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QUEENSLAND
THURSDAY 8TH MARCH, 2018

GRAINS RESEARCH UPDATE

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GRDC Welcome

Welcome to the 2018 GRDC Grains Research Updates

Ensuring growers, advisors and industry stakeholders are informed about the latest research and development outcomes in their quest to improve on-farm profitability is a key role of the annual Grains Research and Development Corporation (GRDC) Updates.

As an industry we face new challenges in terms of climate variability, technology and market conditions, so it is important for all of us to have up-to-date knowledge to make informed decisions and drive practice change.

Last season, New South Wales and Queensland grain growers experienced everything from moisture stress, to heat stress, frosts and waterlogged paddocks. This highlights the importance of robust and rigorous research to help underpin profitability across a range of climatic and environmental conditions.

It also emphasises the value of GRDC investments into regional extension to equip growers and advisors with the information and support they need to make key farm management decisions.

For 25 years, the GRDC has been driving grains research capability and capacity with the understanding that the future of Australian grain growers' hinges on relevant, rigorous, innovative research that delivers genuine profitability gains.

Despite the challenges the grains industry remains confident about the future, willing to embrace new concepts, and keen to learn more about innovations and technology that bring cost efficiencies, promote sustainability and grow productivity.

The GRDC Updates deliver research direct to growers, agronomists and industry. This year the Updates will offer information from the latest research and development from short- and medium-term investments that address on-farm priority issues from farming systems, agronomy, soils, weeds to pests and diseases.

So I hope you enjoy the Updates and that the events provide a valuable opportunity for learning, knowledge sharing and networking. I encourage you to use these events to interact with GRDC staff and GRDC Northern Panel members, who are committed and passionate about your success and the future of the northern grains industry.

Jan Edwards

GRDC Senior Regional Manager North

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Allora GRDC
Grains Research Update
Thursday 8th March, 2018

Time	Topic	Speaker(s)
9:00 AM	**Welcome**	
9:10 AM	**Setting the farm up for automation;** options for establishing broadband connectivity; sensors; telemetry; data capture and management - experience from the UNE SMART Farm and elsewhere	*David Lamb (UNE)*
9:35 AM	**Chickpea: temperature and other factors affect flowering, pod set and yield**	*Andrew Verrell (NSW DPI)*
9:55 AM	**Chickpea water use efficiency.** Neutron probes, where and when chickpeas draw water from and manipulating biomass	*Kerry McKenzie (DAF Qld)*
10:25 AM	**How much N is fixed by different pulse crops and how does agronomy and season impact the amount fixed?**	*Nikki Seymour (DAF Qld)*
10:45 AM	**Morning tea**	
11:15 AM	**Calculating how much N is needed in pulse-cereal rotations**	*Howard Cox (DAF Qld)*
11:35 AM	**Panel discussion** - implications for decision making in 2018	
11:50 AM	**Understanding and managing frost risk**	*Peter Hayman (SARDI)*
12:25 PM	**Farming systems impact on nitrogen and water use efficiency, soil borne disease and profit**	*Lindsay Bell (CSIRO)*
12:55 PM	**Lunch**	
1:45 PM	**Analysis of Australia's competitive position in global grain markets and relative supply chain costs**	*Ross Kingwell (AEGIC Senior Economist) & Peter White (AEGIC Senior Projects Manager)*
2:25 PM	**Treat your weeds badly** - deprive them of sunlight and space - crop competition research in the northern grains region	*Michael Widderick (DAF Qld) and Bhagirath Chauhan (QAAFI)*
2:55 PM	**The P story thus far** – how much, when, how and with what expected benefit?	*Mike Bell (QAAFI)*
3:25 PM	**Close**	

Contents

Connecting to our farming future

David Lamb, Precision Agriculture Research Group, University of New England

Key words

SMART farm, sensors, telecommunications, technology, future

Call to action/take home messages

The progression of telecommunications and technology must be accompanied by education and extension. A recent survey identified that more that 60% of Australian farmers did not know of on-farm connectivity options or who to talk to about getting connected. And 'connectivity is king'. Lack of connectivity is identified as one of THE constraints to adopting tools that improve productivity, safety and workflow. There are many challenges and opportunities of getting connected into a SMART farming future that, in 5-10 years, will just be farming. Farmers need to understand the basics of how connectivity works to be able to make informed decisions when getting connected. Government, policy makers and telco providers need to understand what farmers need and why.

Introduction

The role of the internet in agriculture is fast approaching a 'third wave.' The first wave was connecting people to data via the World Wide Web (1990s); the second wave was about connecting people to people e.g. through Facebook and Twitter (2000s). The third wave will connect people to 'things' (2010 onwards). These waves are not specific to agriculture. Developments in the agricultural field are contained within and mirror wider technological progressions that have led us to a place where every part of our lives relies on an internet connection.

In terms of on-farm developments, advances in wireless sensor networks coupled with in-situ, low-cost machine, crop, animal and asset sensors; the so-called 'internet of things' means our farms and fields will become sources of high-quality, real-time management data. Big data is really made up of lots of small data, and will become increasingly useful in day-to-day and long-term management decisions. Some of this data will be utilised alongside intelligent and autonomous systems operating both on ground and in the air.

The SMART farm

I lead the University of New England's SMART Farm project (Sustainable Manageable Accessible Rural Technologies Farm). UNE has transformed a 2,900 ha, predominantly sheep farm into a SMART Farm which showcases the latest technologies aimed at improving productivity, environmental sustainability, safety, workflow and social/business support networks on Australian farms (www.une.edu.au/smartfarm, 2018). Buts is a CONNECTED farm; linked via AARNet and the national broadband network (fibre, terrestrial wireless AND satellite) because the predominantly grazing SMART Farm is a national demonstrator site.

Examples of the types of sensors we use include 100 soil moisture probes, which create a living map of soil moisture. The farm also has another telemetry network that allows devices to be 'plug-and-played' ranging from monitoring water use in trees, pasture growth through to honey accumulation in beehives.

We are also working with livestock tracking and are investigating opportunities around developing fingerprints of animal behaviour ranging from when they're attacked, if they're calving, whether they have internal parasites and also how much pasture is left behind from grazing.

Live satellite derived pasture data is available through the Pastures from Space^{TM} program. This provides estimates of pasture production during the growing season by means of remote sensing.

Satellite data is used to accurately and quantitatively estimate pasture biomass or feed on offer, or combined with climate and soil data is used to produce estimates of pasture growth rate (https://pfs.landgate.wa.gov.au/).

The SMART Farm is just an example of what the future of farming will look like- buts it's connected to the hilt. In order for that future to be realised across 137,000 Australian farms, action is required in the telecommunications sector.

Telecommunications

As well as sensor technology and big data, telecommunications is a key enabling part of the SMART Farming future. In 2016, the Commonwealth Department on Agriculture and Water Resources initiated a Rural R&D for Profit Research Project entitled 'Accelerating Precision Agriculture to Decision Agriculture' or 'P2D'. One of the aims the project was to deliver 'recommendations for data communications to improve decision making - or decision agriculture'; effectively to undertake a 'telecommunications review' for agriculture. During the period of August 2016 – June 2017, a series of eight workshops, numerous phone interviews and site visitations around Australia sought to understand the current status of on-farm telecommunications at the farm level in support of a big data future for agriculture. This review sought a 'producer-eye' view, seeking to understand the dimensions of key enabling telecommunications utilised by producers, factors constraining the uptake or adoption of available enabling technologies, as well as investigating the future telecommunications needs and opportunities. Information was solicited from not only producers, but also developers and providers of technologies and data services, as well as looking at the developments 'top-down' such as the ACCC Inquiry into Domestic Mobile Roaming and the Productivity Commission Review of the Universal Services Obligation (USO).

In the last couple of years the notion of telecommunications as a 'critical infrastructure' for rural and regional Australia, and in particular in agriculture, has at last well and truly taken root. Over this period there has also been a significant increase in the development of end-to-end telecommunications technologies and services offered to producers. These so-called 'second-tier' telecommunications providers (as distinct from the 'big telcos'), also offer their own transmission backhaul capability and in some cases associated cloud based services. Moreover they seek to 'guarantee' speeds. Second tier providers will help extend the value and potential of existing NBN and mobile telecommunication networks. The role of telecommunications in supporting a big data future in agriculture is not necessarily technology constrained; if a farm has access to the mobile network somewhere on the farm, or NBN into the farm house then there is invariably technology available to beam it to where it is needed. But the external connectivity MUST be stable 24/7. There is little value having high speed internet for only short periods of the day. If this is the case, as it often is, then at least we should be able to know IN ADVANCE when that will be so we can work to get the best out of it. Reliability is as important as absolute speed, and speed is different from signal 'strength' or 'reception'. The other real constraint is around service and price. Entirely new innovative methods of extending connectivity over remote regions are in the R&D pipeline; some are even surfacing now. Others have been around for some time and overlooked. It is time to visit or revisit them. Business models are evolving, and need to evolve further to support the types of connectivity functionality that farmers need.

The on-farm telecommunications market is rapidly evolving but like with all things in precision agriculture, education is one of the biggest challenges faced by both those looking for solutions and those offering solutions. Industry needs well-curated case studies and education/educators must target not only consumers of telecommunications services but also technology developers and service providers seeking to put something in the market place.

Conclusion

The progression of telecommunications and technology must be accompanied by education and extension. A recent survey identified that more that 60% of Australian farmers did not know of on-farm connectivity options or who to talk to about getting connected. There are many challenges and opportunities of getting connected into the SMART farming future that, in 5-10 years, will just be farming.

Acknowledgements

The project that delivered the 'telecommunications review' referred to in this presentation was led by Cotton Research and Development Corporation (CRDC). The 'P2D' project was jointly funded by the Department of Agriculture and Water Resources Rural Research and Development (R&D) for Profit Program and all 15 rural Research and Development Corporations including the Grains Research and Development Corporation (GRDC). A copy of the full report "A review of on-farm telecommunications challenges and opportunities in supporting a digital agriculture future for Australia" (ISBN 978-921597-75-6 Electronic) is available for free download on the Australian Farm Institute website (http://www.farminstitute.org.au/p2dproject).

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The impact of wheat residue on air temperature in the canopy and phenology of chickpea in 2017

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Key words

stubble, frost, temperature, radiant, phenology

GRDC code

DAN00965 - Thermal responses of winter pulses

Call to action/take home message

- Surface wheat residue increases the incidence and severity of radiant frosts.
- The average minimum surface temperature declines by -0.10^{0}C/ tonne of residue.
- High residue loads can change the thermal profile of the crop and lead to delays in the onset of flowering, podding and maturity in chickpeas.
- Inter-row sowing into standing residue (>30cm) led to less frosts and higher minimum temperatures in chickpeas.
- Some chilling tolerant chickpea lines flowered 3 to 11 days earlier than PBA HatTrick⊕ but this did not translate into earlier 1st pod dates.

Introduction

Chickpea productivity in the northern grains region (NGR) is constrained by several abiotic stresses (Whish *et al.* 2007) and temperature is one of the most important determinants of crop growth over a range of environments (Summerfield *et al.* 1980) and may limit chickpea yield (Basu *et al.* 2009).

The potential evaporative demand for water usually exceeds the water available to the crop and represents the greatest limitation to crop production in the northern grains region (NGR). Low-disturbance direct seeding into standing or flattened cereal stubble is the most effective practice to reduce the impact of water stress on chickpea crops. However, surface residues can cause an increase in radiant frost risk and may also affect the micro-climate of the crop canopy, with impact on floral initiation, pod set and seed development.

The impact of surface residue on air temperature in the canopy, phenology, biomass and grain yield of chickpea was explored in a series of experiments across the NGR in 2017.

Stubble effects on soil and air temperature

During the day, stubble reflects solar radiation. A bare, darker soil absorbs more solar radiation than a stubble-covered soil and warms up more readily. The stubble also acts as insulation as it contains a lot of air which is a poor conductor of heat. Finally, the stubble affects the moisture content of the soil. It takes more heat to warm up moist, stubble covered soil than dry, bare soil.

This causes soil temperature of a bare soil to be higher than stubble covered soil during the day (especially in the afternoon). At night, however, the bare soil loses more heat than stubble covered soil due to the lack of insulation (the air-filled stubble being a poorer heat conductor). This is especially noticeable when skies are clear. The air above the bare soil is therefore warmer during the night than the stubble covered soil, while the soil temperature differences become negligible. Therefore stubble cover may lead to a higher incidence of frost than bare soil.

Methods

A range of experiments were conducted at Rowena and Tamworth in 2017 (Table 1).

Table 1. Experiments, treatments and locations for 2017

Experiment	Tamworth	Rowena
Row orientation	North - South	East - West
Stubble loading	0, 3, 6, 12, 24 t/ha residue Chickpea, faba bean, field pea	0, 3, 6, 9, 12 t/ha residue 4 x chickpea genotypes
Stubble height	0, 10, 30, 50 cm Chickpea, faba bean, field pea	0, 5, 10, 17 cm 4 x chickpea genotypes
Chilling tolerance	Plus and minus residue 16 chilling tolerant chickpeas	Plus and minus residue 16 chilling tolerant chickpeas
Genotype screening	Plus and minus residue 20 selected chickpea lines	

In all of the stubble experiments, treatments were not invoked until just prior to sowing. This ensured there was no treatment effect on soil stored water at sowing. In the stubble loading experiments, residue was removed, bulked and weighed into treatment amounts and re-applied to the plots immediately post-sowing. In the stubble height experiments, treatments were cut using a small plot header the day before sowing. Stubble was stripped and captured at the back of the header for removal.

In all experiments, tiny tag temperature data loggers were used in selected treatments and plots. Sensors were placed at 0cm and 50cm above ground in-crop. Temperature was logged at 15minute intervals. Another Tiny Tag sensor was placed outside the crop area at 150cm above the ground to record ambient temperature at similar time intervals.

Detailed phenology was recorded on a daily basis. At physiological maturity, whole plant samples were taken for detailed plant component analysis and whole plots were harvested for grain yield.

Results

The 2017 growing season

The 2017 growing season has been one of the most difficult and extreme on record equivalent to the 1994 and 1982 seasons with record frost events and below average in-crop rain.

The Rowena site failed due to lack of soil moisture exacerbated by the high frost incidence. Nothing was recoverable. Table 2 shows the long term average (LTA) monthly rainfall and minimum screen temperatures and the monthly rainfall and average minimum temperature for Tamworth in 2016 and 2017.

Table 2. Long term average (LTA) monthly rainfall and minimum temperature and monthly rainfall and mean minimum temperature for 2016 and 2017 at Tamworth

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall 2017 mm	125	19	124	22	61	49	20	21	10	90	64	39
Rainfall 2016 mm	100	1	22	5	61	169	29	83	133	76	12	97
LTA rainfall mm	85	67	49	42	44	49	46	46	48	58	66	72
Mean Min 2017 (°C)	19.6	18.5	15.3	9.2	6.3	3.5	-0.1	1.2	4.5	11.4	11.9	16.5
Mean Min 2016 (°C)	17.0	16.1	15.7	12.2	6.6	6.1	3.7	3.2	7.2	7.1	10.1	16.9
LTA min temp (°C)	17.4	17.1	14.8	10.6	6.7	4.1	2.9	3.7	6.1	9.9	13.1	16.0

Rainfall leading into the 2017 growing season was on par for the LTA, but July-September was below the cumulative LTA by 88mm. Rainfall in October saved these crops and resulted in average yields (Table 2).

The mean minimum temperatures started to dip below the LTA from April right through to September, with mean minimums for July, August and September being, -3.05, -2.52 and -1.58^{0}C colder than the LTA, respectively. The frost incidence at Tamworth in 2017 was unprecedented, with 49 screen frosts compared to 22 in 2016. Rowena experienced 26 screen frosts up to the 1st week in September when the crop failed.

At Tamworth, the extreme weather events led to complete death of ALL field pea blocks. This was through frost events followed by a wipe out due to bacterial blight infection.

Elevation and air temperature

Figure 1 shows the effect of slope on average minimum air temperature at ground level at the Tamworth site. Minimum temperature declined by - 0.22^{0}C per m drop in elevation measured on bare soil.

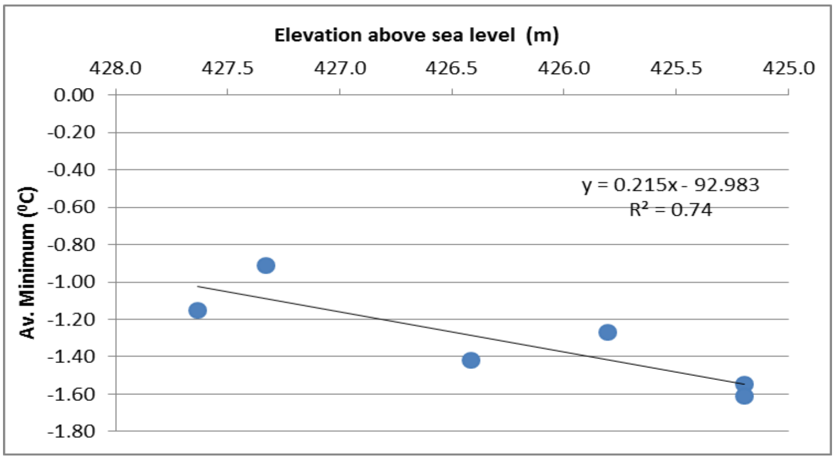

Figure 1. Effect of slope on average minimum temperature (7/7 – 8/8/2017) at ground level at the Tamworth Agricultural Institute (TAI)

Stubble loading effects on in-crop temperature

The effect of different amounts of wheat residue, flat on the ground, and its impact on the temperature profile of different pulse species was examined.

Table 3 shows the effect of residue loading on minimum temperature at the residue surface in chickpea at TAI.

The bare soil surface was on average, -1.0^{0}C colder than the minimum screen temperature. Both the average minimum and absolute minimum declined as the amount of surface residue increased, with the high residue loading (24 t/ha) -1.4^{0}C colder on average than bare soil. Frost incidence was similar across all residue level loadings, but there were 5 more ground frosts recorded compared to the screen temperature. The absolute minimum decreased with increasing residue load, with the high residue treatment reaching -7.5^{0}C compared to -6.4^{0}C on bare soil (see Table 3).

Table 3. The average minimum, absolute minimum and number of frosts (<0^{0}C) for a range of stubble loadings at the residue surface in chickpea compared to the screen temperatures at TAI (7th July to 8th August).

		Residue loading				
	Screen	Bare soil	3 tonne	6 tonne	12 tonne	24 tonne
Av. Min	0.5	-1.5	-1.9	-2.1	-2.2	-2.9
Abs. Min	-5.2	-6.4	-6.7	-6.9	-6.9	-7.5
No. Frosts	20	25	25	25	25	26

Table 4 contains data from the Rowena site prior to it succumbing to terminal drought. The temperature response to residue loading is the same here as at TAI. Average minimum temperature declined with increasing residue load, with a -1.2^{0}C difference between bare soil and 12 t/ha of residue.

Table 4. The average maximum and minimum, absolute minimum and number of frosts (<0^{0}C) for a range of stubble loadings at the residue surface in chickpea at Rowena (1st June to 10th August).

	0 tonne	3 tonne	6 tonne	9 tonne	12 tonne
Av. Max	10.3	10.5	10.4	10.4	10.3
Av. Min	0.4	0.1	-0.3	-0.4	-0.8
Abs. Min	-6.5	-7.2	-7.9	-7.6	-8.9
No. frosts	36	42	42	43	43

At Rowena, frost incidence rose with the addition of residue compared to bare soil, but was similar across residue loading treatments. Maximum temperatures did not vary across treatments.

Figure 2 shows the linear relationship between residue loading and average minimum surface temperature in chickpea.

