough into the soil profile to match the distribution of water – at least for the targeted crop season. We also grow a very low frequency of legumes in our crop rotation, which increases overall fertiliser demand and produces residues that are slow to decompose and release nutrients during the fallow and for the following crop. This means that nutrients like N are mineralised later in the fallow, again with less chance to move deeper into the soil profile for co-location with stored water.

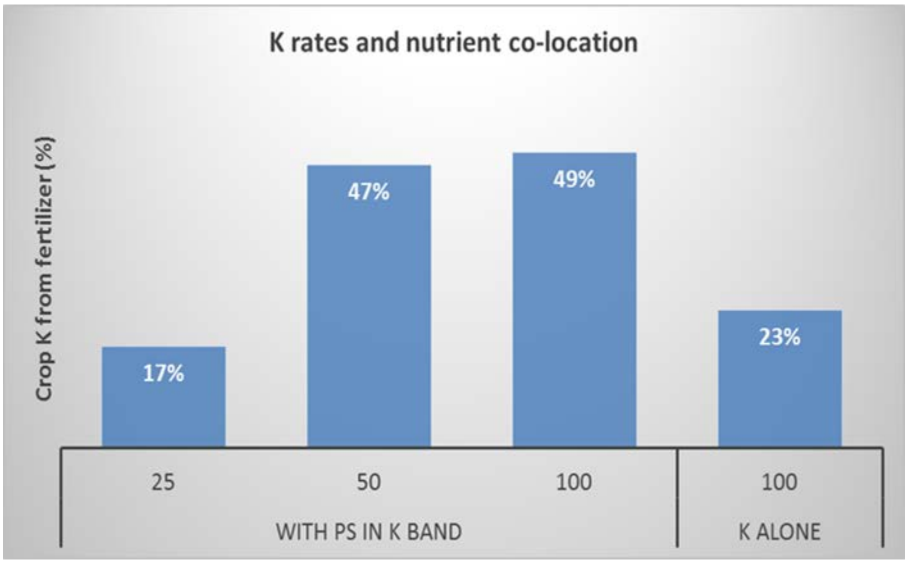

Figure 5. The impact of rate of applied K and co-location of K with other nutrients in a band (in this case P and S) on the proportion of crop K that was derived from applied fertiliser.

The net result is an increasing frequency of dislocated reserves of stored soil water and nutrients, with in-crop rainfall at critical stages being a major determinant of whether the crop will be able to acquire the nutrients to achieve the water-limited yield potential. Unless our management systems change to address these issues, there will inevitably be a decline in overall water use efficiency across the cropping system, with an increasing frequency of poor or unprofitable crops. The changes that we think are needed require a stronger focus be placed on the 'forgotten' 3R's – right product (product choice/combination), in the right place, at the right time.

In the concluding section of this paper, we provide a brief outline of what we feel are going to be key strategies that need to be considered in future nutrient management programs. We note that a number of these have not yet been extensively validated, or are simply hypotheses that are worthy of testing. However, they do provide what we think are opportunities to address some of the main nutrient supply issues outlined in the preceding sections of this paper.

Future nutrient management opportunities

In general

- Focus more on feeding the soil to support the farming system, in addition to targeting the next crop in the rotation sequence. This will involve applying nutrients at a time and in a part of the soil profile that maximises the chance of having nutrients co-located with water when future crops need it. Making those decisions once the profile water has largely accumulated and the planting decision is more certain is resulting in frequent spatial dislocation between nutrient and water supply
- Where possible, legume crops should be grown with greater frequency, as they reduce the fertiliser N demand. This will allow diversion of money from the fertiliser budget spent on N into other nutrients that can be exploited across the rotation
- Be adaptive in your fertiliser management program. Respond to the opportunities that are offered to put the right nutrient in the right place at the right time, and chose the right combination of products to match the soil nutrient status. This will involve a good understanding of the variation in profile nutrient status from field to field, and also understanding how seasonal conditions may impact on those application decisions.

For specific nutrients

Nitrogen (N)

- Understanding the soil water holding and drainage characteristics is critical, as strategies appropriate for heavy clays will not be suitable for lighter textured soils. For example, in clay soils you should be prepared consider changing the timing of at least some of the fertiliser N input, so it is applied into dry soils at the beginning of a fallow. The Daniel et al. (2018) paper showed nice examples of how early fallow N applications can increase the proportion of fertiliser N that is accumulated in deeper profile layers, potentially ensuring N availability with deep water to enable continued growth when the crop is experiencing dry periods. The greater efficiency of recovery of distributed 'soil' N compared to freshly applied fertiliser may allow possible rate reductions that could help to offset any interest paid on early fertiliser investment
- Be aware when conditions have changed from the 'normal' upon which your current fertiliser strategies have been based. For example, what would differences in (especially shallow) profile moisture status at the beginning of a fallow mean for the denitrification risk to early N applications? How should you respond to an unusually large crop that has depleted the soil N profile and left stubble that is low in N? How would you respond to an unseasonal rainfall event after N applications had been made?
- Legume residues should better synchronise the release of N with the recharge of profile moisture during a fallow. This should result in soil N that is more readily accessible during a following crop, as well as a lower fertiliser N requirement.