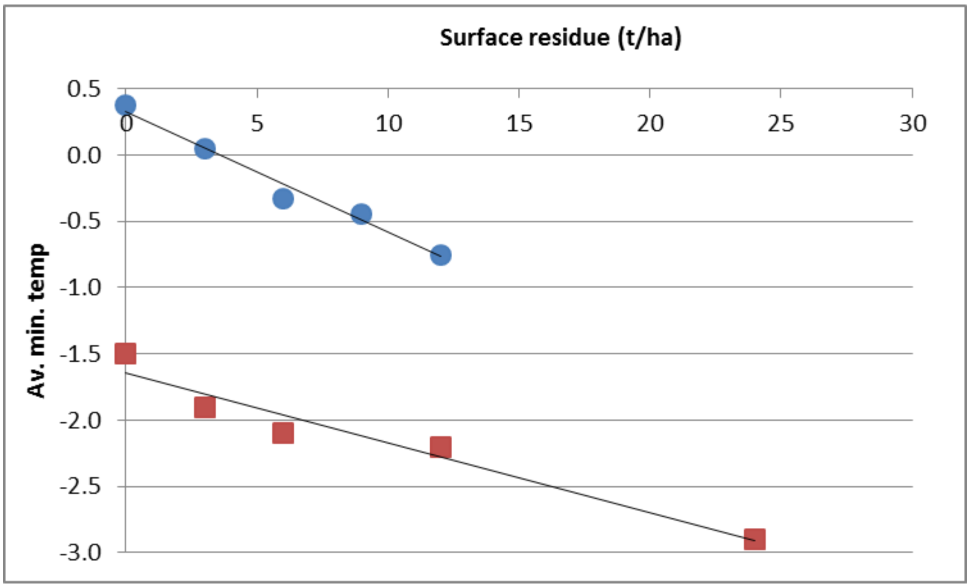

Figure 2. The effect of surface residue loading on average minimum temperature at the residue surface at Rowena (●) and TAI (■) in the chickpea crop

Both responses are linear but the steeper slope at Rowena would suggest that residue amount had a more significant impact on minimum temperature and frosting in 2017 than at TAI. Minimum temperature declined by -0.10 and -0.05 ^{0}C, per tonne of residue at Rowena and TAI, respectively.

Stubble height effects on in-crop temperature

Table 5 shows the effect of stubble height on temperature parameters at the soil surface on inter-row sown chickpea at TAI.

Table 5. The effect of residue height on absolute and average maximum and minimum temperature and number of frosts in chickpea at the soil surface at TAI (7th July to 20th September)

Parameter	Bare soil	10cm	30cm	50cm
Abs. Max	37.1	37.0	36.7	35.0
Av Max	25.5	25.3	24.9	23.5
Av Min	-0.8	-0.7	0.2	0.0
Abs. Min	-5.6	-5.4	-4.3	-4.9
No. frosts	51	51	41	42

There was no change in temperature parameters between the bare soil and 10cm high residue. Changes started occurring once residue reached 30cm high, with the average and absolute minimums rising 0.4^{0}C and 1.3^{0}C, respectively. There were 10 less frosts in the 30 and 50cm high residue treatments compared to bare soil. Average and absolute maximums were 2.0^{0}C cooler in the tall 50cm stubble treatment compared to bare soil (see table 5).

Stubble loading effects on phenology

The effect of surface residue loading on the time taken, recorded as days after sowing (DAS), to reach 20% flower, 1st pod, 50% pod and flowering cessation are shown in figure 3.

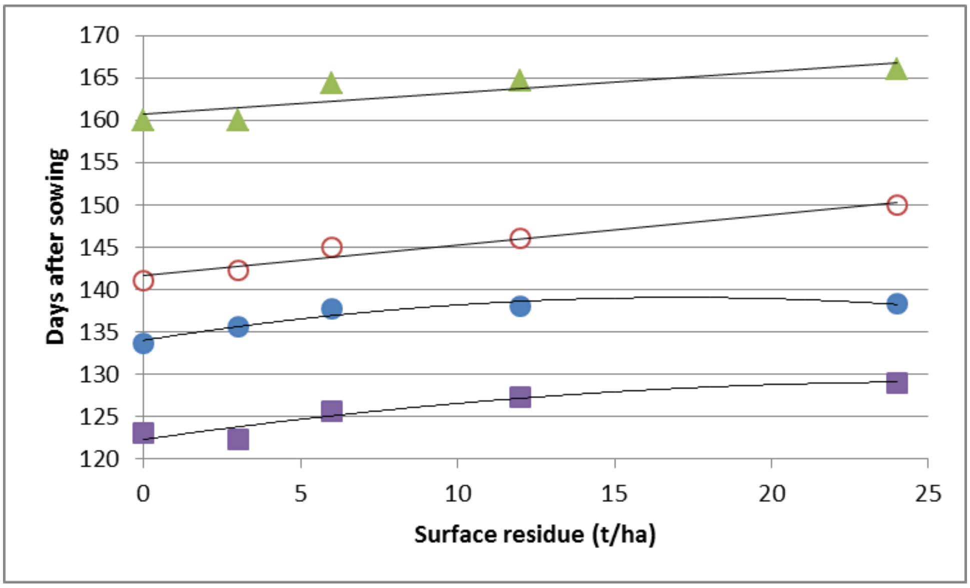

Figure 3. The effect of surface residue loading on the time taken (days after sowing) to reach 20% flower (■), 1st pod (●), 50% pod (○) and flowering cessation (Δ).

Across all parameters the time taken to reach these increased with increasing residue load on the surface. This effect was even more pronounced for 50% pod set and development and flowering cessation (Figure 3).

Assessment of chilling tolerant lines

Table 6 contains phenology data for selected lines from the chilling tolerance experiment at TAI.

Table 6. The effect of surface residue treatment on the time taken (days after sowing) to reach 1st flower, 50% flower and 1st pod for selected genotypes

		Days after sowing		
Stubble	Variety	1st Flower	50% Flower	1st Pod
Bare	CICA-1521	101	124	132
Flat residue	CICA-1521	104	126	132
Bare	PBA HatTrick⟨l⟩	110	126	132
Flat residue	PBA HatTrick⟨l⟩	115	126	137
Bare	CT-3	97	126	132
Flat residue	CT-3	118	129	137

In the bare soil treatment, genotypes reached 1st flower 3 to 11 days earlier than in the flat residue treatments. The residue treatments delayed 50% flowering in the numbered lines, but not in PBA HatTrick⟨l⟩, while the bare soil treatments led to earlier 1st podding. CICA1521, a fixed line, is substantially earlier at flowering than PBA HatTrick⟨l⟩, but similar in time to 1st pod set. CT-3 is a new line with enhanced chilling tolerance which is evident from its earlier time to 1st flowering, but this didn't translate into earlier pod set when compared to PBA HatTrick⟨l⟩.

Conclusion

The 2017 season was unprecedented with record frost events coupled with below average in crop rainfall. The severe weather conditions led to the complete death of the field pea blocks at TAI, due to frost and bacterial blight. Terminal drought led to the eventual loss of the Rowena site.

The slope of cropping country can contribute to spatial variability in soil surface temperatures, with minimum temperatures declining by - 0.22^{0}C per m drop in elevation measured on bare soil.

Surface residue loading increased the severity of radiant frosts which impacted on all species. Field peas are the most susceptible, while faba bean and chickpea can tolerate some vegetative frosting. The number of frosts increased with residue loading, while the average minimum surface temperature declined by -0.10 ^{0}C, per tonne of residue.

Standing stubble led to changes in air temperature at the inter-row soil surface. There was no difference in temperature parameters between bare soil and 10cm high residue. Once residue was above 30cm average, absolute minimums rose by 0.4 to 1.3^{0}C and there were fewer frosts. Maximum temperatures were cooler by up to 2.0^{0}C.

Numbered lines assessed for chilling tolerance showed that they could flower 3 to 11 days earlier than PBA HatTrick⊕, but this did not translate into earlier pod set. Post-harvest assessment will determine whether earlier flowering has led to more viable flowering and podding sites compared to PBA HatTrick⊕.

In all cases, sowing chickpeas between standing wheat residue gave equivalent grain yield outcomes to the bare soil treatment.

This remains the preferred strategy to maximise fallow efficiency and grain yield.

Acknowledgements

The research undertaken as part of project DAN00965 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. Thanks to Michael Nowland and Peter Sanson, (NSW DPI) for their assistance in the experimental program.

References

Basu PS, Ali M, Chaturvedi SK (2009) Terminal heat stress adversely affects chickpea productivity in Northern India – Strategies to improve thermotolerance in the crop under climate change. In 'ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture'. 23–25 February, New Delhi, India. (Eds S Panigrahy, SR Shankar, JS Parihar) pp. 189–193. (International society for Photogrammetry and Remote Sensing, India)

Summerfield RJ, Minchin FR, Roberts EH, Hadley P (1980) The effects of photoperiod and air temperature on growth and yield of chickpea (Cicer arietinum L.). In 'Proceedings of International Workshop on Chickpea Improvement'. 28 Feb. –2 March 1979, The International Crops Research Institute for the Semi-Arid Tropics, Patancheru, AP, India. (EdsJMGreen, YLNene, JB Smithson) pp. 121 –149. (ICRISAT Publishing: Hyderabad, India)

Whish JPM, Castor P, Carberry PS (2007) Managing production constraints to the reliability of chickpea (Cicer arietinum L.) within marginal areas of the northern grains region of Australia. AJAR, 2007, 58, 396-405.

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

Preliminary data on phenology of Australian chickpea cultivars in the northern grain belt and prebreeding for heat avoidance traits

Angela L. Pattison, Helen Bramle and Richard Trethowan, University of Sydney

Key words

chickpea, phenology, heat, chilling, prebreeding

GRDC code

US00083

Call to action/take home messages

- This research aims to identify chickpea traits and germplasm with superior tolerance to high temperatures and produce pre-breeding lines with improved productivity for the northern region. Results from this project will be published over the next few years.
- Results from contrasting 2016 and 2017 seasons in delayed sowing experiments were used to benchmark the phenological response of current and older cultivars to temperatures during flowering and podset.
- Approximately 1250 internationally-sourced lines (including both *Cicer arientinum* and wild relatives) are being screened for performance in the northern grain belt to select appropriate parents for pre-breeding for high yield under terminal heat stress. Earlier podding is one of several traits being targeted.

Introduction

Chickpea is rapidly growing in its importance as a winter legume crop in Australia. Research and pre-breeding in Australia is expanding in the areas of abiotic stress tolerance to build on gains in disease control over the past 40 years.

Terminal heat stress is one of the most widespread abiotic stressors in Australian cropping regions. There are several ways in which heat can reduce yield, which include death/sterility of reproductive tissues (Devasirvatham *et al.* 2013), reduced pod set, a reduction in the duration of developmental stages (Devasirvatham *et al.* 2012) and investment in heat-shock proteins (Jha *et al.* 2014). These factors are controlled by different genes and require different breeding strategies, but relevant traits could potentially be 'pyramided' into new pre-breeding lines to enhance the performance of chickpea in hot and dry seasons.

Compared to most other winter legumes, chickpea has a reputation as relatively tolerant to hot, dry conditions (Sadras *et al*. 2015). The temperatures required to sterilise flowers are relatively high (sustained >33^{o}C daytime temperatures in sensitive genotypes – Devasirvatham *et al.* 2013) and are not usually persistent during the key weeks of pollination in September and October in the Australian grain belt. Conversely, temperatures which delay the onset of podding (average daily temperature of 15^{o}C, termed "chilling temperatures" – Croser *et al.* 2003) are quite common, and delays in the commencement of podding of up to 35 days post flowering have been recorded in Mediteranean-type climates in Australia due to long periods of chilling temperatures (Berger *et al* 2004). Reduced pod set has been observed in mean temperatures up to 21^{o}C (Berger *et al.* 2011). This has been attributed to a reduced ability of the pollen to grow through the style and fertilise the ovule under low temperatures, despite both pollen and ovule being fertile (Srinivasan *et al.* 1999; Clarke and Siddique 2004).

It has been argued that greater yield gains for Australian growers are possible by bringing the podding period earlier by a week in September (heat avoidance) rather than extending the podding period a week into November (heat tolerance), when moisture availability is usually also a significant constraint (Clarke *et al.* 2004). Several approaches to breeding for improved chilling tolerance have been attempted in Australia, including pollen screening utilising internationally-sourced *Cicer arientinum* germplasm, which resulted in early-podding cultivars Sonali and Rupali (Clarke *et al.* 2004), and screening wild relatives for chilling tolerance (Berger *et al.* 2011). It has been suggested that little genetic variation exists amongst domesticated chickpea to breed for chilling tolerance (Berger *et al.* 2011), however a difference of a few days in the onset of podding, though scientifically small when compared to wild *Cicer* species or other crops, can be economically large to a grower, particularly in seasons of terminal heat or drought stress (Berger *et al.* 2004).

The aim of this research is to investigate mechanisms for heat tolerance and avoidance, screen Australian and international germplasm for genetic sources of relevant traits, and incorporate these traits into pre-breeding lines which can be used for development of future Australian cultivars by breeders. The data presented in this paper are preliminary phenological results from a subset of lines to illustrate the potential to breed for chilling tolerance as a mechanism to increase the time available for podding in seasons/environments which experience terminal heat and drought stress.

Methods for preliminary results

A field experiment was conducted at the I. A. Watson Grains Research Institute, Narrabri (30.34^{o}S; 149.76^{o}E) in 2016 and 2017. Up to 76 chickpea genotypes were planted in two replicated plots (each plot 1.8 x 4 m). Data presented here is from a subset of lines representing released cultivars or publically available genotypes.

The experiment consisted of two sowing dates - a sowing date typical for the northern region and a later sowing when plants would be exposed to higher temperatures. Planting dates were 14 June and 29 July in 2016, and 31 May and 25 July in 2017. The experimental years provided two contrasting seasons: 2016 was dominated by high rainfall (529 mm Jun – Oct) and relatively cool September daytime temperatures, with large amounts of cloud associated with precipitation in the first few months of growth. In contrast, 2017 started with good stored moisture, but had less in-crop rainfall (135 mm Jun-Nov), with concurrent warmer days and cooler nights. Temperature profiles for the period before and during the reproductive phase are given in Figure 1.

Plots damaged by severe ascochyta infection in 2016 were excluded from the analysis and hence, the results for some cultivars represent data from single plots.

Phenology for the time of sowing (TOS) trial was recorded as the days after planting (DAP) that 50% of plants in the plot had produced its first flower or first pod. Growing degree days (GDD) was calculated by

$$[(T_{max} + T_{Min}) / 2] \ - \ T_{base}$$

Where T_{max} is the daily max temperature and T_{Min} is the daily minimum, unless the minimum dropped below T_{base} in which case T_{base} was used. A T_{base} of 0^{o}C was assumed (Soltani *et al*. 2006). Daily temperatures were measured by an on-site weather station.

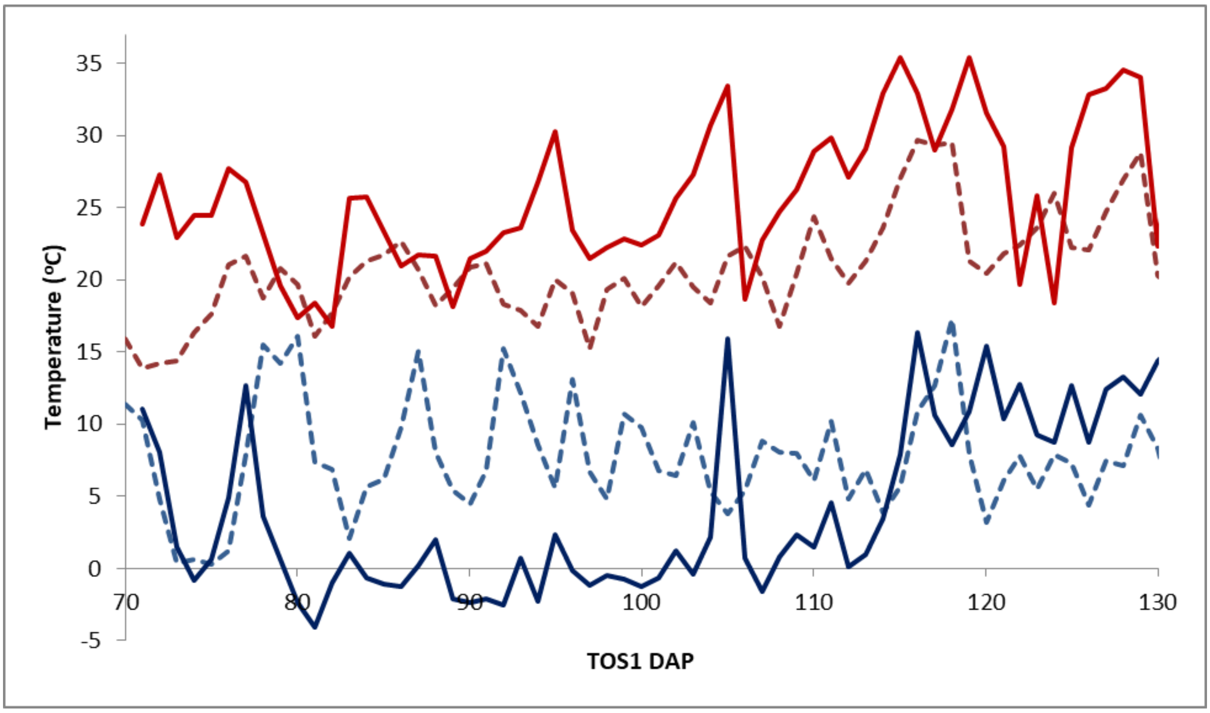

Figure 1. Temperature profiles for the two experimental seasons before and during the reproductive phase. Dotted lines = 2016 daily minimum and maximum temperatures; solid lines = 2017 daily minimum and maximum temperatures.

In addition, over 1000 genetically-diverse chickpea genotypes were obtained from the Australian Grains Genebank (AGG), plus a subset of 241 lines from the ICRISAT reference set were obtained via the Australian Centre for Plant Functional Genomics (Adelaide, South Australia). These sets included wild relatives of domesticated chickpea, wild-collected accessions of *Cicer arientinum*, and breeding lines/cultivars from a diverse range of growing environments around the world. All genotypes were sown in single 1.5m rows in 2016 in a netted bird-exclusion cage at Narrabri between the 18th and 27th July, with the late and long sowing period being due to high rainfall, which continued for most of the growing season. PBA HatTrick⚘ and PBA Slasher⚘ were included as comparators. Phenology was determined for plants within each 1.5m row as per TOS trial.

The data were analysed using the REML function I Genstat (version 17). Years, sowing dates and genotypes were considered fixed effects and row-column coordinates within sowing dates and seasons as random effects.

Preliminary results and discussion

The contrasting seasons provided interesting study years for the influence of temperature on phenology. DAP for flowering, podding and the flower-pod interval exhibited a significant interaction between genotype, year and TOS (P=0.036, P<0.001 and P<0.001 respectively). The range in flowering dates between genotypes for TOS1 was greater than the range in podding dates (Table 1). However, the range in flowering and podding dates within TOS2 were similar (approximately 12 days), but much narrower than TOS1. This suggests that either the warmer temperatures in TOS2 induced earlier pod set, or that cooler temperatures in TOS1 delayed pod set.

This data shows clear relationship between flowering and podding date, with 58-63% of the variance in podding date being explained by flowering date in regular sowings. Hence, selecting for earlier flowering will result in earlier podding. However, based on this data and considering only this set of genotypes, selecting for 1 day earlier podding will only bring forward podding by 0.31 days. Hence the economic value of selecting for earlier flowering/podding amongst this set of germplasm is quite low, considering that the range in flowering dates from which to select is only a couple of weeks.

Cultivars which had a flower-pod interval which was more than 2 weeks greater in TOS1 compared with TOS2 were Genesis 079, PBA Monarch⦶, PBA Pistol⦶, PBA Slasher⦶, PBA Striker⦶ and Sonali. These cultivars tended to have both earlier flowering and earlier podding times than other cultivars, and were the earliest in both TOS1 and TOS2.

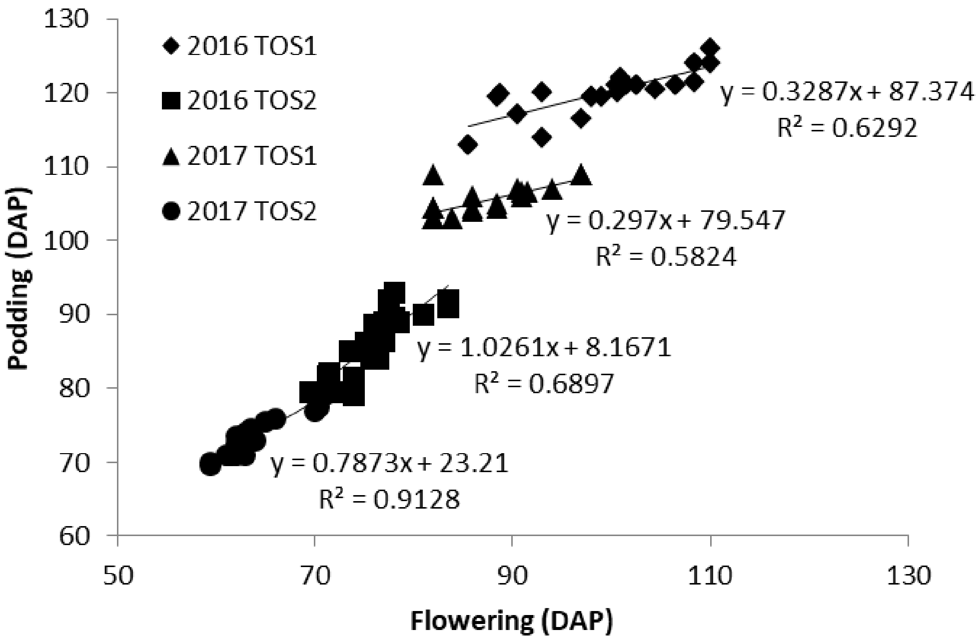

Figure 2. Correlations between the flowering and podding dates of genotypes in two contrasting seasons

The thermal time requirements to the commencement of the flowering and podding periods are given in Table 2. Earlier commencement of podding in 2017 cannot be explained by faster accumulation in thermal time. Commencement of podding in TOS1 was 207 GDD later in 2016 than 2017. This trend was also evident in TOS2, albeit to a lesser extent. Whilst the average daily temperatures (essentially what is used to calculate GDD where $T_{base} = 0^oC$) in both seasons were similar during the commencement and early reproductive stage (Figure 1), the daily maximums and minimums were quite different, and the amount of cloud was much higher in 2016 due to the large number of rainy days. It is possible that lower light intensity due to cloud cover had a significant influence on chickpea development. Note that irrigation was used to top up stored soil moisture in 2017 such that there was minimal to zero water stress during flowering and podding (no irrigation was required in 2016).

The shorter intervals between flowering and podding in TOS2 compared to TOS1 are also not explained by differences in GDD alone, with podding commencing 330 GDD earlier in TOS2 than TOS1 in 2016 and 246 GDD earlier in 2017. This lends support to the importance of considering daylength as well as temperature in delayed sowing trials (Sadras *et al*. 2015).

Table 1. Number of days between flowering and podding in heat stress trials at Narrabri in 2016 and 2017

	Flowering		Podding		Flower-pod interval	
	TOS1	**TOS2**	**TOS1**	**TOS2**	**TOS1**	**TOS2**
2016						
Amethyst	102	79	121	89	20	11
Flipper⌽	105	77	121	89	16	12
Genesis 079	89	71	120	82	31	11
Genesis 090	101	76	120	84	19	8
Genesis Kalkee	107	77	121	87	15	10
Howzat	99	77	120	84	21	8
ICCV 05112	101	74	121	85	21	12
ICCV 05301	109	81	122	90	13	9
ICCV 05314	110	78	124	90	14	12
ICCV 06109	98	78	120	91	22	14
ICCV 98818	97	76	117	89	20	13
Jimbour	109	84	124	91	13	9
Kyabra⌽	110	84	126	92	16	12
PBA HatTrick⌽	98	75	120	86	22	11
PBA Monarch⌽	93	72	120	82	27	11
PBA Pistol⌽	93	74	114	79	21	5
PBA Slasher⌽	91	72	117	80	27	8
PBA Striker⌽	89	74	120	82	31	8
Sonali	86	70	113	80	28	10
Tyson⌽	103	78	121	93	19	15
Yorker	101	78	122	92	21	15
Range	*25*	*14*	*13*	*14*	*18*	*10*
Mean	*99*	*76*	*120*	*86*	*21*	*10*
2017						
Ambar⌽	84	64	103	75	19	11
Amethyst	89	64	105	73	17	9
Genesis 079	82	62	103	73	21	11
Genesis 090	91	65	107	76	16	11
Genesis Kalkee	92	66	107	76	15	10
ICCV 05112	97	71	109	79	12	8
ICCV 05301	89	71	105	78	16	7
ICCV 05314	91	70	106	77	15	7
ICCV 06109	97	71	109	80	12	9
ICCV 98818	97	71	109	80	12	9
Jimbour	86	62	104	74	18	12
Kimberly Large	82	63	109	71	27	8
Kyabra⌽	86	63	106	74	20	11
Neelam⌽	91	63	107	73	17	10
PBA Boundary⌽	94	62	107	71	13	10

PBA HatTrickⓓ	86	63	105	72	19	10
PBA Monarchⓓ	82	64	105	74	23	11
PBA Pistolⓓ	82	60	103	70	21	10
PBA Seamerⓓ	82	62	103	71	21	9
PBA Slasherⓓ	82	62	105	71	23	10
PBA Strikerⓓ	82	60	103	70	21	11
Sonali	82	61	105	71	23	10
Range	*15*	*12*	*6*	*11*	*15*	*5*
Mean	*87*	*64*	*106*	*74*	*18*	*10*
s.e.	*4.384*		*2.079*		*2.880*	

Podding for all genotypes in TOS2 began between 80 and 92 DAP in 2016 and 71 and 76 DAP in 2017. The mean flower-pod interval was 10 days in both 2016 and 2017 for this treatment, which was between 9 and 14 days shorter than TOS1. Given that it is not GDD alone which causes shorter flower-pod intervals in TOS2, two possible factors are proposed: longer daylength/greater incidence of solar radiation (Soltani and Sinclair, 2011), and/or a critical minimum temperature under which sporogenesis or pollenation cannot occur (Clarke and Siddique 2004). The large number of cloudy days in 2016 likely played a role in alteration of phenology.

Further field trials over the next few years will quantify the influence of these various factors, as well as growth rate, changes in canopy temperature using aerial remote sensing, model phenology relative to canopy temperature rather than weather station data, and quantify photothermal time rather than simply GDD. Another factor that warrants further research is that average daily temperature is not the best measure of chilling but rather temperatures after dawn (when pollen is released).

Table 2. Accumulated GDD up to the commencement of flowering and podding for the earliest genotypes in each treatment

	Flowering		**Podding**	
	TOS1	**TOS2**	**TOS1**	**TOS2**
2016	999	892	1374	1044
2017	940	729	1167	921

Of most value to prebreeding is that differences existed between genotypes, even amongst the fairly narrow genetic diversity found in current Australian cultivars. To expand this genetic range and seek lines with earlier podding capacity (and suitability to other climatic features of the Northern Grain Belt), the phenology and yield potential of a diverse range of chickpea genotypes were quantified at Narrabri (Figure 3). Heavy rains in June and July caused significant planting delays, such that the planting date was closer to TOS2 in 2016 and thus the discrimination between podding dates was anticipated to be small. Nevertheless, up to 6 days difference in podding date between PBA HatTrickⓓ and the earliest podding lines, and 7 days difference in the flower-pod interval, were observed. Podding dates of PBA Slasherⓓ and PBA HatTrickⓓ standards were 91 DAP and 85 DAP respectively, and flower-pod intervals were 15 days and 12 days respectively. This placed these lines (and by deduction most Australian cultivars) well within, but slightly earlier than average, the range of podding dates found in the diverse lines. It is anticipated that when sown within the optimum sowing window for chickpea there would be greater variation in podding dates and flower-pod interval, as experienced in the TOS1 trials.

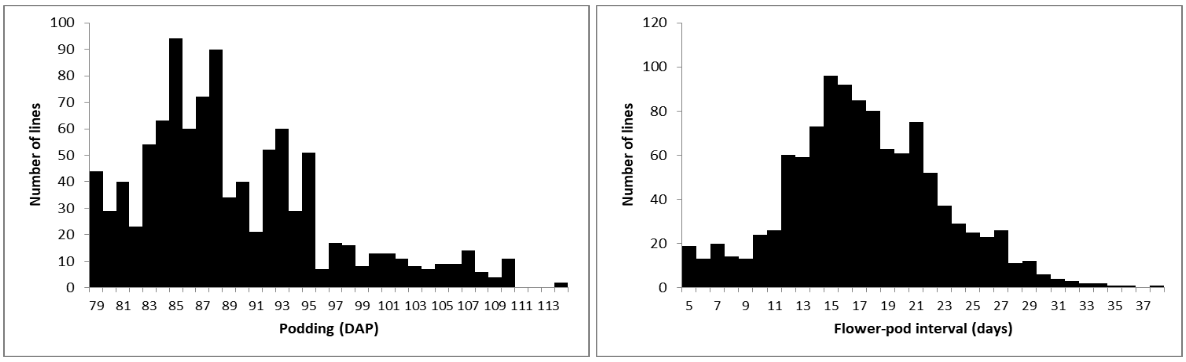

Figure 3. Histograms showing distribution of podding and flower-pod intervals amongst a range of >1000 diverse genotypes including closely related *Cicer* species and wild lines.

A subset of approximately 200 of the diverse lines from 2016 were increased in 2017 and will undergo field-based screening in 2018. Selection amongst diverse genotypes will be made for earlier podset as well as a host of other traits likely to lead to yield gains in the northern grain belt. The most promising lines will be crossed with high-yielding Australian cultivars and sent to the PBA chickpea breeding program at Tamworth for incorporation into future chickpea cultivars.

Acknowledgements

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References

Berger, J.D., Kumar, S., Nayyar, H., Street, K.A., Sandu, J.S., Henzell, J.M., Kaur, J., Clarke, H.C., 2011. Temperature-stratified screening of chickpea (Cicer arietinum L.) genetic resource collections reveals very limited reproductive chilling tolerance compared to its annual wild relatives. Field Crops Res. 126, 119-129.

Berger, J.D., Turner, N.C., Siddique, K.H.M., Knights, E.J., Brinsmead, R.B., Mock, I., Edmondson, C., Khan, T.N., 2004. Genotype by environment studies across Australia reveal the importance of phenology for chickpea (Cicer arietinum L.) improvement. Aust. J. Agric. Res. 55, 1071–1084.

Clarke, H.J., Khan, T.N., Siddique, K.H.M., 2004. Pollen selection for chilling tolerance at hybridisation leads to improved chickpea cultivars. Euphytica 139, 65–74.

Clarke, H.J., Siddique, K.H.M., 2004. Response of chickpea genotypes to low temperature stress during reproductive development. Field Crops Res. 90, 323–334.

Croser , J.S., Clarke, H.J., Siddique, K.H.M, Khan, T. N., 2003. Low temperature Stress: Implications for Chickpea (Cicer arietinum L.) Improvement. Crit Rev in Plant Sci 22, 185-219.

Devasirvatham, V., Tan, D. K. Y., Gaur, P. M., Raju, T. N., Trethowan, R. M., 2012. High temperature tolerance in chickpea and its implications for plant improvement. Crop Pasture Sci 63, 419–428.

Devasirvatham, V., Gaur, P. M., Mallikarjuna, N., Raju, T. N., Trethowan, R. M., Tan, D. K. Y., 2013. Reproductive biology of chickpea response to heat stress in the field is associated with the performance in controlled environments. Field Crops Res. 142, 9-19.

Jha, U.C., Bohra, A., Singh, N.P. 2014. Heat stress in crop plants: its nature, impacts and integrated breeding strategies to improve heat tolerance. Plant Breeding 133, 679-701.

Sadras, V. O., Vadez, V., Purushothaman, R., Lake, L., Marrou, H., 2015. Unscrambling confounded effects of sowing date trials to screen for crop adaptation to high temperature. Field Crops Res. 177, 1-8.

Soltani, A., Hammer, G.L., Torabi, B., Robertson, M.J., Zeinali, E., 2006. Modeling chickpea growth and development: Phenological development. Field Crops Res. 99, 1-13.

Soltani, A., Sinclair, T. R., 2011. A simple model for chickpea development, growth and yield. Field Crops Res. 124, 252-260.

Srinivasan, A., Saxena, N.P., Johansen, C., 1999. Cold tolerance during early reproductive growth of chickpea (Cicer arietinum L.): genetic variation in gamete development and function. Field Crops Res. 60, 209–222.

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Chickpea agronomy and water use with neutron moisture meters

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Key words

chickpea, agronomy, row spacing, harvest index, water use

GRDC code

UQ00067

Call to action/take home messages

- Chickpea yields are maximised when planted on narrow rows (50cm and below).
- Avoid planting early and excessive biomass production.
- Aim to establish 20-30 plants/m^2 .
- Chickpeas will extract water from soils to 1.2m and below.
- Water Use Efficiency is improved by narrow rows; more water extracted and higher yields.

Background

The Queensland Pulse Agronomy Initiative planted its first chickpea trial in the 2013 winter, and with the next 2 years of trials our understanding of what drives yield improved, but also left many unanswered questions regarding crop physiology and how to best manage the crop to maximise yield.

The initial trials across southern Queensland confirmed that the latest release varieties such as PBA HatTrick⟨PBR⟩, PBA Boundary⟨PBR⟩ and the now released PBA Seamer⟨PBR⟩ (formerly CICA 0912) responded similarly to several agronomic factors:

- All maximised yields when planted at narrow row spacings with peak yields obtained when planted at row spacing of 25cm, however across several sites and years yields at 50cm were statistically the same as 25cm; yields then dropped when planted at wider spacings of 75cm and 100cm. This was observed in both low and high yielding environments (Figure).
- Plant population had less effect than did row spacing on final yields, with a flat response curve across 20, 30 and 40 plants/m^2, with a slight drop in yield at 10 plants/m^2. Hence it is recommended that planting rates remain at the current recommended rate of 20-30 plants established/m^2 for dryland plantings.
- There were no interactions that suggest any variety be planted at different populations for different row spacings. Planting early in the planting window had no grain yield benefit, however early plantings generated more biomass.
- Later plantings have mixed results for yield and biomass. It has been observed that harvest index (HI) improves with later plantings due to lower dry matter production (Figure 2) & (Table 1).

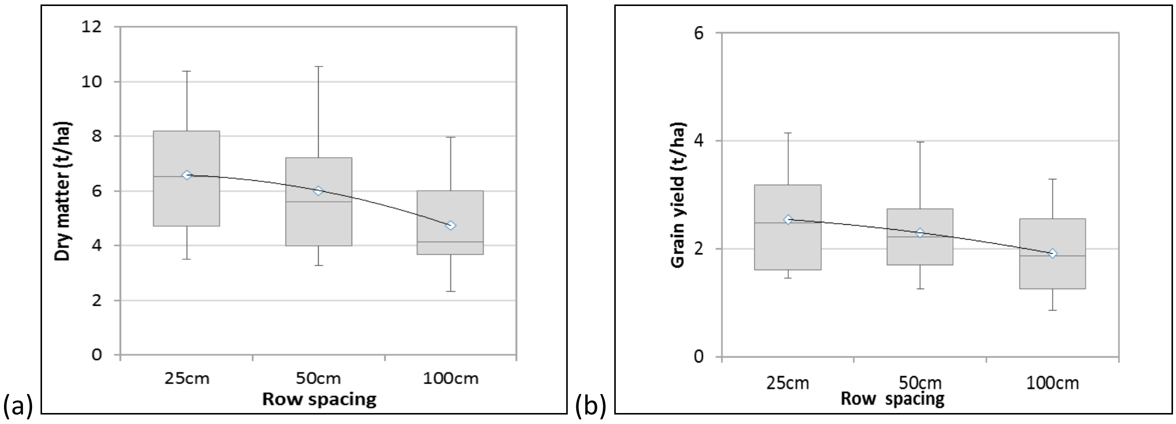

Figure 1. Summary of 12 chickpea sites from 2014 and 2015 [diamond marker indicates average across all sites and the trend line for the 3 row spacings]. (a) shows the effect of row spacing on dry matter production and (b) final grain yield. Row spacing has a larger effect on dry matter production than grain yield, however both trend lower as row spacing increases.

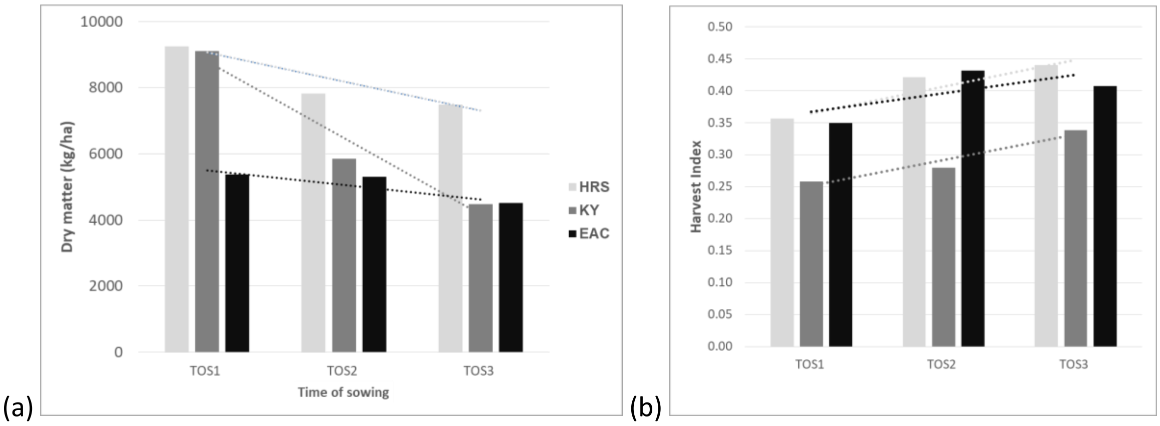

Figure 2. Time of Sowing (TOS) trials in 2015 at 3 sites; Hermitage [HRS], Kingaroy [KY] and Emerald [EAC]. All sites had a decreasing trend for dry matter production when planted later in the season (a). Harvest Index (HI) improves with later sowing dates as dry matter is reduced (b).

Table 1. Dry matter production and grain yield at Hermitage 2015 (relates to Figure 2).

Hermitage	**TOS 1 20/5**	**TOS 2 12/6**	**TOS 3 3/7**
Dry matter (t/ha)	9.250a	7.825b	7.492b
Grain Yield (t/ha)	3.3d	3.3d	3.3d

* Note that grain production in this trial was the same for all TOS even with high biomass in the early sowing

Combining dry matter and yield data across 10 sites over 3 years which includes trials sites at Emerald, Kingaroy, Warra, Dalby, Goondiwindi and Hermitage in Figure 3, indicates that chickpeas do not convert biomass to grain with the same efficiency as the production of dry matter increases. There is a very good straight line relationship up to 8t/ha dry matter and it plateaus after this, i.e. the highest yield potential crops do not fully meet their grain production potential. There could be many reasons for this including terminal droughts as a consequence of growing large biomass crops.