Phosphorus (P) and Potassium (K)

- Don't ignore starter fertilisers, but also be aware that they are not an effective solution to meeting crop P demand in most seasons, and adding K to starter blends can impact the 'salt' risk to crop establishment
- While there is no requirement for starter K to meet early growth demands, starter P has an important role to play in early season growth and establishing yield potential, even though the amount of P acquired from the starter P band is quite small. There may be opportunities to reduce the rates of P applied at planting if uniform distribution along the seeding trench can be maintained, where fluid forms of P may possibly having a role. The 'saved' P should be diverted into increased rates or frequencies of deep P application
- Starter P is especially important in very dry seasonal conditions, and can have an unusually large impact on crop P uptake due to restricted access to the rest of the P-rich topsoil. Under these conditions, starter P can also have a large impact on secondary root growth and improved soil P access
- Deep P and K work – use them. Question marks still exist about the length of the residual effect, and some of the risks from co-locating products in a band. Minimise the risk by applying products in more closely spaced bands (i.e. at lower in-band concentrations) more often (i.e. lower application rates)
- Remember that the main subsoil constraint has generally been P, so get the P rate right and complement that with additional K as funds allow
- Don't let subsoil P and K fall too far! Whilst we have got some great responses to deep P (and K) bands, and they are certainly economic, we have not seen evidence that a deep banded application (of P at least) is sufficient to completely overcome a severe deficiency. The band is a very small proportion of the soil volume, and when roots proliferate around a band, they dry it out. Unless the band area re-wets during the season, allowing roots a second opportunity to access the banded nutrient, the amount of nutrient recovered will be limited. In short, bands provide a useful but not luxury supply. Nutrient concentrations in foliage and grains still show signs of crops that are still P deficient in many situations, and it is obvious that the greater the

volume of subsoil that can be fertilised (more bands, more often) the greater the chance we have of meeting crop demand.

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Grower experience with Deep P

Tom Woods, Woods Pastoral Pty Ltd, Billa Billa

Take home message

This is a rare opportunity to utilise existing resources (land, equipment, moisture, present cropping options) to increase production

Why?

- David Lester's Research
- Age of cultivation
- Soil tests are low
- Yield targets

Rates

- What rate?
- 100 / 120 kg starter
- 20 units P

When

- Ideally after sorghum
    1. Longer time to melt down with no fear of loss
    2. Can apply with urea on same pass with some risk of loss
    3. Can apply after chickpeas but there is less time for country to recover

How to apply?

- Tractor
- Implement
- Spacing
- Direction
- Depth (15cm to 25cm)

Costs

- Approximately $80 per ha for product
- Approximately $20 per ha for fuel, wages, wear and tear
- Total cost $100 per ha

Cost recovery

- With grain @ $300 per tonne, need an extra 1/3 tonne yield increase per ha over the life of the application

How often?

- Currently unanswered. Possibly 5 to 10 years

Unforeseen benefits and pitfalls

- Benefits - deep ripping, opening soil and breaking hard bands
- Pitfalls - application too wet or too late

Other cost comparisons

- Shire rates - No yield increase
- Chemical - No yield increase (sustains only)
- Camera spray - Reduces costs but no yield increase

Nutrition discussion session

Notes

New technologies for the Australian grains industry - observations from a 4 month Fulbright Fellowship study tour of the USA and Germany

Craig Baillie, NCEA, University of Southern Queensland

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Notes

Modifying variety and sowing date with frost risk and slope - how big are the potential gains and why?

Matt Gardner, AMPS Research

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Notes

Cover crops improve ground cover in a very dry season

Andrew Erbacher[1], David Lawrence[1], David Freebairn[2], Neil Huth[3], Brook Anderson[3] & Graham Harris[1]

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Key words

cover crops, millet, ground cover, soil water storage, fallow management, stubble, evaporation, infiltration, plant available water

GRDC code

DAQ00211

Take home messages

- Previous trials have shown cover crops can increase stored fallow water and improve crop performance and returns in northern farming systems
- A cover crop in a long fallow (14 months) in a dry season allowed improved ground cover with no net deficit in soil water. The extra ground cover improved the opportunity to deep plant wheat.
- A cover crop in a short fallow had a water cost that translated to a yield penalty.
- When the sorghum stopped growing in dry conditions it continued to use water, for no biomass (or cover) increase when it wasn't sprayed out.

Cover crops in the northern region

After missed or failed crops over recent seasons, ground cover is becoming increasingly important for maintaining fallow efficiency and importantly, for protection from wind and water erosion. Cover crops, sprayed out and left for ground cover, have been used to protect the soil from erosion in low stubble situations, with added benefits of returning biomass that helps maintain soil organic matter and biological activity and provide additional nitrogen when legumes are used. Cover crops also offer an opportunity to increase infiltration and fallow moisture storage for more profitable grain and cotton crops across the northern region of New South Wales (NSW) and Queensland.

Scientific rationale

Stubble and evaporation

Retained stubble provides ground cover, protects the soil from rainfall impacts and so improves infiltration to store more water in the soil. Conventional wisdom is that increased stubble loads can slow down the initial rate of evaporation, but that these gains are short-lived and often lost due to evaporation, unless follow-up rainfall occurs within several weeks. However, further rain within this period and the manipulation of stubble to concentrate stubble loads provides an opportunity to reduce total evaporation and to accumulate more plant available water.

Advances in agronomy and commercial agronomist support have seen growers better use their available soil water and improve individual crop performance. However, more effective capture and storage of rainfall across the whole farming system remain as major challenges for northern grain and cotton growers where only 20-40% of rainfall is typically transpired by dryland crops, up to 60% of rainfall is lost to evaporation, and a further 5-20% lost in runoff and deep drainage. Every 10 mm of extra stored soil water available to crops could increase dryland grain yields for growers by up to 150 kg/ha, with corresponding benefits to dryland cotton growers as well.

The GRDC funded Farming systems projects (DAQ00192/CSA00050) are assessing ways to improve this system water use, and to achieve 80% of the water and nitrogen limited yield potential in our cropping systems. Previous GRDC Eastern Farming Systems and Northern Growers Alliance trials both suggest that cover crops and increased stubble loads can reduce evaporation, increase infiltration and provide net gains in plant available water over traditional fallow periods. Consequently, cover crops have potential to be part of improved farming systems; providing increased profitability and better soil protection.

Dryland grain systems

Cover crops are used in southern Queensland and northern NSW to overcome a lack of stubble and protect the soil following low residue crops (e.g. chickpea, cotton) or following skip-row sorghum with uneven stubble and exposed soil in the ‘skips’.

In long fallows leading to a winter crop, growers typically plant white French millet or sorghum, and spray them out within ~60 days, to allow recharge of the soil water extracted by the cover crop. Allowing these ‘cover crops’ to grow through to maturity led to significant soil water deficits and yield losses in the subsequent winter crops. However, the Eastern Farming Systems projects showed only small deficits (and even water gains) accrued to the subsequent crops when millets were sprayed out after 6 weeks, with average grain yield increases of 0.36 t/ha in subsequent crops. Furthermore, the Northern Growers Alliance showed that the addition of extra stubble (from 5-40 t/ha) after winter crop harvest appeared to further reduce evaporation, with initial studies showing between 19 mm and 87 mm increases in plant available water. These gains will be valuable if validated in further research and are able to be captured in commercial practice.

Our current project is monitoring sites intensively to quantify the impact of different stubble loads on the accumulation of rainfall, the amount of water required to grow cover crops with sufficient stubble loads, the net water gains/losses for the following crops and the impacts on their growth and yield.

Summary of previous results

Experiment 1 was a winter cover crop followed by overhead irrigated cotton near Yelarbon. Barley cover crops grew 1.2 t/ha biomass for early spray out and up to 5 t/ha for the late sprayed out barley. The early terminated barley had the most plant available water (PAW) when the cotton was planted, however, the extra resilience of the mid and late terminated barley captured more of the applied water in the soil, once irrigation of the young cotton crop commenced. Cotton yield showed a large benefit in all of the cover crop treatments over the bare fallow (control).

Experiment 2 was a spring cover crop followed by dryland wheat near Bungunya. The millet cover crops at this site produced 1.5 t/ha biomass (early terminated), and up to 4.5 t/ha for the late sprayed crop. The treatments with the most cover (and biomass) had the most stored water at the end of April. With the longer fallow after the cover crop, the early terminated cover crop broke-down before the wheat was planted. In deep planted wheat the treatments with higher ground cover established even wheat stands, while the bare fallow (control) and some treatments with fragile cover had an uneven / gappy wheat establishment. The wheat crop in the bare control yielded 1.4 t/ha, while the wheat following late terminated millet had 20 mm more PAW at planting and a more even wheat stand which enabled it to extract more of the stored water, so had an improved yield of 2.8 t/ha (net economic benefit of $280/ha).

A detailed summary of these trials can be found in Queensland grains research 2018-19: https://www.publications.qld.gov.au/dataset/queensland-grains-research/resource/3865017c-7ebf-40bc-89c9-640829b313c7

Or in a 2019 GRDC Update paper at: https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/03/cover-crops-can-boost-soil-water-storage-and-crop-yields

Learnings from a dry season

This paper reports on two dryland sites in southern Queensland in the record breaking 2018/19 drought years.

The first experiment (Yagaburne) was in a long fallow from sorghum to wheat, so the cover crop was planted earlier in the season allowing earlier spray out and a longer fallow period to recharge the soil water used. This experiment had improved planting opportunities with higher ground cover, but no PAW difference at planting, so the evenly established wheat yielded the same in all treatments.

The second experiment (Billa Billa) was in a short fallow from chickpea to wheat. This cover crop was planted later in spring and had a shorter fallow period after spray out to recharge the PAW used by the cover crop. There was a PAW penalty for growing the cover crop in this season, which translated to reduced grain yield.

Experiment 3 – Yagaburne (Skip-row sorghum, long- fallowed to dryland wheat)

The Yagaburne experiment was in a long-fallow paddock following skip-row sorghum that was harvested in February 2018. This paddock was a zero till fallow, with standing sorghum and wheat stubble present. There were two times of planting for cover crops, with winter cover crops planted in July 2018 with 65 mm of PAW, and spring cover crops planted in October 2018 with 90 mm PAW. The subsequent wheat crop was planted on 30 May 2019, harvest in October 2019. Soil water was measured at key times with gravimetric soil coring, then more regularly with a neutron moisture meter and EM38. Cover crop biomass, and ground cover was measured at termination of the cover crop and periodically through the fallow. Grain yield of the wheat crop following the cover crop was measured to quantify the value of plant available water (PAW) differences between cover crop treatments.

The winter cover crop was wheat at 100 plants/m^2 and winter multispecies cover crop was half recommended rates of wheat, vetch and tillage radish (50, 30 & 20 plants/m^2). The summer cover crop was white French millet at 100 plants/m^2, sorghum cover crop was a sudan x sudan hybrid at 65 plants/m^2, and multispecies was with white French millet, lab lab and tillage radish at half recommended rates (50, 30 & 20 plants/m^2) (Table 1).