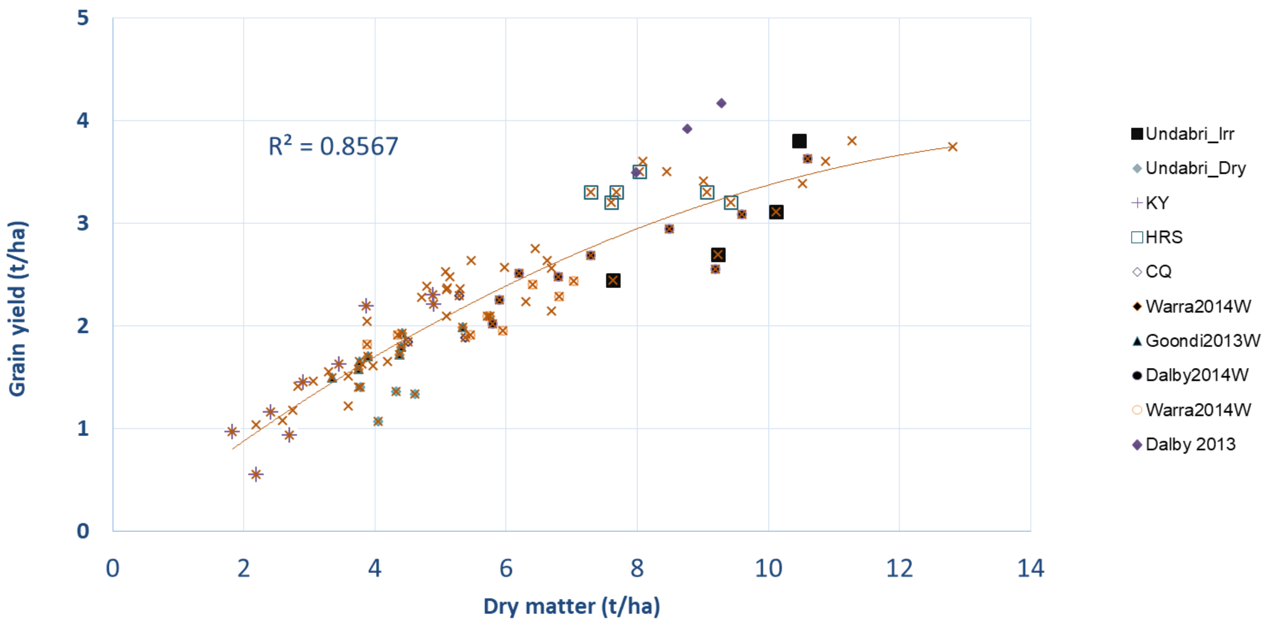

Figure 3. The relationship ship between dry matter production and grain for chickpea trials at 10 sites over 3 years

New directions

These findings have directed subsequent research questions in the Queensland Pulse Agronomy Initiative. The questions to be answered include; can harvest index be manipulated in chickpeas? How best to manage high biomass crops? Can early biomass production be reduced to conserve soil moisture for later in the season?

Trials with many plant growth regulators (PGRs) and other chemicals were conducted in 2016. While there were some products that did have a minimal effect on harvest index (HI), no products improved yields. Work with PGR's has many seasonal, rate and timing variabilities that make consistent results difficult to obtain. Due to this and that currently there are no PGR products registered for use on chickpeas, this aspect of the research was not pursued further.

In other trials, the water use of chickpeas was monitored with neutron moisture meters (NMM) to determine when and where the crop was accessing soil water and to explain why narrower row spacings were able to access more water and convert it more efficiently to grain.

Water use

To monitor soil moisture and where chickpeas are drawing moisture from using the neutron moisture meter (NMM), plots were planted at 2 different row spacings of 50 and 75 cm. Within the plot 2 access tubes were installed, one in the planted row and the other between the 2 rows. In 2016 the variety was PBA HatTrick ⦶ planted at 30 plants/m^2. Access tubes were in all 3 replicated plots and measurements averaged.

This chickpea trial at Hermitage in 2016, had an unusually wet late winter and spring with close to 500 mm of in-crop rain for the main season planting time and 350mm for the later sowing. This led to a very late January harvest and a badly lodged crop. Grain yield results from this trial had no statistical differences across variety and row spacing, with a trend for higher yields at the later sowing time.

For the earlier sowing time, flowering commenced by mid-September. The critical 15°C average temperature for pod retention was not consistent until well into October, with below 5°C minimum temperatures recorded on the 25th of October.

Due to the very wet season, NMM data shows that the crop grew from August to mid-October on rainfall, with soil moisture depletion only starting to occur after this time. This soil draw down coincided with the warmer temperatures and pod retention of the crop. The NMM data shows that even with the high rainfall, soil moisture was removed from the profile to the deepest measuring point of 125 cm (Figure 4). We can only assume the chickpea crop was the cause of this as roots were not assessed.

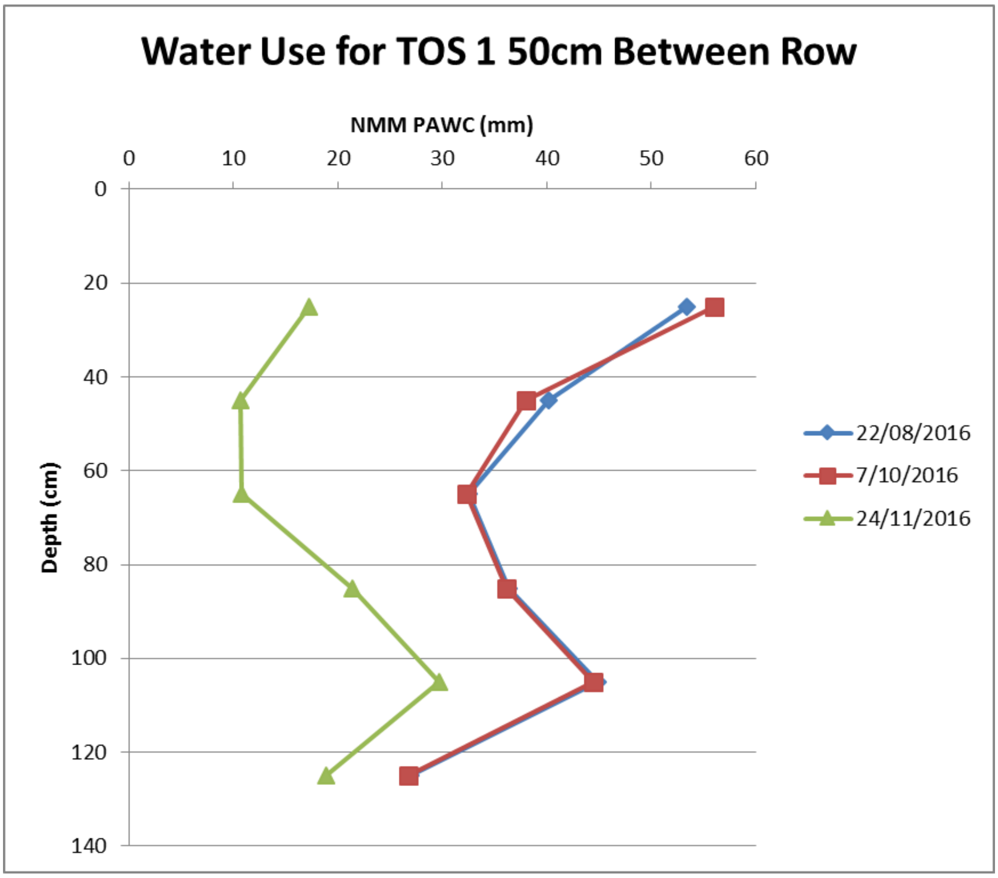

Figure 4. Soil water use as measured by neutron moisture meter at Hermitage Qld. at 3 times during the growing season. Access tube was in the middle of 2 rows planted 50 cm apart.

A further point of interest was from where water was extracted in the different row spacings of 50 cm and 75 cm. In the 50 cm, plots water extraction patterns were virtually the same where measured in the planted row or between the row. In the wider spaced rows at 75 cm, as the season progressed, more water was extracted in the between row space and this occurred in the top 65 cm of the profile. The difference over the season was 30 mm of additional PAWC removed in the inter row space as compared to the on row readings. If you averaged the 2 tubes it would mean an additional 15mm of water extracted in 75cm plot for no additional yield benefit.

In previous trials within the Pulse Agronomy project where starting and ending gravimetric assessments of soil water were taken, the results show that crops planted on narrow row spacing access up to 20mm more of the stored soil water, and due to higher yields convert this moisture more efficiently to grain.

The trial data for chickpeas grown in 2017 which will provide additional NMM data were unavailable at the time of publishing.

Discussion

Chickpeas have the potential for yields approaching 5 t/ha given the right environment/season (this project's best small plot yield 4.7 t/ha dryland). Dry matter production of above 10t/ha and up to 13 t/ha have been produced, and results have seen harvest index of 0.45, however the crop seems unable to maintain a constant harvest index above 8 t/ha dry matter and it is difficult to get the combination of high dry matter and HI.

The results suggest several management options to give the crop the greatest potential; starting with narrow rows. The farming system also needs to be considered, as well as any associated risk with disease for the coming season. Improved yields from narrow rows are evidenced in high and low yield scenarios, with disease pressure high 1 in 7 – 10 years.

Planting early produces large biomass that has a higher disease risk potential. The bigger risk however, is using up stored soil moisture and adding to the possibility of terminal drought and being unable to maintain this yield potential through pod fill.

Chickpeas should be sown into paddocks with good soil depth and minimal soil constraints. It has long been known that chickpeas are very adept at chasing deep moisture and NMM suggests extraction to 125 cm in a soft year. Choosing paddocks with the biggest bucket is highly adventitious for high yields.

Continue with best management crop scouting for pests and diseases and utilise preventative fungicide applications as appropriate.

Management options once the crop is growing, apart from the usual crop protection/good agronomy, have been elusive and work will continue to manipulate the crop to improve harvest index particularly for high biomass crops but also for lower biomass situations.

Current farming systems aim to store rainfall and fill the soil profile between crops. Good management enable the crop to withdraw more from this bank of stored soil water.

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How much nitrogen is fixed by pulse crops and what factors affect fixation?

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Key words

nitrogen fixation, chickpea, fababean, soybean, mungbean

GRDC code

DAQ00181

Call to action/take home messages

- The amount of nitrogen (N) fixed by pulses varies widely (from 0 to 400 kg N/ha) and is impacted by crop species, soil nitrate at planting, effective nodulation and agronomic factors such as time of sowing, row spacing, plant population and variety.
- Narrower row spacing in pulses not only improves crop biomass and yield but also the proportion of N in that biomass that is fixed from the atmosphere and hence free for crop use. This allows crops to be produced on lower levels of soil nitrate and gives more opportunity for crop residues to be higher in N that can mineralise for the following crop.
- Time of sowing should be optimised for maximum biomass production and longer time to accumulate fixed N. The proportion of N in plants that is derived from the atmosphere (%Ndfa), i.e. fixed, is significantly greater when crops are sown earlier in the planting window rather than late, particularly in soybean and fababean crops. If growers are planting late, more N will be fixed if plant populations are significantly increased.
- Some minor varietal differences in N fixing potential do exist and growers can aim for higher biomass varieties to fix more N.

Background

Average amounts of nitrogen (N) fixed annually by crop and pasture legumes are around 110 kg N/ha (ranging from close to zero to more than 400 kg N/ha). The actual amount fixed depends on the species of legume grown, the site and the seasonal conditions as well as agronomic management of the crop or pasture. The legume crop uses this N for its own growth and may fix significantly more than needed, leaving a positive N balance in the soil for proceeding crops.

Average estimates of N fixation for the major crop legumes grown in Australia (derived from many research trial studies) are given in Drew et al (2012) (Table 1), however, huge variations around these figures exist in practice. Actual percent N fixed and amounts of N fixed by individual crops are influenced by environment and management effects, including soil nitrate levels at planting. Importantly, both root and shoot N must be considered when calculating the total amount of N that was fixed and used by the plant for growth. Root N is substantial for all crops but does vary with species, for example chickpea have equal portions of N in their roots as they do in their shoots wheareas faba bean and mungbean have approximately half as much N in their roots as their shoots (Unkovich et al. 2010). N remaining in residues of shoots and roots of the pulse crop after harvest is a slow release form of N for the subsequent crop. In this form, less is likely to be moved through the loss pathways that lead to loss of inorganic N fertiliser in the short term.

Table 1. Estimates of amounts of N fixed annually by crop legumes in Australia from Drew et al. (2012).

Legume	%N fixed	Shoot dry matter (t/ha)	Total crop N[1] (kg/ha)	Total N fixed[2] (kg/ha)
Lupin	75	5.0	176	130
Pea	66	4.8	162	105
Faba bean	65	4.3	172	110
Lentil	60	2.6	96	58
Soybean	48	10.8	373	180
Chickpea	41	5.0	170	70
Peanut	36	6.8	268	95
Mungbean	31	3.5	109	34
Navy bean	20	4.2	148	30

[1] Total crop N = shoot + root N
[2]Total N fixed = %N fixed x total crop N; Data sourced primarily from Unkovich et al. 2010

Results

Improving the amount of N fixed in a farming system by changing agronomic practices has been a focus in a recent northern region project. Our results show that altering management practices such as row spacing, time of sowing and variety used can have large implications for the amount of N fixed by that crop. This means better N nutrition for the pulse crop and also potentially for the crop following that pulse

Row spacing

Field trials with chickpea, mungbean, soybean and fababean have shown that significant increases in %Ndfa (percentage of nitrogen derived from the atmosphere) occurred when plants were grown on a narrower row spacing (i.e. 25 or 50 cm rows compared to 75 or 100 cm rows), keeping plant population the same. This then translated into higher amounts of N (kg/ha) fixed by the plants as biomass was also greater and ultimately more N was left behind post-harvest for the following crop. Figure 1 below demonstrates this higher amount of N fixed with narrower row spacing for two chickpea trials; one at Billa Billa near Goondiwindi and one near Dalby. After accounting for the N removed in the grain at harvest, an estimated 59 kg N/ha was added to the soil by the chickpeas at the Dalby site when grown on 0.25m rows, while only 23 kg N/ha was added at the 1.0 m row spacing. In the trial at Goondiwindi, N fixation and biomass were much lower overall. Just 6 kg N/ha was added through N fixation at 0.25 m row spacing however if grown at on 1.0m rows, the crop actually depleted soil N by 6 kg/ha

Reducing rows from 90 down to 30 cm in mungbean also significantly increased both %Ndfa and total amount of N fixed. Differences in varieties in their potential to fix N also was evident (Figure 2).

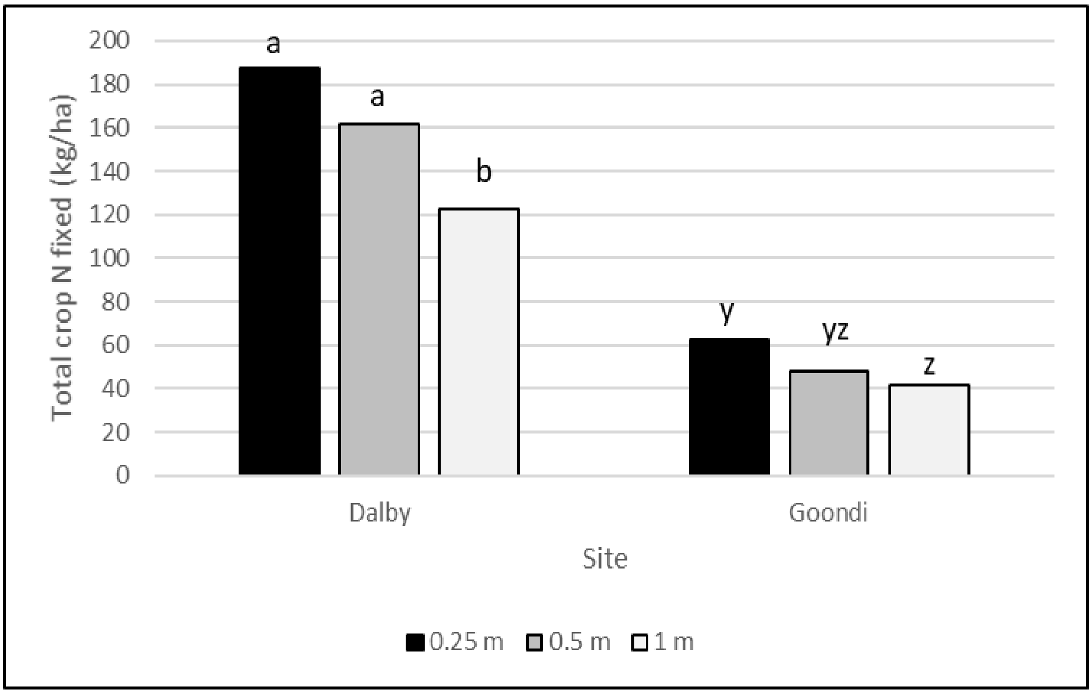

Figure 1. Total N fixed in chickpeas (shoots and roots) when grown at 3 different row spacings but keeping plant population the same at 30 plant/m^2.

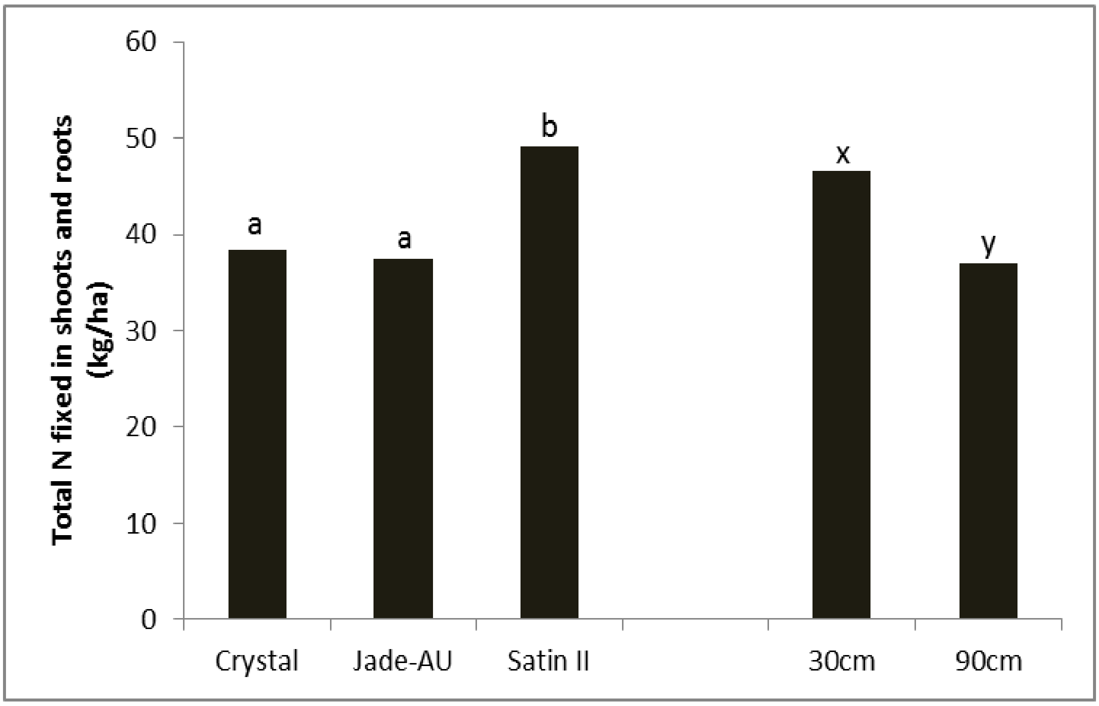

Figure 2. Differences in total shoot and root nitrogen for 3 mungbean varieties, Crystal⦶, Jade-AU ⦶ and Satin II ⦶ (LSD 5% = 7.65) and for two row spacings of 30 and 90cm (LSD 5% = 6.24).

Time of sowing

Mungbean, soybean and faba bean have all shown significant impacts of time of sowing on N fixation. Not only is biomass of the crop reduced in a late planting for all three crops, so too is the proportion of the N in the plants that is fixed by the rhizobia (%Ndfa). Higher plant populations are therefore required to try to compensate for this loss in production and reduced amount of free N.

Faba bean varieties PBA Nasma⁽ᵇ⁾ and PBA Warda⁽ᵇ⁾ both showed that sowing late decreased %Ndfa by more than half and this combined with the reduced amount of biomass produced by the plants from this late May sowing date, meant much less N was fixed by the plants (Figure 3). Increasing plant population partially compensated but did not completely overcome this loss.

Soybean planted in late January rather than December also was negatively impacted, with much lower %Ndfa and N fixed. One variety from the Australian Soybean Breeding Program, 'Richmond'⁽ᵇ⁾ fixed half the amount of N (81 kg N/ha less) in shoots when planted later (15 January 2014 compared 20 December 2013). The variety PR443 fixed only a third as much N (163 kg/ha less) when sown at the later planting time.

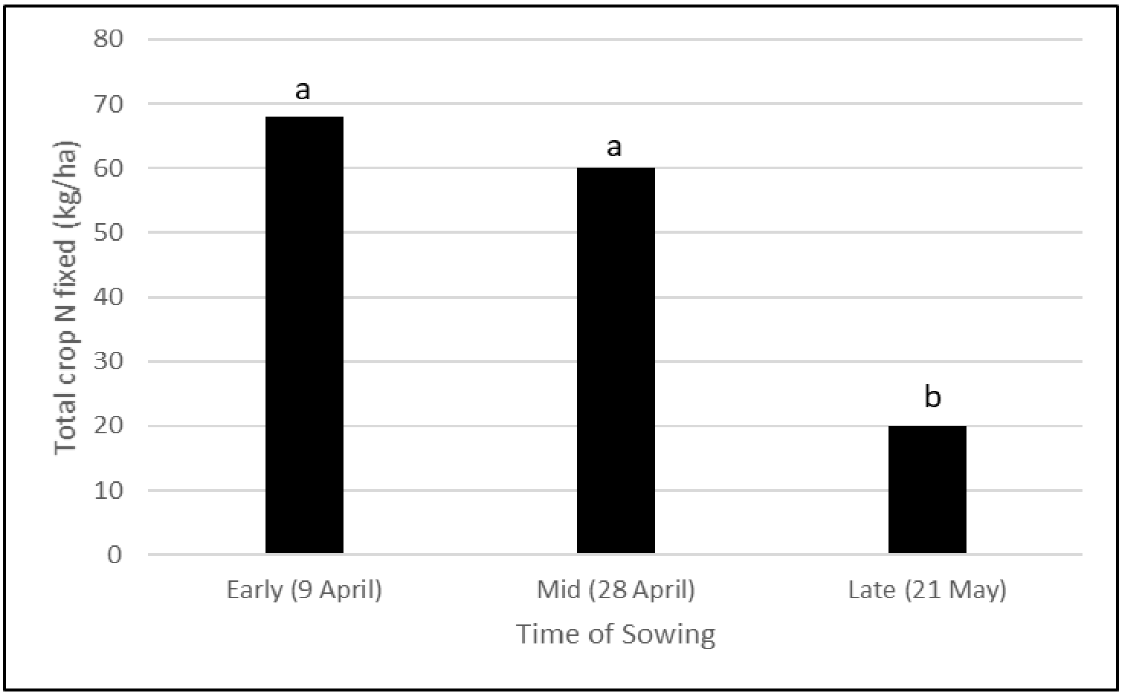

Figure 3. Total amount of N fixed by fababean (mean of two varieties PBA Nasma⁽ᵇ⁾ and PBA Warda⁽ᵇ⁾) was much lower when the crop was planted late. (N.B. Figures are for total N in shoots and roots assuming 40% of N in roots).

Inoculation

Trials focussing on the best form of inoculum for soybean and peanut in particular have shown little differences between peat, freeze-dried and granular inoculum forms. Growers should be able to use either form with confidence depending on available equipment. The use of liquid Zn fertilisers at recommended application rates and mixed with the chickpea inoculum strain CC1192 did not significantly impact the rhizobia or nodulation. Mixing of inoculum with concentrated forms of any fertiliser however is not recommended and extreme caution must be taken at all times to protect the live bacteria in the inoculum which are extremely sensitive to heavy metals and low or high pH levels. Further research with rhizobia strain compatibility for soybean, mungbean and fababean strains is required.

Establishment of good nodulation is vital for N fixation and hence good inoculation practices are crucial for survival of the rhizobia on the seed or in the soil at planting. Manufacturer guidelines as given on the packets should be followed and the correct rhizobia strain must be used.

Conclusions

Improving the amount of N fixed in a farming system by changing agronomic practices has been a focus in this project. Our results show that altering management practices such as row spacing, time of sowing and variety used can have large implications for the amount of N fixed by that crop. This can mean better N nutrition for the pulse but also for the crop following that pulse. Field trials have compared the impact of different row spacing, plant population, time of sowing and variety on effective nodulation and N fixation in pulse crops. This work has shown that narrower row spacing (for example 25 and 50cm rather than 75 or 100cm) in pulses can lead to higher levels of N fixed by the crop. This has correlated well with growth of the tops (biomass) and in some cases yield. Also, importantly, it has translated to greater amounts of N left in the soil.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

References

'Inoculating legumes: A practical guide.' Ground Cover Direct

http://www.grdc.com.au/GRDC-Booklet-InoculatingLegumes

Unkovich M, Baldock J and Peoples M (2010) Prospects and problems of simple linear models for estimating symbiotic N_2 fixation by crop and pasture legumes. Plant and Soil 329:75-89.

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Calculating how much N is needed in pulse-cereal rotations

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Key words

fertiliser, nutrients, budget, yield, nitrogen rate

Call to action/take home messages

- Nitrogen (N) - the element that is removed in the largest quantity with crop production.
- Calculate the contribution of pulse crops to the N supply and consider if you can change the N fertiliser rate for crops.
- Keep a watch on soil organic carbon (soil organic matter).
- When calculating target yield for crops, consider the plant available soil water.
- Consider the need for any other nutrients to be applied.
- How about a year-to-year nutrient budget?
- As a monitoring tool, place zero N and high N strips in the paddock.

Background

The question is often asked, "How much nitrogen (N) does a pulse crop contribute and how do I account for this in calculating the N fertiliser rate for a following cereal crop?" To give a definitive answer is tricky, as there are many factors that influence this decision:

- How the pulse crop performed which directly correlates to nutrient removal and N fixed;
- The fallow leading into the cereal crop;
- Estimating the yield potential and nutrient requirements for the cereal crop;
- Underlying fertility of the paddock; and
- Your goals for soil fertility management.

How much N will the pulse crop supply to the following crop?

Pulse crops have the ability to 'fix' atmospheric N (in association with bacteria) for their own requirements. This assumes that the root inoculation by the bacteria is sufficient and effective. Otherwise, soil N will be utilised the same as for cereals. Also, if available soil N is greater than 100kg N/ha, the N fixation by the bacteria is significantly reduced. The pulse stubble breaks down rapidly and hence the N will be available more quickly to the next crop.

The extra benefit from a chickpea crop compared to an equivalent wheat crop at the next planting opportunity will be in the range 20 to 70 kgN/ha. For example a chickpea crop yielding 2.4 t/ha should supply approximately 35 kgN/ha.

Calculating the extra N benefit form a winter pulse compared to a wheat crop

The extra contribution of a chickpea crop compared to a well-fertilised wheat crop (wheat yield approximately usually 50% more than a chickpea). This also applies to faba beans.

i) For a well-grown crop without any yield restrictions;

Extra N contribution (kgN/ha) = grain yield (t/ha) * 20 (approximately)

ii) For a semi-failed crop (e.g. frost, insects)

Extra N contribution (kgN/ha) = crop biomass (t/ha) * 10 (approximately)

Should this be included in a subsequent N fertiliser rate calculation?

If the calculation indicates that the N benefit could be more than 40 kgN/ha a reduction in the N fertiliser rate using the calculation, may be appropriate. Perhaps a partial reduction in the N fertiliser rate could be made, with the potential extra N 'banked' for the future.

If the calculation indicates that the N benefit could be smaller (10 to 20 kgN/ha) it may be better not to reduce the fertiliser rate. Any extra N could be considered as a bonus that is available for supporting yield of future crops.

How much N does a cereal crop require?

Nutrient removal

Grain that is harvested from a paddock contains a range of elements which can only be derived from the soil or from fertiliser. Of all the elements contained in grain, N is present in the greatest quantity. Table 1 shows the typical quantity of the main elements that are contained in grain. The quantity removed by high yielding crops is significant. For example, the total nitrogen removed by a 4 t/ha wheat crop, with 12% protein, over 1ha is 85kg of elemental N and 14kg of elemental P. This is calculated using the typical grain concentrations in Table 1, but the nutrient concentrations can vary quite widely because of different seasons (yields), inherent soil nutrition, applied fertiliser rate and cultivar. Thus, annual testing the grain for nutrient concentration will give a clearer quantification of the actual nutrient removal.

Table 1. Typical nutrient removal levels (kg element/t grain)

Crop (% protein)	N	P	K	S
	Nutrient removal (kg/t) grain			
Wheat (12%)	21.3	3.5	3.5	1.0
Barley (10%)	16.0	3.5	4.5	1.3
Sorghum (9%)	14.3	3.4	5.0	1.6
Chickpea (22%)	36.0	3.6	10.0	2.0
Mungbean (24%)	40.0	4.0	13.3	2.0
Maize (9%)	14.4	3.0	3.0	1.1
Baled wheat stubble	7.5	0.8	14.5	1.2

Calculating an N fertiliser rate

This simple budgeting process involves calculating the nitrogen demand from a crop of certain yield and protein, subtracting the soil supply value and the difference is the N fertiliser requirement.

i) Total nitrogen demand can be calculated from the equation:

N demand (wheat) = Grain yield* protein * 10/5.7 * 1.7

N demand (sorghum) = Grain yield* protein * 10/6.25 * 1.7

This takes into account the efficiency of uptake of N from soil, and in-crop mineralisation.

The grain N removal is the equation without the 1.7 multiplier.

ii) The soil supply is calculated from a soil test for N to a depth of 90cm, although approximately 80% of the nitrogen is accessed from the top 60cm (M Bell pers comm).

iii) The N fertiliser rate is the difference of Soil N supply – Crop N demand

The Nitrogen Book contains more detail on calculating N fertiliser rates. It can be access via the DAF website.

https://publications.qld.gov.au/dataset/the-nitrogen-books

Estimating the target yield

The above equation requires the use of a target yield. This can be an estimate from experience, or there are a range of tools available to assist in the understanding of the yield ranges that may occur. The CropARM tool can be used to create scenarios of yield ranges, effect of N application rates and the effect of SOI phases on yield outcomes. (see www.armonline.com.au)

With this program, you are able to create a scenario showing the potential yield response to N rate (Figure 1) or add an effect of a climate outlook (Figure 2). Note that an SOI analysis for summer crop is shown because there is less opportunity to use the climate outlook for winter crop. The skill level is generally low for earlier winter-crop planting dates. The result indicates an increase in the median yield from approximately 5 t/ha to 7.5 t/ha and yields generally in a higher range.

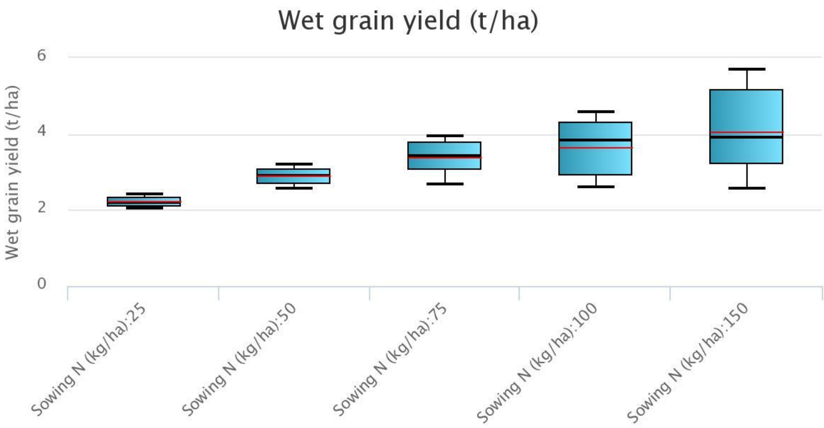

Figure 1. Modelled effect of N fertiliser rate on potential wheat yield (at 11% grain moisture). The scenario relates to Pittsworth, soil N = 50 kgN/ha, soil 190mm PAWC, 90% full at planting.

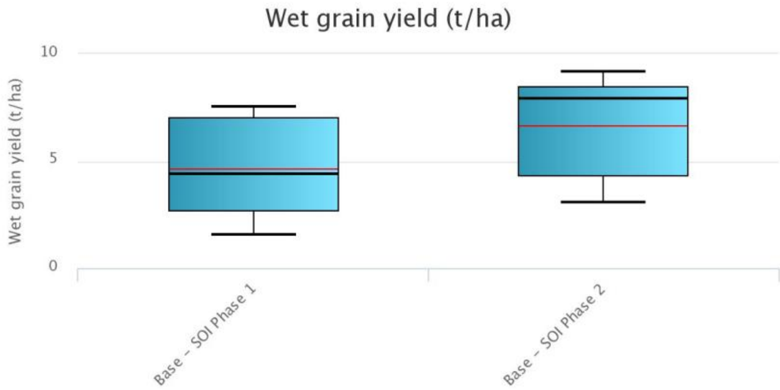

Figure 2. Modelled effect of a negative SOI phase (Phase 1) vs a positive SOI phase (Phase 2) in July/August, prior to sorghum planting on 15 September. Soil N = 50 kgN/ha, N fertiliser rate = 150 kgN/ha, soil 190mm PAWC, 60% full at planting.

Considerations to maximise N application

How efficient is an N fertiliser application?

It is only in relatively infrequent circumstances that loss of urea occurs. The most significant losses can occur from denitrification under the combined conditions of; warm temperatures, high soil water content, a source of nitrate-N and a source of energy for micro-organisms. Surface applied N fertiliser can also be subject to losses under conditions of warm temperatures, high pH, moist soil (but not enough water to move the N into the soil), wind and high humidity. Ammonium sulphate is less subject to volatilisation, as are the treated products such as Green urea® and Entec®. These products are more expensive per unit of N than straight urea.

N fertiliser is transformed in the soil by micro-organisms to forms readily taken up by plants, principally nitrate-N (but also ammonium-N). Figure 3 shows generalised quantities of losses and uptake.

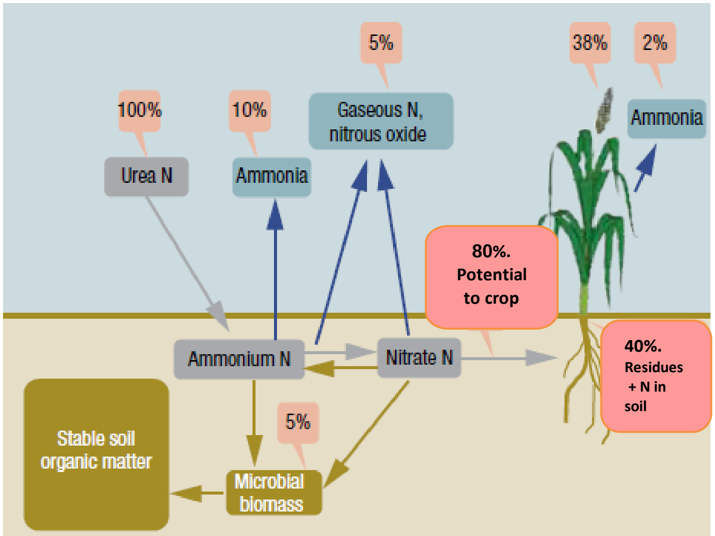

Figure 3. Generalised percentage distribution of applied N fertiliser in a winter crop system. Source: Adapted from D Herridge 2013.

Thus, 80% of applied N fertiliser is potentially available for plant uptake. However, in the northern cropping region, the figure is likely to be closer to 50% to 60%, with perhaps 20% of product left in the soil on many occasions. This N will be mostly available to the next crop unless an exceptional loss event (denitrification) occurs. Total losses are typically 15% to 20% in winter (Dr Wayne Strong's trials) but more recent work by Dr Mike Bell has found losses of 20% to 40% in summer systems even with only an occasional wet event.

The percentage of applied N that ends up in the grain will be in the range of 30% to 45% in average to good seasons (average around 38%) (Table 2). In dry seasons, relatively less applied N (an average of 20%) will have made it into the grain, with the remainder distributed in stubble or soil.

The N in the stubble, or remaining in the soil, will be largely re-cycled in the soil N pools and available for future crops. In good seasons, with high yield and with well balanced N supply, a greater proportion of the applied N fertiliser will end up in the grain relative to the stubble (up to 85% in grain vs 15% stubble). With a dry finish, less of the applied N fertiliser will remain in the grain relative to the above-ground stubble (typically 70% in grain vs 30% stubble). More of the applied N fertiliser will remain in the soil (typically 20% to 40%).

Under waterlogged conditions, high losses can occur (at least 40%). High stubble loads will tie up more N (typically 7 kg/t of grain removed). This could be up to 35% of the applied N fertiliser.

Table 2. The effect of season type on the percentage partitioning of an N fertiliser application in wheat. Adapted from Herridge 2013.

Season type	Soil N relative to yield	Lost[1]	Immobilised[2]	Left in soil[3]	Grain vs Stubble[4]	In grain[5]
Normal finish	Adeq. soil N or high yield	15	5	**0**	**85**	**45**
	Moderate soil N	20	15	0-20	**70**	**30**
	High soil N or low yield	20	15	20	60	20
Dry finish	Adeq. soil N	20	5	20	70	**27**
	Moderate soil N	25	15	**20**	60	**18**
	High soil N or low yield	25	15	**40**	50	**8**
Waterlogging	Moderate soil N	**40**	15	0	70	20
High stubble load	Moderate soil N	20	**35**	0	70	20

[1] Denitrification, volatilisation, [2] in micro-organisms, [3] percent of the N fertiliser application left in soil, [4] ratio of N fertiliser application in grain vs above ground residue, [5] percentage of the N fertiliser application that is in the grain.

How can I make the N fertiliser application as efficient as possible?

Seasonal conditions will largely determine if the applied amount of N was adequate, excessive or efficiently used. However, there are some things that can be done to make the best estimation.

Assuming that the fallow period has not been unusually wet or dry, the steps for efficient application are:

- knowing the soil N prior to the crop (soil test)
- calculating the N demand for a realistic target yield
- allowing for the contribution of a previous, failed or semi-failed pulse crop
- do test strips with nil N, intermediate and high N rate. The nil N rate is needed to calculate Agronomic Efficiency. The high N rate will show what might have been (in a good season) and be a point of reference for future applications.

After the crop is harvested

- evaluate the grain yield and protein of the crop (how did the removal match the application rate?)
- calculate the Agronomic Efficiency (AE) (yield increase with amount of N applied);
  - the formula is; AE = (Yield with N rate – Yield with nil N)/N rate (all rates in kg/ha)
  - a value of > 25 is good in a well-managed system

Remember- there are usually greater economic losses from under-fertilising than over-fertilising (in the longer term).

Applying N fertiliser

Especially for the northern region, applying the most appropriate N rate is considered more important than the timing of the N application. However, with respect to timing, there are a few factors to consider;

i) Early application for winter crop (January to March) – biggest risk is denitrification losses

ii) Close to winter planting (soil disturbance, N can be stranded in surface). Consider mid-row application which is showing good result in southern Australia.

iii) At or close to sorghum planting (can be denitrification losses). Consider applying earlier in the fallow when the soil is dry

Surface application vs incorporated?