Three planned termination times matched key growth stages of the main cereal treatments: Early-termination at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production. The site was planned to be planted to wheat in May 2019, but with no planting opportunity and no rain forecast, it was dry planted on 27 May 2019 using the growers single disc planter (33⅓ cm row spacing), with trickle irrigation applied for crop establishment.

Table 1. Cover treatments applied at the Yagaburne site prior to planting wheat, biomass at termination of each cover crop (does not include the 1700 kg/ha of residual stubble, centred mostly on the sorghum row, in all treatments including the 'bare control') and percentage ground cover at the last termination date and at the end of the fallow period.

#	Cover crop	Termination time	Biomass grown (kg/ha)	Ground cover % 5/12/2019	Ground cover % 2/05/2019
1.	Bare (control)		0	8	8
2.	Wheat	Early-sprayout	86	12	11
3.	Wheat	Mid-sprayout	410	26	24
4.	Wheat	Late-sprayout	697	45	42
5.	Wheat	Late-sprayout + roll	718	50	45
6.	Winter multi-species (wheat, vetch, radish)	Mid-sprayout	538	38	31
7.	Millet	Early-sprayout	527	62	37
8.	Millet	Mid-sprayout	1412	89	80
9.	Millet	Late-sprayout	2043	94	87
10.	Millet	Late-sprayout + roll	1945	97	84
11.	Sorghum	Mid-sprayout	2551	96	93
12.	Summer multi-species (millet, lab lab, radish)	Mid-sprayout	1117	65	46

With the late planting date of the winter cover crop the early sprayed wheat grew 86 kg/ha of biomass, which did not provide useful levels of cover (Table 1).

The mid terminated winter cover crop had 36 mm less PAW at termination than planting (Figure 2) for 400 kg/ha biomass. With 50 mm rainfall in October the late terminated wheat was 5 mm drier than at planting with 700 kg/ha of resilient straw. All winter cover crops had recovered to similar PAW as the control when the summer cover crops were planted.

With an extra 90 days and 75 mm rain in fallow, the summer cover crop had 26 mm more PAW than when the winter cover crop was planted. The early, mid and late terminated millet cover crops were 25 mm, 46 mm and 80 mm drier at termination than when they were planted (Figure 2). Biomass produced by the millet was ~ 500, 1400 and 2000 kg/ha for early, mid and late termination respectively (Table 1).

The sorghum cover crop sprayed-out at its mid termination growth stage was sprayed out on the same day as the late terminated millet and used the same volume of water and grew similar biomass as the late terminated millet.

With the dry autumn of 2019, the paddock was assessed on 14 May for the potential to plant wheat across the trial. At ten days after 8 mm rain and 45 days since the last significant rainfall, the conclusion was that only the plots with the highest levels of cover (i.e. greater than 40% cover, but more was better, Table 1), had enough surface moisture to allow an even establishment of wheat. The four treatments with the best cover (mid, late and late + rolled millet and sorghum cover crops), had good moisture for planting; three treatments were too dry (bare control, early and mid wheat cover crops) and the other five treatments would have been a marginal planting opportunity. With no rain received by the end of May and no forecast rain, it was decided to dry plant and apply trickle irrigation to the seed row for crop establishment.

When the wheat 'cash crop' was planted, the bare control had similar PAW as when the trial commenced 11 months earlier after 240 mm rain (580 mm average annual rainfall). Previous trials have shown variability in sampling of +/- 10 mm, so there was no real difference in PAW at this time with the best cover crop treatments having 10 mm more PAW than the control and the worst had 10 mm less than the control. Volumetric soil water post-harvest had a similar spread with the wheat extracting on average 61 mm of PAW from the profile. With only 17 mm of in crop rain the wheat yielded 570 kg/ha.

Two plot header runs were taken for each plot at this site: one over the previous sorghum rows and the other over the skip (Figure 1). There was a consistent yield increase for yield in header runs taken over the old sorghum rows when compared to runs taken over 'the skip row', with an extra 126 kg/ha yield measured on the old sorghum rows versus the skip (632 kg/ha vs 506 kg/ha).

Figure 1. Residual stubble at the Yagaburne site at emergence of the winter cover crop and undisturbed on the right.