Recent research is indicating fairly small losses from surface-applied urea. Research by Graeme Schwenke et al. (2014) reported the following losses;

Average loss in fallow 11% - (range 5% to 19%), in wheat crop 3% to 8%, in pasture 27%.

However, note that the maximum loss was 19%. Thus under conditions of high temperature, high pH, high wind, and high humidity, losses can be moderately high. Incorporation of urea into soil will reduce losses from volatilisation but of course will be subject to denitrification losses if conditions become conducive for it to occur.

Fertiliser products

Urea is a cheap and convenient N fertiliser product. Modified urea products are available that can reduce losses by volatilisation or denitrification. Entec® has a component that delays the conversion of ammonium to nitrate nitrogen and thus can reduce denitrification losses. Volatilisation losses can still occur and the least losses will occur if the fertiliser is incorporated into the soil. Green Urea® has a component that slows the conversion of urea to ammonium. Thus when surface-applied, this product may allow more time for it to be moved into the soil by rainfall, irrigation or cultivation. Denitrification loss can still occur once the conversion to nitrate occurs. Losses have been shown to decrease and there are farming systems where these products are very suitable. Because these products are more expensive than standard urea, the cost:benefit ratio and overall risk of losses needs to be taken into account when making a decision to use the product.

Contribution of organic matter (using organic carbon results)

Organic carbon is a laboratory measure from which the amount of organic matter (OM) can be calculated. The organic carbon (OC) level is a good indicator of the ability of the soil to supply nutrients. OC levels have declined as nutrients have been removed in grain (Figure 4). Nutrients such as phosphorus (P) and potassium (K) will be declining along with N. Organic matter has biological benefits (energy for micro-organisms and provision of nutrients) but also has benefits to the physical (structure) and chemical (pH and CEC) functions of the soil. Declining OM levels under cropping systems has resulted in reduced soil nutrient reserves, creating a greater reliance on fertilisers. Allowing the soil OM level to decline too far may result in the soil being permanently unproductive and unable to grow crops or pastures.

The best way to prolong the productivity of a cropping soil is to supply adequate fertiliser to grow the maximum biomass, use minimum or zero-tillage, don't burn residues. Including pulse crops in the farming system will almost certainly be valuable financially, but will not increase soil organic matter. The best way to restore OM levels is to return the paddock to a grass/legume pasture. Research has shown that approximately 0.65 t C/ha/year can be added (Dalal et al. 1995). This will equate to almost 0.1% increase in OC for each year that the grass/legume pasture was growing compared to continuous conventionally-tilled wheat. (Figure 5).

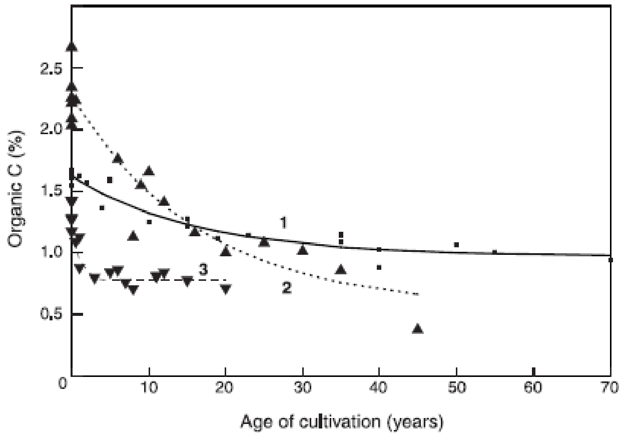

Figure 4. Soil N OC decline over years of cultivation. Soil 1 = Waco clay (vertosol), soil 2 = Langlands Logie, grey clay), soil 3 = Red Earth, Kandosol. Source: Dalal and Chan 2001.

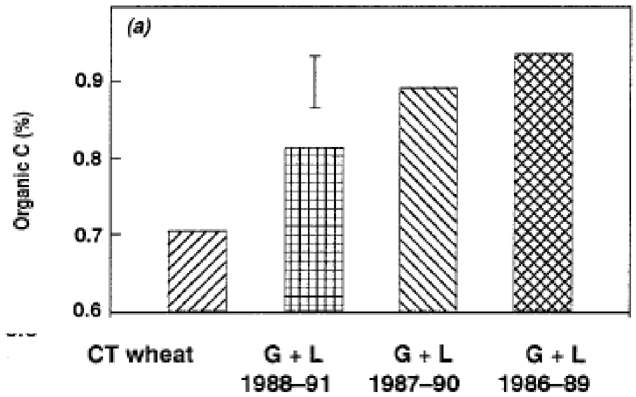

Figure 5. Soil OC concentration in May 1989 after continuous conventional till wheat, and after grass+legume pasture commencing 1988, 1987 or 1986 (0-2.5cm). Source: Dalal and Chan 2001.

References

ARMonline. www.armonline.com.au

H Cox and W Strong (2015). The Nitrogen Book. https://www.daf.qld.gov.au/plants/field-crops-and-pastures/broadacre-field-crops/cropping-efficiency/nitrogen-books

Dalal R. C. Chan K. Y. (2001) Soil organic matter in rainfed cropping systems of the Australian cereal belt. Soil Research 39, 435-464.

R. C. Dalal, W M. Strong, E. J. Weston, J. E. Cooper, K. J. Lehane, A. J. King and C. J. Chicken (1995). Sustaining productivity of a Vertisol at Warra, Queensland, with fertilisers, no-tillage, or legumes 1. Organic matter status. Aust. Journal of Experimental Agriculture, 35, 903-913.

D Herridge (2013). Managing legume and fertiliser N for northern grains cropping.

GD Schwenke, W Manning, BM Haigh (2014) Ammonia volatilisation from nitrogen fertilisers surface-applied to bare fallows, wheat crops and perennial-grass-based pastures on Vertosols. Soil Research, 52(8), 805-821.

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Panel discussion on nitrogen and pulse crops- implications for decision making in 2018

Notes

Spring frost damage in northern GRDC region in 2017 – a long term risk management perspective

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[2] CSIRO

Key words

frost, risk management, ENSO

GRDC code

CMA00002

Call to action/take home messages

- 2017 will be remembered as a year of severe frost damage across the northern region and we need to learn from this damaging but relatively rare sequence of events.
- While it is useful to focus on the unique aspects of frost risk, it is important to consider the interaction between frost, heat and water.
- Recent modelling studies suggest that the northern region suffers the greatest direct impact of frost, but also the greatest indirect impact from strategies to avoid frost .
- There is useful information from the GRDC National Frost Initiative on genetics, management and environment aspects of reducing frost risk. In this paper we focus on the weather and climate information available for frost risk management.

The GRDC national frost Initiative

Frost is estimated to cost the Australian grains industry over $300 M every year. The GRDC National Frost Initiative conducts RD&E to manage the impact of frost and maximise grower profit. The initiative has three components;

1. Genetics – develop more frost-tolerant wheat and barley germplasm and rank current wheat and barley varieties for frost susceptibility;
2. Management – develop best practise crop canopy, stubble, nutrition and agronomic management strategies to minimise the effects of frost, and search for innovative products that may minimise the impact of frost; and
3. Environment – predict the occurrence, severity and impact of frost events on crop yields and frost events at the farm scale to enable better risk management.

Most of the resources can be found here: https://storify.com/theGRDC/frost

Widespread damage in northern region in 2017 growing season

The 2017 season will be remembered for the widespread and frequent frost events across the northern GRDC region.

For a local perspective of the damage to canola, chickpeas and cereals in the northern region as of September 2017 see:

https://grdc.com.au/news-and-media/news-and-media-releases/north/2017/09/resources-available-to-help-growers-deal-with-frost-affected-crops.

The 2017 damage in the northern grains region followed severe damage in the western region and parts of the southern region in 2016 and 2017 and widespread stem frost in the southern region in

2014. Any regional overview of frost impact will underplay the damage experienced in individual paddocks and for individual grain businesses.

Unfortunately frost was not the only climate concern for grain growers in the northern region in 2017. Although Queensland and northern NSW had a wet October, most of the region experienced rainfall in the lowest decile for the six months April to September. The second half of September was extremely hot. On the 23rd of September, NSW recorded the hottest day since records were kept in 1911 (BoM 2017). Across the grain growing regions of northern NSW and southern Queensland the mean maximum temperature for the week ending 28th of September was 8 to 12^{o} C above average. Experienced agronomists will point to difficulties in separating the impact of frost from drought and heat on final wheat yield.

Cold temperatures do some damage each year

The severe frost damage experienced in 2017 is a low frequency but high consequence event. It is likely that there are more frequent, but less damaging losses in most years. According to GRDC & WA DIPIRD (2017) cold damage can occur when wheat plants are exposed to temperature less 5°C which can cause spikelet damage if this occurs during pollen development (Z39 -45). From 0°C to -2°C moisture is drawn from the leaves resulting in desiccation damage. The greatest damage is freezing damage which might be expected at 0°C; however 0°C is the melting point of ice not the freezing point of water. Freezing usually occurs at temperatures below -2°C and the damage is caused by ice crystals physically rupturing cell walls and membranes.

There is useful guidance on identifying frost damage at: https://storify.com/theGRDC/frost

Ten days after a frost event, bleached leaves, stems, heads and reproductive tissue might be evident (GRDC & WA DIPIRD 2017).

An indirect cost comes from strategies to avoid frost

In addition to the direct damage from frost, there is an indirect effect from conservative sowing time /flowering time strategies to avoid frost. This is captured in the statement in the 1970s by the pioneer of frost research at Tamworth, Dr Bill Single, that the fear of frost does more damage than frost itself. Local advisers and growers will have their own views on whether this is still the case but some recent modelling research indicates that this indirect cost is greatest in the northern region.

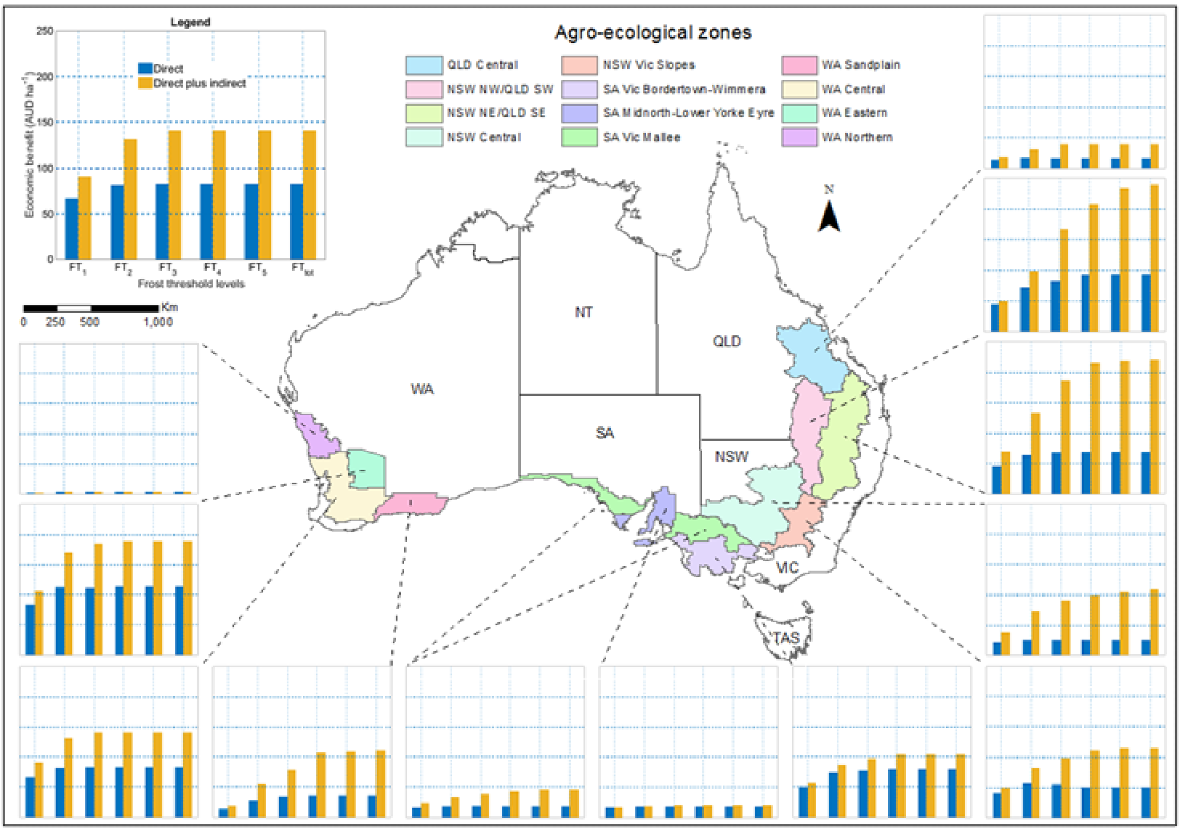


Figure 1. (reproduced from Mushtaq et al. 2017 – see paper for details). Economic benefits (AUD ha–1) of various levels of post head emergence frost (PHEF) tolerance both direct (first bar) and direct plus indirect (second bar).

Under the assumptions of the simulation modelling (described in detail in Mushtaq et al. 2017 and Zheng et al. 2015) the greatest benefit of frost tolerance (because of the greatest current damage) is found in the northern grains region and parts of the western region. The northern region also has the greatest indirect impact (shown as difference between each pair of bars). Not only is thinking about the trifecta of frost, heat and water stress important when diagnosing and attributing damage to frost in a year like 2017, this modelling shows that it is essential when managing frost. The importance of radiation, water, frost and heat in identifying the ideal flowering time is supported by extensive modelling for sites between Dubbo and Eyre Peninsula by Flohr et al. 2017. Similar results have been shown for canola (Lilley et al. 2017).

The need for a risk management approach

The interaction of frost with heat and water stress is a good reason for a risk management approach to frost. A further reason is the acknowledgement that frost is not an issue that can be simply solved or removed from grain farms. Rather it is a something that has to be lived with and managed. Frost risk differs for each grain grower; not only does each paddock have a unique physical exposure to frost, each grain business has its' own financial exposure and the people behind the business have different risk appetites. Under these circumstances, being prescriptive is dangerous.

Frost management decisions at different times

There are some common features of frost management across grain farms. For example, decisions are different depending on the time of the year. A pre-season planning might be held with an adviser in say January or February, this contrasts to decisions in the immediate lead up to sowing or responses to frost within a growing season. Although there are overlaps, separating the timing and types of decisions provides a useful framework and is consistent with the format of the GRDC Frost Tips and Tactics.

Not only do the decisions occur at different times of the year, there are differences in the type of decisions. Running a farm involves many day to day operational decisions but these are influenced by longer term strategic decisions which set the overall direction of the farm and a series of tactical decisions made each season. One way to distinguish between tactical and strategic decisions is that tactical decisions respond to the state of the system such as stored soil water, time of season break, and potentially a seasonal climate forecast. This framework is used in GRDC business management fact sheets (Making effective business decisions, June 2013; Simple and effective business planning, May 2014). Unlike larger corporations, in a grain farming business the same person is usually making the strategic and tactical decisions while carrying out many of the day to day operations.

The time lines or planning horizons of operational, tactical and strategic decisions can be matched to weather forecasts for operational decisions, seasonal climate forecasts for tactical decisions and strategic decisions using longer term climate records, including how these are shifting with climate change. In the following section we have matched weather and climate information to the timing and type of decision. This is based on discussion with farmers and advisers and the purpose is to sort weather and climate information by decisions and complement the information in the GRDC NFI Tips and Tactics fact sheet.

1. Strategic pre-season planning Planning enterprise mix across the farm such as crops vs livestock vs hay. Crop choice for different paddocks. Decisions about leasing extra land and/or purchasing and selling land.	
Information currently available: Many experienced farmers are aware of the frostier parts of their farms, some have data loggers. The spatial climate information can be supplemented with historical climate data that is analysed the BoM data such as CliMate and YieldProphet and Flowerpower in WA.	*Emerging resources:* The NFI is funding research on the fine scale mapping of frost across paddocks using loggers and remote sensing. This will optimise the use of this equipment. *Ongoing challenge:* As the cost of loggers and imagery becomes cheaper and more available, the spatial coverage will greatly improve. However there is an ongoing challenge is to link 2 to 3 years of fine scale records with the 50 years of Stevenson screen data from the Bureau of Meteorology. One of the impacts of climate change is that it makes historical records less reliable for future risk assessments. There are some concerning shifts in frost likelihood that make it difficult to know how to use past data.
2. Tactical adjustments at sowing time Decisions include area of dry sowing, refining choice of crop and variety and changing input levels. Choosing varieties. Input levels. Making plans for extra hay production.	
Information currently available: Some farmers tend to use CliMate, FlowerPower or YieldProphet when there is a sowing opportunity outside of the normal sowing window There has been a history of using SOI based forecasts for frost likelihood. In general when there is a forecast for an increased chance of El Nino,	*Emerging resources:* We can expect there will be ongoing improvements in the decision aids such as CliMate, Flowerpower and YieldProphet. They will be aided by improved phenology predictions. Climate forecasts of the likelihood for frost at this time of the year currently only have marginal skill. However there is increasing attention to forecasting of extremes. *Ongoing challenge:* Seasonal forecasting remains a relatively low signal to noise and many growers will require very large shifts in forecasts of extremes to change decisions.

<table>
<tr><td>expect more frost.</td><td>We are hampered by relatively rudimentary understanding of the exact relationship between minimum temperature and wheat yield.</td></tr>
<tr><td colspan="2">3. Responding to frost forecast within the season
Management options are greatly restricted once the crop is sown, however a frost warning for the coming week can be useful for herbicide decisions and as a prompt to check for damage. For some enterprises, a warning can be used to plan for hay and grazing options. A forecast for the coming months might influence nitrogen topdressing decisions and possibly forward selling. Some farmers might graze a crop to slow development.</td></tr>
<tr><td>Information currently available
The BoM issues short term frost warning http://www.bom.gov.au/jsp/watl/weather/frost.jsp
In terms of seasonal outlook, the state of climate drivers such as ENSO become clearer as the season progresses.</td><td>Emerging resources
The accuracy of 1-7 day forecasts is continuing to improve.
The experimental multi-week forecasts from the Bureau of Meteorology will provide some information on the likelihood of lower than expected minimum temperatures.
Ongoing challenges
Although forecasts within season will be more accurate than pre-season, the question remains as to whether they will be good enough to change decisions. It is also challenging knowing how to link uncertain forecasts to uncertain damage functions.</td></tr>
<tr><td colspan="2">4. Responding to a frost
To cut for hay or graze or leave for recovery</td></tr>
<tr><td>Information currently available
The main task after a frost is to rapidly assess the damage.
This can be aided by accessing temperature data from the Bureau of Meteorology and other networks of temperature loggers from departments of primary industry and NRM bodies.</td><td>Emerging resources
NFI has guidance on where to place loggers and is researching innovative methods of rapid frost assessment. There is also excellent material on identifying frost damage.
Simulation modelling like YieldProphet along with other spreadsheet based decision support system (DSS) can help with the decisions to cut for hay or graze
Ongoing challenges
If a frost occurs relatively early in the season, the decision to cut for hay, graze or leave for recovery is still made difficult by uncertainty in estimating the potential damage and the potential for recovery.</td></tr>
<tr><td colspan="2">5. Post season evaluation
Severe frost is a relatively low frequency but high consequence event. It is important to place the season in context and avoid the natural human response of either over reacting or under reacting to a major event.</td></tr>
<tr><td>Information currently available
Although the BoM network of stations is relatively coarse, the access to archive maps for individual nights is excellent. In some regions this network is enhanced with local data.</td><td>Emerging resources
Improvements in networks of loggers and links to remote sensing will improve the assessment of temperature.
Ongoing Challenges
Placing a single year in context will always be difficult in a variable and changing climate. There is an abundance of psychology evidence that as human's we will always struggle to distinguish between decisions that are wise/unwise and those that are lucky/unlucky.</td></tr>
</table>

Analysis of frosts in the region in 2017

Table 1. Minimum temperatures at a range of locations in GRDC northern grains region for 19, 20, 28 and 29 August 2017

	Parkes	Dubbo	Gunnedah	Narrabri	Moree	Goondiwindi	Warwick
19-Aug	0.8	1.8	2.5	-1.5	2.7	4.5	5.3
20-Aug	-5.6	-4.9	-3.7	-2.5	-1	-2	-3.9
28-Aug	-5.4	-3.7	-0.9	0.4	1.7	1	-3
29-Aug	-4.7	-1.1	-2.5	-0.3	-0.1	-1.5	-3.7

Table 1 shows the minimum temperatures for widespread and damaging frost events on the 20th and 29th of August. Overnight temperatures at ground level or the top of a wheat canopy can be up to 5°C lower than those measured in a Stevenson screen. The offset used in the DSS Wheatman was that head height was 2.2 degrees colder than the Stevenson screen, but differences of up to 10°C have been recorded.