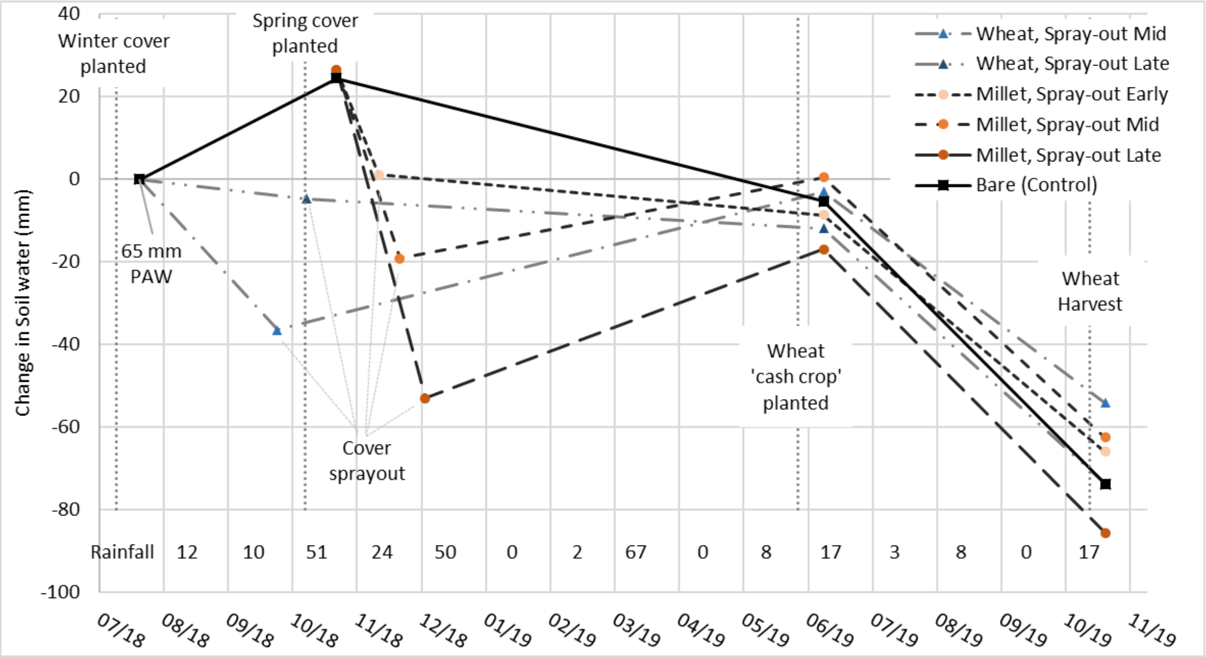

Figure 2. Change in plant available water for a range of cover crops at the Yagaburne site, measured with soil cores to 150 cm depth. Grids represent each month and numbers in the bottom row are mm rainfall for that month.

Experiment 4 – Billa Billa (Chickpea or wheat fallowed to dryland wheat)

The Billa Billa experiment had plots pre-planted to wheat or chickpeas to create areas of high and low stubble cover, with the view to grow cover crops in the low cover plots left by the chickpea crops. The wheat plots were also harvested tall (50 cm) and left standing or rolled or harvested short (25 cm) with tops removed or left as mulch (Table 2).

Wheat and chickpea were harvested on 26 October 2018 and a sudan X sudan hybrid sorghum cover crop was planted a month later with 90 mm PAW. The sorghum established over 100 plants/m^2.

Three planned termination times matched to key growth stages were planned similar to previous experiments: early, mid and late. Early termination was sprayed five weeks after planting. With no in crop rainfall and high plant populations, the crop stopped development at second node, so mid termination was sprayed three weeks after the early spray, and late termination was held off until after rain fell, being sprayed 25 March 2019 (four months after planting).

Table 2. Crops planted at the Billa Billa trial to generate different cover levels and stubble or cover crop managements imposed in the fallow period.

Preceding crop	Treatment
Wheat	Harvest high (50 cm)
Wheat	Harvest high and rolled
Wheat	Harvest low (25cm), tops spread
Wheat	Harvest low, tops removed
Chickpea	Bare (control)
Chickpea	Sorghum spray-out early
Chickpea	Sorghum spray-out mid
Chickpea	Sorghum spray-out mid + rolled
Chickpea	Sorghum spray-out late
Chickpea	Sorghum spray-out late + rolled

At planting of the cover crop, the wheat stubble plots had 34 mm more PAW than the chickpea stubble plots. From the time of cover crop planting, PAW had decreased by 59 mm to early termination; by 81 mm to mid termination and by 60 mm to late termination (Figure 3). This shows that the sorghum continued to use water after it stopped developing, with minimal increase in biomass (Table 3). Biomass produced by the cover crops averaged 1.3 t/ha for the three termination timings. Whilst this offered a significant improvement in ground cover over the bare control, the cover crops had ~1 t/ha less biomass and ~15% less ground cover than the wheat stubble plots.