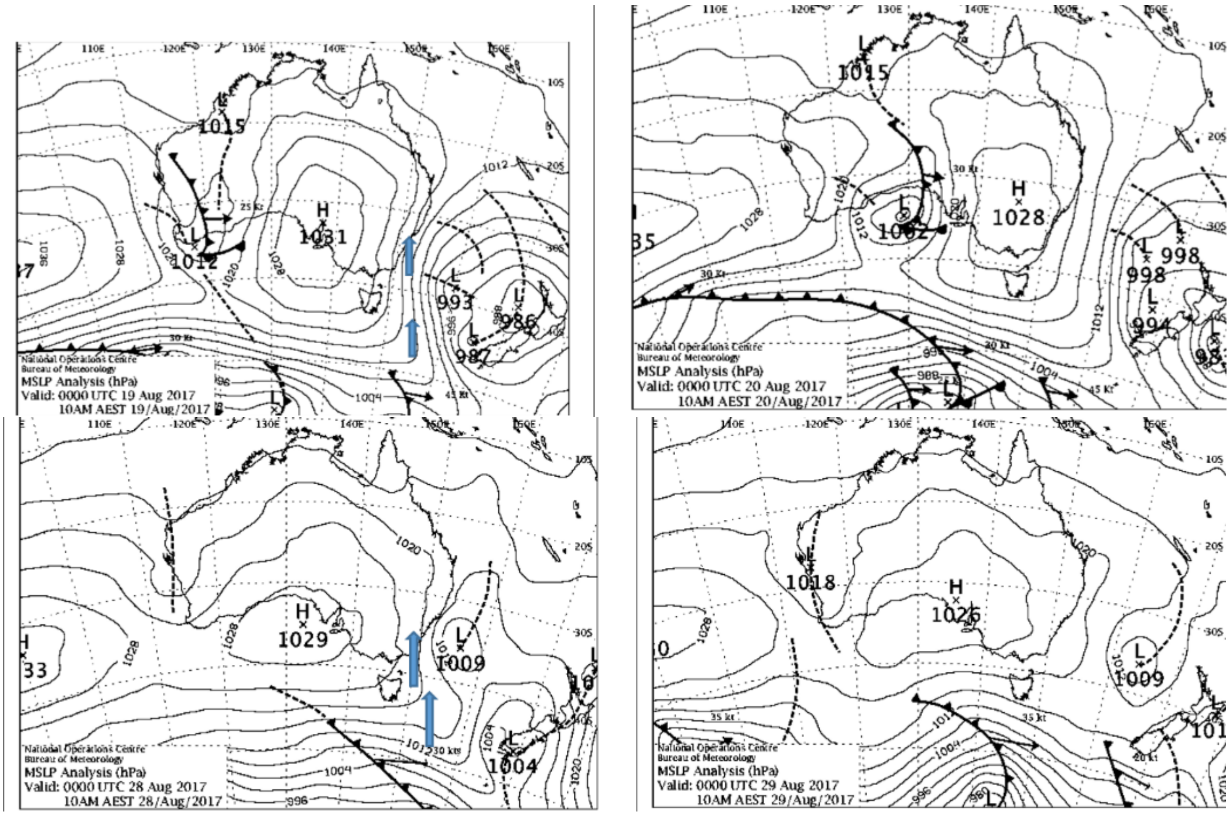


Figure 2. Weather maps showing the mean sea level pressure on 19, 20, 28 and 29 August 2017. Source Bureau of Meteorology. Blue arrows have been added and show southerly flow of air.

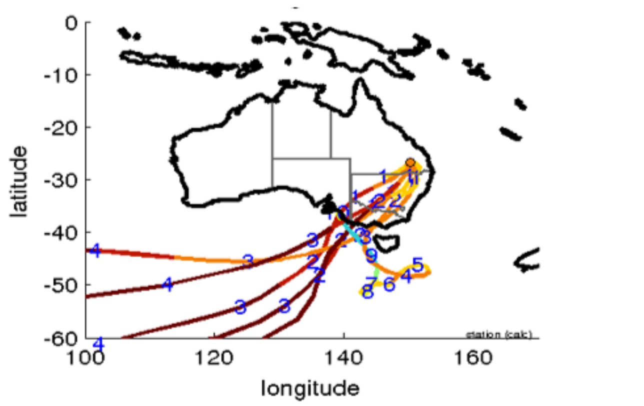
Being located near the centre of a high pressure system provides the stable, descending, dry air required for the clear, calm, night conducive to a rapid temperature fall at dusk and a radiation frost. This raises the question as to why a radiation frost doesn't occur each time there is a high pressure system. Part of the explanation comes from the synoptic pattern of the previous day providing a southerly flow of air (shown as blue arrows). A fuller understanding of the process comes from examining more levels of the atmosphere than the ground level.

Improving the understanding of atmospheric dynamics behind frost events

A team at CSIRO Hobart, led by James Risbey, set out to better understand the synoptic weather events leading up to and during frosts. An understanding of the synoptic drivers provides a basis for confidence and testing of seasonal forecasting, especially if there are broad-scale patterns in the atmospheric dynamics across the southern hemisphere. In discussion with industry, eight high quality climate stations were selected across the Australian grains belt Merredin, Katanning, Kyancutta, Snowtown, Nhill, Wagga Wagga, Gunnedah, and Miles. The historical record from 1955 to 2014 was used to identify mild (T min < 2), moderate (T min < 0), and severe (T min < -2) frost events in the three month period between 15th August and 15th November.

The left hand panel of Figure 3 shows the backtracking of air in the days prior to medium frosts at Miles. This highlights that even northern sites require the inflow of air from a long way south. Not only is the air cold, because it is descending from the middle of the troposphere, it is very dry. Such extreme southerly origin air trajectories are not associated with most high pressure systems in the region and occur mostly in association with the developing blocking high. The blocking highs develop rapidly and persist and are efficient at drawing in and entrapping the cold, dry air. Similar patterns are shown for other locations in the western and southern regions.

A.



B.

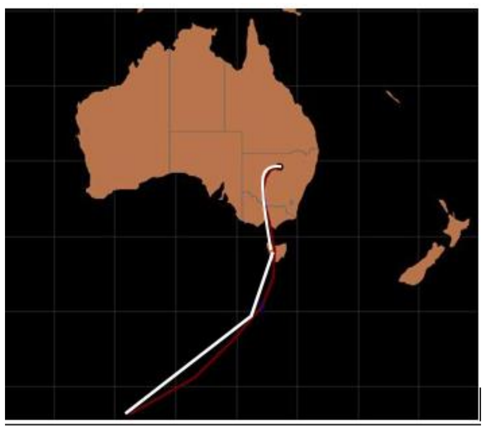


Figure 3. A: Back track of air parcels for spring frost events at Miles Qld (1955 to 2014). The numbers refer to the days prior to the event. B: Backtrack of air parcel for 29th August 2017.

Both the frost events of the 20th and 29th of August involved a front coming through, then a high developing with cold, dry descent trajectories and very cold air mass. These are consistent with the general pattern derived from the 1955 to 2014 data. The late August event was an especially persistent and strong pattern.

The atmosphere flows from west to east sets up what is called a zonal flow which follows the latitudinal lines. The contrast is meridional flow along longitudinal lines. Widespread frosts require meridional flow, that is the interaction of the front and high pressure systems enhance the southern transport of cold dry air. The answer to why each high pressure system is not accompanied by a frost lies in the fact that most high pressure systems are relatively shallow circulation features and do not have the deeper vertical organisation required to entrain very cold, dry air from higher latitudes. The developing blocking high system associated with frost has the appropriate vertical structure to provide cold, dry entrainment. Blocking highs are much rarer at a given location, and thus frost is a relatively rare event.

Research in this project has also shown the importance of synoptic patterns that set up meridional flow to bring hot northern air for spring heat events. The encouraging aspect of the research is that these patterns are not only show consistent synoptic patterns over cropping regions, there is also a strong pattern in the broad-scale southern hemisphere circulation.

Concluding remarks

There is much more climate research on heat and drought than spring frost events. This is not surprising given the enormous interest in heat events due to the direct impact on human health and safety, infrastructure, bushfires and demand for electricity. Likewise drought has always attracted research due to the widespread impact on agriculture but also ecology and increasingly, on urban water supplies. In contrast, spring frosts are only really of concern to grain farmers and horticulturists. This not only applies to the climatology, as there is better understanding on the impact of heat and drought on wheat than post head emergence frost. Although freezing temperatures are an issue for wheat growth in many parts of the world, most of the literature on spring frosts or post head emergence frost damage comes from Australia and South America. The GRDC National Frost Initiative is guided by growers and agronomists and will continue to provide updates on findings as it builds on previous research, much of it from the northern region.

References

Australian Bureau of Meteorology 2017. Special Climate Statement 62—exceptional September heat in eastern Australia October 2017 http://www.bom.gov.au/climate/current/statements/scs62.pdf

DPIRD (WA) and GRDC 2017 Frost frequently asked questions.

Flohr, B. M., J. R. Hunt, J. A. Kirkegaard and J. R. Evans (2017). "Water and temperature stress define the optimal flowering period for wheat in south-eastern Australia." Field Crops Research 209: 108-119.

GRDC 2016 Managing Frost Risk Tips and Tactics. GRDC Grownotes February 2016

Lilley, J. M., B. M. Flohr, J. Whish and J. A. Kirkegaard (2017). "Optimal flowering periods for canola in eastern Australia." Proceedings of the 18th Australian Society of Agronomy Conference, Ballarat, VIC. (http://www.agronomyaustraliaproceedings.org/).

Mushtaq, S., D.-A. An-Vo, M. Christopher, B. Zheng, K. Chenu, S. C. Chapman, J. T. Christopher, R. C. Stone, T. M. Frederiks and G. M. Alam (2017). "Economic assessment of wheat breeding options for potential improved levels of post head-emergence frost tolerance." Field Crops Research 213: 75-88.

Zheng, B., S. C. Chapman, J. T. Christopher, T. M. Frederiks and K. Chenu (2015). "Frost trends and their estimated impact on yield in the Australian wheatbelt." Journal of Experimental Botany 66(12): 3611-3623.

Climate analysis tools

Australian CliMate: https://climateapp.net.au/

FlowerPower: https://www.agric.wa.gov.au/frost/flower-power

Yield Prophet: https://www.yieldprophet.com.au/yp/Home.aspx

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Farming system impact on nitrogen and water use efficiency, soil-borne disease and profit

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Key words

crop sequence, rotation, economics, legumes, break crops

GRDC code

CSA00050

Call to action/take home messages

- Start examining the performance of the whole crop sequence, not just individual crops. We propose using system WUE as a useful metric i.e. $ GM/mm water used (rain + change in soil water).
- Alternative legume and break crops have legacy benefits for soil nitrogen (N) and soil-borne pathogens.
- Crop sequences involving alternative break crops (e.g. canola, fababean and durum wheat) can achieve similar or higher returns per mm of water used to conventional crop sequences.
- Double-crop mungbeans have legacy impacts on soil moisture and root lesion nematode populations for subsequent crops.
- Consider the risks of mungbean yield reductions where root lesion nematode (RLN) is a problem and particularly if they follow susceptible crops (e.g. wheat) in double crops.
- Low crop intensity < 0.6 crops per year are showing lower system WUE, but differences due to crop intensity at higher crop frequencies so far are small.

Introduction

The northern farming systems projects are investigating how several modifications to farming systems will impact on the performance of the cropping system as a whole over several crops in the sequence. This involves assessing various aspects of these systems including water use efficiency, nutrient balance and nutrient use efficiency, changes in pathogen and weed populations and changes in soil health. The key modifications we are examining involve changes to:

- ***Crop intensity*** – ie. the proportion of time that crops are growing which impacts on the proportion of rainfall transpired by crops and unproductive water losses. This is being altered by changing soil water thresholds that trigger planting opportunities. High crop intensity systems have a lower soil water threshold (30% full profile); moderate intensity systems have a moderate soil water threshold of 50% full profile, and low intensity systems require a profile > 80% full before a crop is sown and higher value crops are used when possible
- ***Increased legume frequency*** – crop choice aims to have every second crop as a legume across the crop sequence, with the aim of reducing fertiliser N inputs required

- ***Increased crop diversity*** – crop choice aims to achieve 50% of crops resistant to root lesion nematodes (preferably 2 in a row) and crops with similar in-crop herbicide mode of action can't follow each other. The aim is to test systems where the mix and sequence of crops are altered to manage soil-borne pathogens and weeds in the cropping system
- ***Nutrient supply strategy*** – by increasing the fertiliser budget to achieve 90% of yield potential for that crop compared with a 50% of yield potential with the aim of boosting background soil fertility, increasing N cycling and maximising yields in favourable years
- ***Using non-crops to build soil resilience*** – by using cover crops or ley pastures in the cropping rotation to increase soil C inputs, biological activity and maintaining soil cover > 50%.

This range of system modifications are being tested across 7 locations spanning from Central Queensland to the central west of NSW. The core experimental site, located near Pampas on the eastern Darling Downs, aims to explore the interactions amongst these various modifications to the cropping systems across a range of crop sequences that occur across the northern grains region. This experiment is comparing 34 different system treatments. Crop sequences have begun to diverge, which allows comparisons of the crop sequences on different aspects of the farming system. Figure 1 shows the crop sequences that have been deployed so far based on the above modifications.

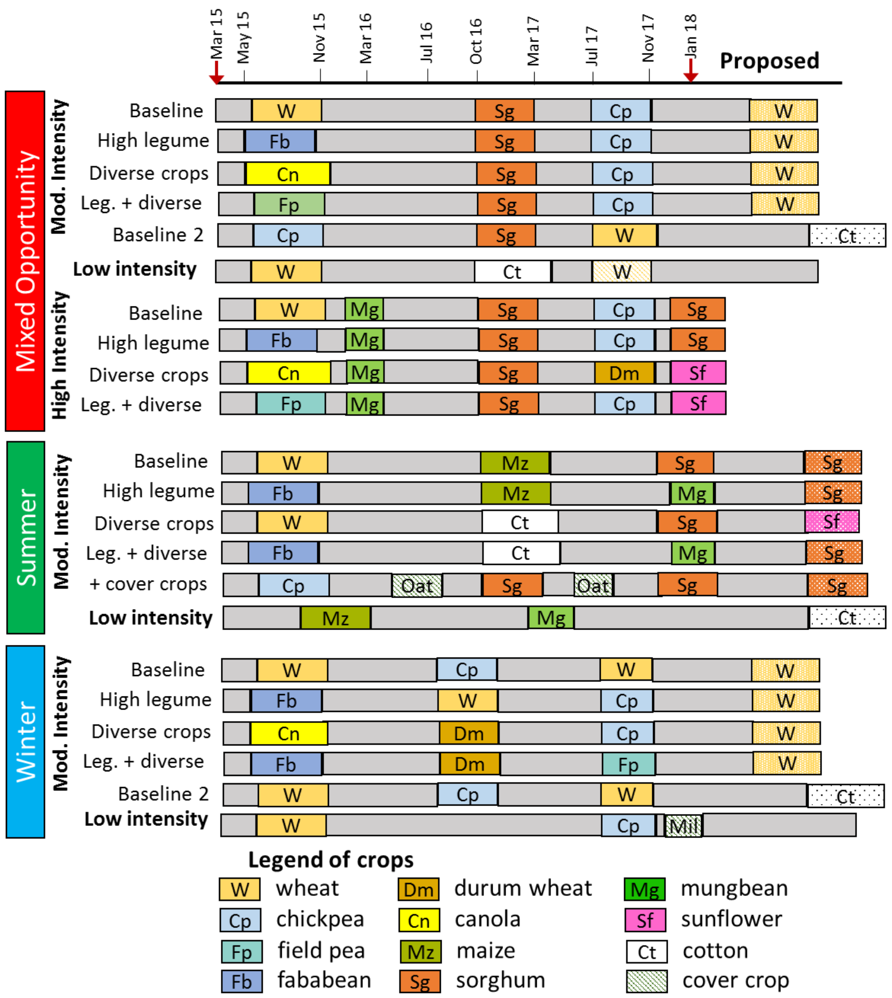

Figure 1. Timeline of different crop sequences deployed over the first 2.5 years (from Mar 15 to Jan 18) at the core farming systems experiment. Different crop sequences have emerged based upon soil water availability triggering a sowing opportunity, rules that dictate crop choice across systems aimed to represent winter dominated, summer dominated or mixed opportunity cropping systems.

This paper will focus on some of the key differences associated with these different crop choices that have emerged over the first 2.5 years of this experiment. Firstly, information on the legacy of different crops used in crop sequences and, secondly, analysis of system water use and nitrogen use efficiencies across the whole crop sequence.

Understanding legacy of different crops in crop sequences

Yield responses

Two clear examples of where crop sequence has impacted on subsequent crop yields have been associated with a) the effect of previous crop on the grain yield of a following mungbean double crop and b) a yield penalty for sorghum following the double-crop mungbean compared to where a long-fallow had been maintained.

1. *Canola benefited subsequent mungbean yields*

Yield of mungbean following canola was 0.3 -0.4 t/ha higher than following wheat or fababean (Table 1). There was no clear difference in soil water amongst these previous crops to explain this difference, however there was a significantly lower population of root lesion nematodes (*P. thornei*) after canola compared to the other winter crops. Fusarium wilt was also slightly less severe after canola. While this observation requires some further testing, this suggests that double-crop mungbean are highly susceptible to RLN in systems where they are double-cropped, which is likely to be amplified under dry growing conditions. The other observation here was the difficulty in controlling volunteer field peas in the mungbean double crop, which contributed to the lowering mungbean yield.

Table 1. Impacts of previous crop on double cropped mungbean yields in summer 15/16.

Previous crop	**Mungbean Grain yield** (t/ha)	**Fusarium wilt incidence** (%)	***P. thornei* at mungbean sowing** (number/g soil)
Canola	0.81	39	8.4
Wheat	0.48	42	18.0
Fababean	0.44	55	13.8
Fieldpea	0.28	58	12.4

2. *Sorghum yield reduced by mungbean double-crop*

Sorghum sown in October 2016 was preceded by a range of previous winter crops followed by either a long-fallow or a double crop of mungbeans. We observed no significant difference in sorghum grain yield between winter crops followed by the long-fallow, all crops yielding around 6.2-6.5 t/ha (Table 2). There was no evidence of long-fallow disorder following the non-mycorrhizal canola which was also then followed by a long-fallow before the subsequent sorghum crop; probably owing to the high soil P content at our site. Potential benefits of additional N provided after legumes were only small and hence not significant; there was also no response to any additional fertiliser N in this season.

On the other hand, sorghum yields were reduced by >0.7 t/ha when they followed the mungbean double-compared to the long-fallow (Table 2). This was likely attributed to 50-60 mm less soil water at sowing in these systems. Larger yield penalties were observed in sorghum following fababean-mungbean due to residues of Spinnaker® herbicide which reduced sorghum plant densities by 50%. Also notable here was that a cover crop following chickpea, had a similar effect of reducing yield of the subsequent sorghum crop by 0.8 t/ha compared with maintaining a long fallow.