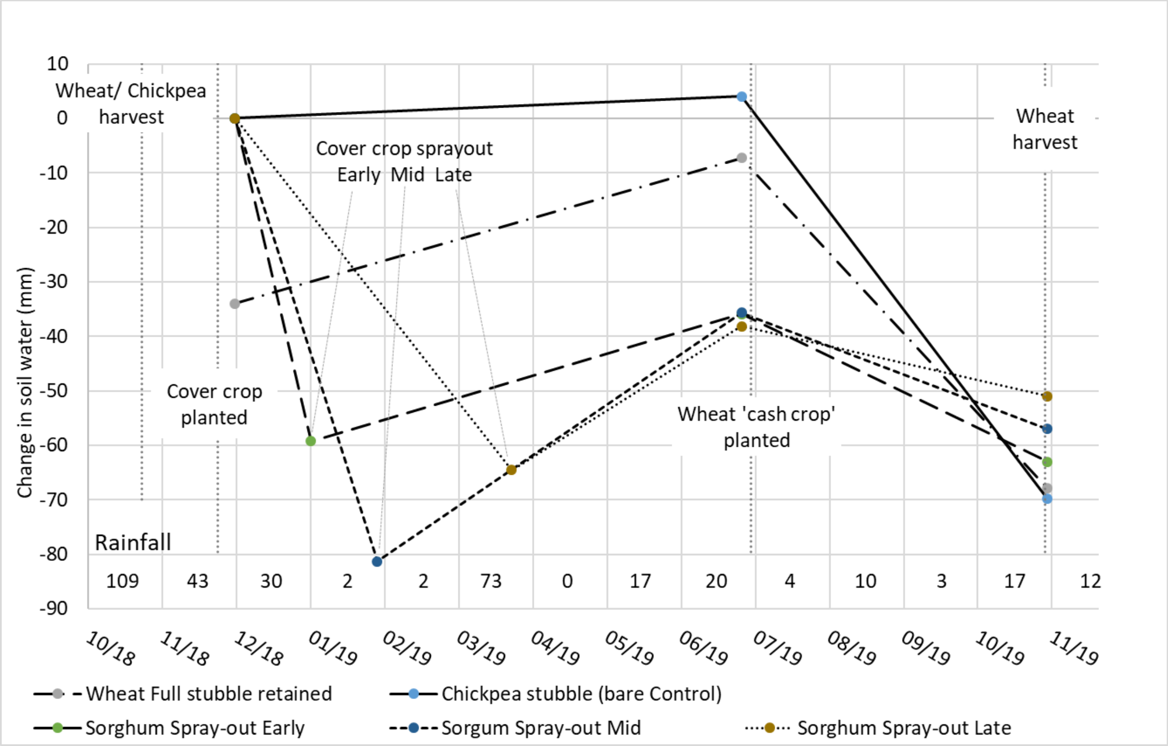

Figure 3. Change in plant available water for a range of cover crops measured with soil cores to a depth of 150 cm, at the Billa Billa site. Grids represent 30 days from the first of each month, and numbers in bottom row are mm rainfall for that month. Nb. Wheat stubble plots were 34 mm drier than ex-chickpea plots when cover crops were planted.

Table 3. Starting crop and stubble or cover crop treatment, stubble and cover crop biomass and percent ground cover at the end of the fallow period, and grain yield of the following wheat 'cash crop' at the Billa Billa site.

Preceding crop	Treatment	Biomass (kg/ha)	Cover % 2 May 2019	Wheat grain yield (kg/ha)
Wheat	Harvest high (50 cm)	2662	77	526
Wheat	Harvest high and rolled	2357	78	566
Wheat	Harvest low (25cm), tops spread	1800	82	529
Wheat	Harvest low, tops removed	1755	73	551
Chickpea	Bare (control)	267	10	727
Chickpea	Sorghum spray-out early	1270	50	364
Chickpea	Sorghum spray-out mid	1419	67	74
Chickpea	Sorghum spray-out mid + rolled	1245	57	61
Chickpea	Sorghum spray-out late	1732	66	34
Chickpea	Sorghum spray-out late + rolled	1106	66	23

With insufficient rain received in May or June and no forecast rain, it was decided to dry plant and apply trickle irrigation to the seed row for crop establishment in the last week of June.

The fallow efficiency of the wheat stubble was higher than that of the chickpea stubble (control) as wheat stubble plots accumulated 23 mm more PAW over the fallow than the control with chickpea stubble. However, with 34 mm more PAW present after chickpea harvest compared to the wheat plots, the wheat stubble still had 11 mm less PAW, when the wheat was planted in June. This trend has also been measured in the farming systems trials, where pulses leave more water at harvest than cereals, but cereals have higher fallow efficiency, and thus reduce the gap by planting of the next crop (or eliminate the gap in non-sodic soils and be ahead after long fallows).

The cover crops recovered some of the water they used with 73 mm of rain in March, but with little rain after this event, the early, mid and late sprayed sorghum cover crops were 25 mm, 44 mm and 48 mm drier than the control when the wheat crop was planted (Figure 3).

The highest wheat yield was achieved by the fallowed chickpea stubble (bare control; 727 kg/ha), followed by the wheat stubble (average 543 kg/ha) and early sprayed cover crop (364 kg/ha). The mid and late sprayed sorghum cover crops had patches of wheat die during the season for final yields of 68 kg/ha and 29 kg/ha (Table 3). Trickle tape irrigation providing even establishment across all plots and with very low rainfall in crop (34 mm) the yield outcomes were directly related to starting PAW. These yields represent an average yield reduction of 11.6 kg/ha for every mm less water the wheat crop used (i.e. planting PAW – harvest PAW + in crop rain) compared to the bare control.

Conclusions

The project has previously shown that cover crops can indeed help increase net water storage across the fallow and early crop growth in situations that have limited ground cover. We have also seen dramatic yield results for the subsequent cotton and wheat crops, which we attributed in part to more even populations established and greater water extraction.

In this dry season, improving ground cover allowed the opportunity to plant a crop, when the bare plots were too dry. At this longer fallow site (albeit dry) the cover crops recovered most of the water used, so planting with irrigation provided an even establishment and no difference in grain yield was observed.

The short fallow site had a PAW penalty for growing the cover crop and with no extra biomass growth in the later terminations, there was no advantages in persisting with the cover crop once it had stopped development. After an even establishment assisted by irrigation, the grain yield penalty to the wheat ‘cash crop’ was highly correlated to starting PAW.

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Recovery after the drought and planning for recovery

Discussion session

Notes

Managing chickpea diseases after the drought

Kevin Moore, Steve Harden, Kristy Hobson and Sean Bithell, NSW DPI, Tamworth

Key words

chickpea, disease risk, Ascochyta, Phytophthora, Sclerotinia, root lesion nematode (RLN), management, fungicide rain fastness

GRDC code

Grains Agronomy & Pathology Partnership - A strategic agreement between GRDC and NSW DPI (DAN00213): BLG209 Pulse Integrated Disease Management – Northern NSW/QLD

Take home messages

- Do not underestimate disease risks after a drought – pathogens survive longer and can still threaten your 2020 chickpea crops
- Unless you are in a high risk Ascochyta situation, it is unlikely there will be a cost benefit applying a foliar fungicide to 2020 crops until after the disease is detected
- However, if you are at a high risk of Ascochyta, apply a foliar fungicide before the first post emergent rain event
- High risk situations include planting into paddocks with active Ascochyta inoculum and planting seed that has not been properly treated
- Recent research has shown the Ascochyta fungicides Aviator Xpro and Veritas are rain fast (up to 100 mm rain in 150 minutes)
- Phytophthora and Sclerotinia levels will not have declined much during the drought and pose a medium to high risk in 2020
- Root Lesion Nematodes may have declined during the drought but if numbers at the start of the drought exceeded 10/g soil, it may still be sufficient to cause damage in 2020 chickpea crops.

How drought affects plant diseases

- Drought reduces the breakdown of plant residues. This means that inoculum of some diseases does not decrease as some might expect and will carry over for more than one growing season. The expected benefits of crop rotation may not occur
- Bacterial numbers decline in dry soil. Some bacteria are antagonists of soil borne fungal diseases. These diseases can be more severe after drought
- Abandoned, or drought stressed crops still set seed. Summer/autumn rains can lead to large numbers of volunteers. Low stock numbers make it difficult to control these volunteers, which can host Ascochyta, viruses and virus vectors, and other pathogens
- Weeds that are stressed by drought may be harder to kill and can harbour pathogens
- Soil water and nitrogen may be unbalanced and these are likely to impact diseases in 2020 and beyond.

Chickpea disease risks after the drought and advice for 2020 chickpea farmers

- Ascochyta is unlikely to cause widespread problems in 2020 unless it is wetter than average as inoculum levels have not increased in past two seasons and even if infected with Ascochyta, all varieties recover well during dry conditions. For these reasons, unless you are in a high risk situation, there will be no cost benefit applying Ascochyta fungicides until the disease is detected. High risk situations include planting into paddocks where active inoculum is known to be present (see following examples at Tulloona and Moree) and planting seed of unknown pathogen status that has not been properly treated. In these situations, apply an Ascochyta fungicide before the first post-emergent rain event, then monitor the crop 10-14 days after rain.

- If Ascochyta is detected, apply a registered fungicide before the next rain event. This is especially important during the reproductive stage as Ascochyta on pods causes abortion, seed infection and seed defects. If you miss a spray; fungicides with limited curative activity are now available however they have a limited time of use and tight intervals for application after an infection event occurs. (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/02/chickpea-ascochyta-research-what-if-i-miss-a-spray-are-there-salvage-options-with-new-chemistry-how-long-do-fungicides-persist)
- Under drought conditions, some plant pathogens survive longer than normal; Ascochyta inoculum for 2020 chickpea crops may have originated in 2017 or even 2016. In August 2019, volunteer chickpeas in a crop of wheat at Tulloona had Ascochyta lesions. That paddock had grown chickpeas in 2016 (under high Ascochyta pressure); wheat in 2017 and chickpeas in 2018 (crop abandoned due to drought). Rain in Oct/Nov 2018 allowed Ascochyta to develop on abandoned plants, and seed left in the paddock germinated on rain in March 2019 to produce the volunteers that got infected during rain events in May, June and July 2019. Another example of how drought can prolong survival of inoculum was provided in August 2019, when we received chickpea stubble from a paddock at Moree that had grown chickpeas in 2017. The stubble contained fungal fruiting bodies. We soaked the stubble in water for several hours then applied the water suspension to chickpea seedlings; 7 days later symptoms and pycnidia of Ascochyta developed on the seedlings, proving that the inoculum had persisted on the nearly two-year old chickpea residue. Both the Tulloona and Moree paddocks are considered high risk if planted to chickpeas in 2020.
- Remember, the Ascochyta fungus is evolving: In our 2010 Tamworth disease management trial, unprotected PBA HatTrickⓓ (then rated moderately resistant (MR)), lost 37% yield to Ascochyta; while in the 2016 trial, unprotected PBA HatTrickⓓ lost 97% yield to Ascochyta. PBA HatTrickⓓ is now rated moderately susceptible (MS) and will require fungicide under conditions that favour Ascochyta. The good news is that whilst Ascochyta can now cause more damage on unprotected PBA HatTrickⓓ, it is just as easy to manage as when PBA HatTrickⓓ was rated MR.
- Phytophthora root rot (soil borne) and Sclerotinia diseases (soil borne and air borne) are considered moderate to high risk in 2020 because although inoculum loads are unlikely to have increased, their survival will have been prolonged by the drought.
- Botrytis seedling disease (BSD, seed borne) is only likely in crops planted with seed produced in the 2016 (and possibly 2017) crop year. In any case proper seed treatment provides 100% control of BSD.
- Botrytis grey mould (BGM, air borne); the BGM fungus is ubiquitous, has a very wide host range and is a good saprophyte - if conditions favour BGM i.e. dense canopies, warm humid weather, it will occur.
- Root lesion nematodes (RLN, *P. thornei* soil borne) can survive dry periods. Recent research has shown it takes a double break of 40 months free of host plants to reduce numbers to a minimum threshold (2/g soil) so it is unlikely the current drought will have reduced RLN numbers if they started high (40/g) which was likely in the 2016 season. Even starting numbers of 10/g still need a break of 30 months https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/how-long-does-it-take-to-reduce-pratylenchus-thornei-populations-in-the-soil.

- Viruses are an unknown threat after a drought. Most need green plants as reservoirs (some are seed borne) and hosts for their vectors. However, as vectors can fly or be blown in from regions that have not experienced drought, viruses are still a risk to 2020 chickpea crops.

Seed quality

Obtaining good quality seed after a drought may be an issue in 2020. In Nov/Dec 2019, we tested seed from as far back as 2016 and whilst germination of all lots exceeded the Pulse Australia (PA) minimum standard of 70%, some lots were slow getting there, indicating possible loss of vigour. All planting seed should be germination tested and if it meets the PA standard, we recommend it be treated and 'test planted' into paddocks intended for chickpeas in 2020, and the number that emerge counted – this is your best indicator of seed and seedling vigour and may assist identify herbicide residues, but should not be relied on as the sole indicator for this, as symptoms of residual herbicides can in some situations be slow to develop. Paddock emergence tests are best done in March/April.

If you are sourcing seed from outside your region e.g. interstate, be sure the variety is suitable for your farming system and have the seed germination and pathogen tested.

Irrespective of age and origin, all planting seed should be treated with a registered seed dressing – these control seed borne Ascochyta (internal and external), seed borne Botrytis (BSD) and protect seedlings from a range of opportunistic soil organisms that can reduce seedling vigour and establishment under less than favourable conditions e.g. cold or wet soils, deep planting. Planting quality, treated seed is your best bet of healthy seedlings – these will have a rapidly growing root system to obtain nutrient and moisture, be more competitive with weeds and less susceptible to disease.

Predicta®B for assessing Ascochyta risk

The value of Predicta®B as an Ascochyta management tool has not been determined because we do not know what the numbers mean in terms of risk or management. Predicta®B results that are positive for Ascochyta on samples collected after the drought should not be surprising give the persistence of inoculum under drought conditions. On the other hand, a negative result does not mean your Ascochyta risk is nil or low as the test is only as good as the sampling method and inoculum can arrive in your paddock after sampling via wind, machinery, vehicle, animals, surface water flows or untreated seed.

Chickpea Ascochyta Research Update: Is efficacy of Aviator Xpro and Veritas reduced by rain after application?

Previous research (2007) at Tamworth using a rainfall simulator showed that efficacy of the fungicides Barrack720® (720g/L chlorothalonil) and Dithane® Rainshield® (750g/kg mancozeb) on chickpea Ascochyta on cultivar Jimbour was not significantly reduced by 50mm rain in 10 minutes. 150mm in 30 minutes also did not reduce efficacy of Barrack720 but did reduce slightly the efficacy of Dithane. Such rainfall intensities are not common in chickpea crops grown in eastern Australia. From these experiments we concluded that plant tissue sprayed with these fungicides would still be largely protected if rain fell after application (new growth after application would not be protected as both products are protectants only). The 2010 chickpea season (that had frequent rain events) supported this conclusion.

The recent registrations of Aviator Xpro® and Veritas® (both in 2018) for chickpea Ascochyta (with restrictions on number of applications and timing – see labels for details) raised the question of how rain fast are these products.

Two experiments were conducted at Tamworth Ag Institute in December 2019 - January 2020 to determine the effect of simulated rain on the efficacy of Aviator Xpro and Veritas on Ascochyta; Unite®720 (720g/L chlorothalonil) and water were the control treatments. The first experiment (4 reps) was with cv KyabraΦ and the second (4 reps) with cvs KyabraΦ and PBA SeamerΦ.

As the results were the same, we report here the second experiment. Plants were sprayed with water, Unite, Aviator Xpro or Veritas using a backpack sprayer with a 1m boom fitted with 110/015 flat fan nozzles at 50cm spacing and a walking pace of approximately 6kph. The fungicide treatments were allowed to air dry for 2hr when the 'rain' plants were placed in the rainfall simulator and exposed to 50mm over 75 minutes or 100mm over 150min (recorded by two rain gauges at each side of the simulator pad). After removal from the simulator, plants were allowed to air dry for 2h, arranged on racks in replicate boxes (55L plastic with clear lids), inoculated to run off with a cocktail (2,000,000 conidia/mL) of 20 Ascochyta isolates obtained from commercial chickpea crops and the boxes placed in a controlled environment facility operating at 12h/12h day/night 15C/20C. Leaf wetness was maintained with ca 50mm depth water in the base of the boxes and firm fitting lids. After 48h the lids were removed and plants were examined for Ascochyta. Five days after inoculation (DAI) first symptoms (petiole wilting) were evident and at 9 DAI, Ascochyta was assessed by counting the numbers of petioles, leaves and stems with symptoms.

The only plants that developed Ascochyta were those sprayed with water; PBA SeamerΦ had less disease than KyabraΦ.

We conclude from this experiment that efficacies of chickpea Ascochyta fungicides Veritas and Aviator Xpro with a 2 hour dry period after spraying and prior to rain occurring, are not affected by simulated rainfall of 50mm in approximately 75min or 100mm in approximately 150min. As such intensities are uncommon during chickpea seasons in areas of Australia where Ascochyta occurs, it is reasonable for growers to be confident that once these fungicides have dried on plant tissues, those tissues will remain protected.

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