Table 2. Sorghum crop yields in Feb 2017 following either long-fallow or double cropped mungbean

Previous crop sequence (X ≈ 6 month fallow)	**Soil water at sowing** (mm)	**Sorghum grain yield** (t/ha)
Wheat-X-X-	225	6.25
Canola-X-X-	215	6.28
Fababean-X-X-	196	6.22
Fieldpea-X-X-	188	6.49
Chickpea-X-X-	199	6.45
Wheat-Mungbean-X-	156	5.56
Canola-Mungbean-X-	125	5.51
Fieldpea-Mungbean-X-	142	5.50
Fababean-Mungbean-X-	133	3.95
Chickpea-X-Cover crop-	151	5.58

Nematode populations

The experimental site initially had moderate levels of root lesion nematodes (RLN) (7-9 per gram). Some clear differences in the dynamics of nematode populations have been observed across the range of crop sequences that have been grown so far (Figure 2 & 3).

1. Winter crop effects on RLN populations

In winter crops in 2015 and 2016, we found that wheat cv. Gauntlet⦶, the most tolerant and resistant wheat cultivar currently available, increased RLN populations by 2-2.5 times, significantly more than other crops. The grain legumes, Warda⦶ fababean, HatTrick⦶ chickpea and Percy⦶ field pea increased RLN populations but less than Gauntlet⦶. Canola and durum wheat did not increase RLN populations, which declined slowly.

2. RLN populations magnify with susceptible double-crops

We found that RLN populations greatly increased during the mungbean double crop of Jade⦶. This increase was far greater when the mungbean double crop followed susceptible crops of wheat or fababean (11-14/g) compared to when it followed canola (5/g) (Figure 1). This demonstrates that extending the period of host crops in the system, by double-cropping with two susceptible crops in a row, can further propagate the RLN population and bring about dramatic increases in their numbers. RLN populations then declined during the subsequent fallow and a sorghum crop after the mungbeans, but they remain higher where mungbean double crops were grown than in the systems that remained fallow after the first winter crop.

3. Resistant crops and fallows reduce RLN populations

Our data confirm the role of resistant crops like canola, durum wheat, sorghum or fallow periods for reducing RLN populations. Two years after starting the experiments, crop sequences of canola-x-durum wheat, and canola-x-x-sorghum are the systems that have the lowest RLN populations. However, even where we have grown a sequence of canola – long fallow – sorghum, i.e. no susceptible crops for 2 years, the reductions in RLN populations are slow (declining from 7-8/g to 4/g). Despite increased levels of RLN after the susceptible winter crops, we have seen that a long-fallow followed by sorghum have reduced RLN populations back to below initial numbers (Figure 2).

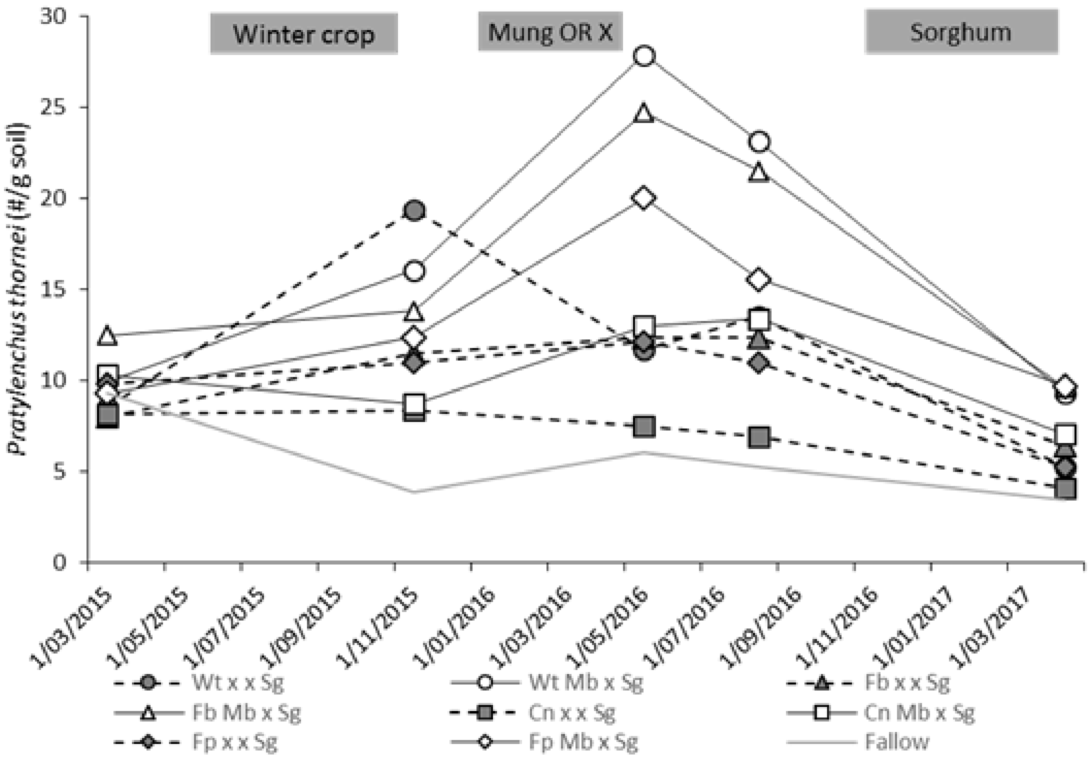

Figure 2. Changes in root lesion nematode population between different opportunity crop sequences where various winter crops in 2015 of wheat (Wt), fababean (Fb), canola (Cn), field pea (Fp) or chickpea (Cp) were followed by either a long-fallow (x x) or a double-crop of Jade mungbean (Mb), and a sorghum crop (cv. MR-Taurus) in summer 2017.

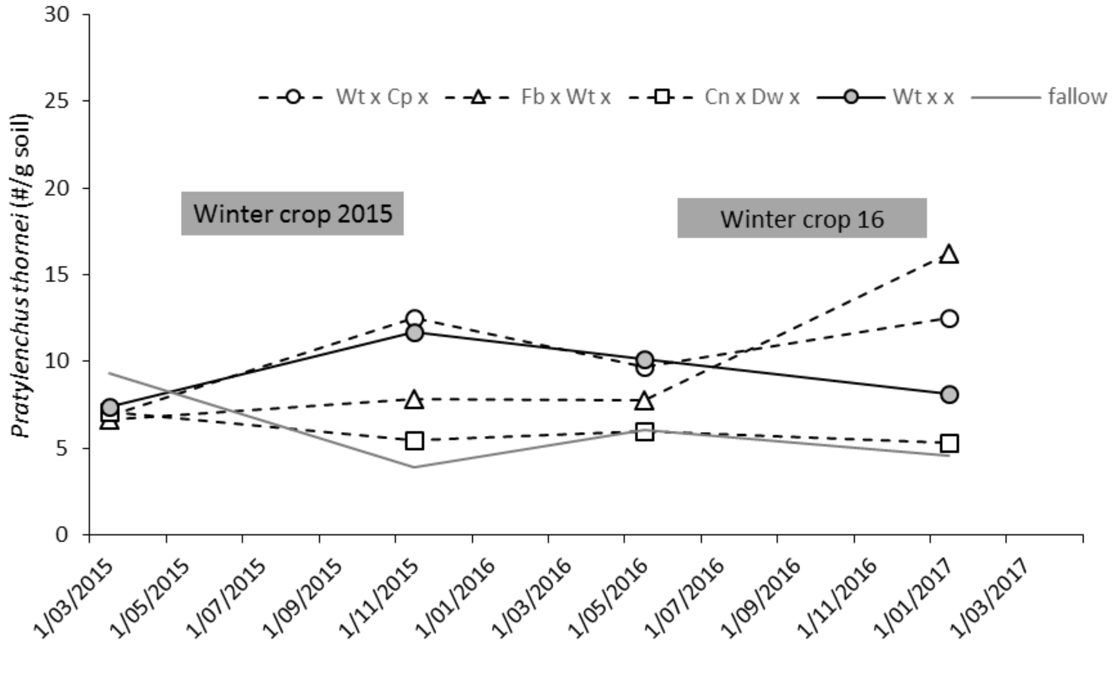

Figure 3. Changes in root lesion nematode population over 5 different winter crop sequences involving either susceptible crops, wheat-chickpea (Wt x Cp x) and fababean-wheat (Fb x Wt x) compared to two resistant crops, canola-durum wheat (Cn x Dw x) or a wheat followed by a long fallow (Wt xxx).

Fallow N accumulation

We have calculated the net accumulation of mineral N over the fallows following the various crops/crop sequences. This demonstrates some interesting legacy impacts of the various crops.

- Mineralisation after canola was found to be higher than other winter crops, particularly during the summer period – due to rapid decomposition of canola leaves where much of the N is stored. When canola was followed with a mungbean crop, soil mineral N content and the N accumulation afterwards was also higher after the mungbean crop.
- Fieldpea resulted in an additional 40 kg of N accumulated over a subsequent long-fallow compared to chickpea and fababean. Chickpea and fababean increased N accumulation by 30-35 kg N/ha compared to following wheat. In the first year, soil N at harvest was 30-40 kg lower after chickpea or fababean than wheat, so this was sufficient to make up for this difference.
- Following the various summer crops in 2016/17 we found no increase in soil mineral N during the fallow following sorghum or maize; cotton was slightly higher. This is presumably due to N immobilisation with their high C:N residues. However, higher rates of N accumulation occurred after the mungbean crop (40-60 kg N/ha) compared to the other non-legume summer crops.

Table 3. Net accumulation of available soil N (kg soil mineral N increase) over fallows following different previous crops under standard nutritional strategy.

Previous crop	Summer	Winter	Total long fallow
2015	Nov-Apr	Apr-Sept	
Wheat	+ 21	+ 40	+ 60
Fababean	+ 47	+ 42	+ 89
Chickpea	+ 40	+ 52	+ 92
Field pea	+ 39	+ 88	+127
Canola	+ 84	+ 49	+132
Canola - High N (+90 kg N)	+120	+ 83	+203
2016	*Dec-May*		
Fallow	+ 43		
Wheat	+ 53		
Chickpea	+ 89		
2015/16		*Apr-Sept*	
Wheat-mungbean		+76	
Fababean-mungbean		+69	
Canola-mungbean		+96	
Maize		+67	
2016/17		*Apr-Oct*	
Mungbean		+54	
Maize/sorghum		-14	
Cotton		+17	

Whole crop sequence performance

System water-use-efficiency

While crop water use efficiency (kg grain/mm crop water use) is a useful metric to compare performance of individual crops, it fails to account for the efficiency of soil water accumulation in the previous fallow, or legacy effects after a particular crop either in the form of residual soil water at harvest, or impact on subsequent fallow efficiency. Hence, to account for the efficiency of the farming system over time, we have calculated system water-use efficiency for the various systems over the first 2.5 years of this experiment. We define system water use efficiency as the $ gross margin return per mm of water used (i.e. rainfall + change in soil water). Gross margin over the whole crop sequence was calculated from the sum of yield multiplied by the 10-year average price for each crop, minus variable costs (fertiliser, seed, herbicides, and operations) accumulated over the whole crop sequence (Figure 4).

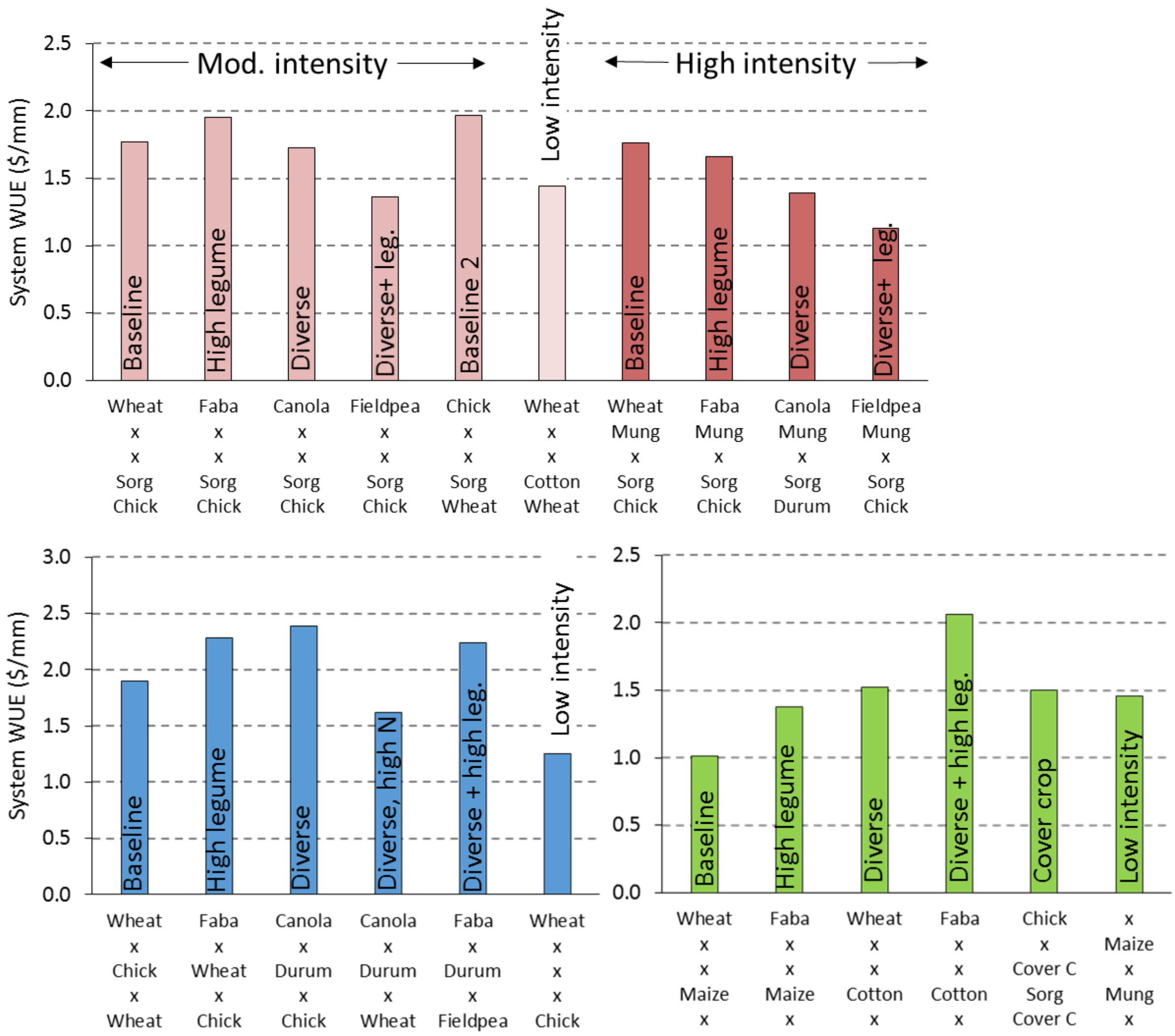

Figure 4. System water use efficiency ($ gross margin/mm water used) for the period from March 2015 to Sept/Dec 2017 for different crop sequences modified to increase or decrease crop intensity, increase legume frequency and/or crop diversity. Opportunity cropping systems (in red) are at the top, b) winter cropping systems (in blue) on bottom left and c) summer cropping systems (in green) on bottom right. Note summer systems are only calculated to September 2017 and have had one less crop so should not be compared with winter or opportunity systems at this time. Crop prices per tonne yield (11% moisture) farm gate after grading and transport costs ($40/t) used were: wheat - $264 (APH), sorghum - $225, mungbean - $710, maize - $285, durum wheat - $284, chickpea - $569, fababean - $394, fieldpea $280, canola - $355.

In the opportunity cropping systems, only small differences have been observed between several of the key system modifications, with 6 of the 10 systems presented here showing WUE of between $1.7 and $1.95/mm. Most notably are that the systems with high legume frequency and with increased crop diversity have similar or higher WUE than the baseline comparisons. The systems with greater crop intensity, at this stage having had an only an additional mungbean crop, have no advantage compared to the moderate intensity farming systems, and in some cases the system WUE is lower ($0.25-0.35/mm). This is due to the sorghum yield penalty was sufficient to balance the gross margin of the mungbean crop. However, the low intensity systems are currently behind in terms of system WUE, this is largely owing to the poor performance of the wheat crop following cotton, while chickpea crops double-cropped after sorghum performed much better. Systems aiming to achieve both crop diversity and high legume frequency objectives were sown to fieldpea in the first year, which had returns $700-1100 less than other crops, and subsequent benefits have not been sufficient to make up this initial cost.

In the summer and winter dominated cropping systems, several of the modifications to the farming system are showing benefits in terms of system WUE. Increased legume frequency and increased use of alternative crops has so far achieved significantly higher WUE than the baseline system. For example, in the winter systems, three of the systems where canola, durum wheat and fababeans have been used are achieving system WUE of $2.25-2.40/mm, which is 20-25% higher than a system involving a crop sequence of wheat-chickpea-wheat. The low crop intensity system, which failed to meet the required soil water to sow a crop in 2016, has significantly lower WUE than the other systems. In the summer systems, fababeans has increased WUE compared to wheat when it was followed by either maize or cotton; low maize yields (3 t/ha) in summer 16/17 has greatly reduced the profitability of these systems.

System nitrogen use efficiency

The nutrient balance (net export of nutrient) and the nutrient use efficiency (kg N exported/kg N used) of the various cropping systems are also being monitored. As with water-use-efficiency, we are attempting to quantify the efficiency that nitrogen is used amongst the various cropping systems. We have calculated this as the ratio of grain N that is removed from the system (yield x grain N content) to the net N used (i.e. the change in soil mineral N plus fertiliser additions). This means that a system NUE of > 1 means that the grain N exported is greater than can be accounted for from N applied or soil mineral N depletion. Hence, these systems have either used fixed N or have effectively utilised N mineralised from the soil. Conversely, systems with a NUE< 1 indicate that additional N has been removed from the system compared to the total N outgoing. This indicates that some N has either been lost or tied up in organic N sources that have not yet become available. Because of differences in timing of results, comparisons between summer, winter and opportunity cropping systems are not meaningful. That is, sampling here for the winter systems is at the end of a fallow and hence NUE is higher than systems sampled at crop harvest.

Fababean and chickpea exported more N and had lower N for subsequent crops than wheat or canola. The high pulse crop yields (3.5 t /ha of chickpea and 4.5 t/ha of fababean) meant they exported more grain N than the corresponding non-legume crops. This demonstrates that grain legumes do export a large amount of N and in the first year, with high levels of soil mineral N, they utilised soil N to a similar degree to the non-legume crops. However, somewhat surprisingly was the lower soil N following the legume grain crops, which resulted in the need to add additional N to meet crop budgets following these crops. Similarly, mungbean double crop also exported around 20 kg N/ha and reduced available N for subsequent crops. Soil N after mungbeans was 40-75 kg lower than the equivalent systems that remained fallow prior to sowing the subsequent sorghum crop, which required an additional 20-25 kg of N to be applied to meet sorghum N requirements.

Despite the high N removal from the legumes, increased cycling of N to subsequent crops and/or inputs of fixed N has increased system NUE relative to systems where less legumes were used. Increasing crop diversity through non-legume crops (e.g. canola or cotton) have had a negative impact on system NUE, presumably due to their higher N uptake relative to the N removed as product.

Table 4. Calculated system grain N exported, nitrogen use (applied N + change in soil mineral N (Δ SMN)), N applied (kg/ha) and system nutrient use efficiency (kg grain N/kg N used) between March 2015 and Apr 2017 across a diversity of crop sequences.

Crop sequence (X ≈ 6 month fallow)	**Net grain N exported (kg/ha)**	**Δ SMN + applied N (kg/ha)**	**N applied (kg/ha)**	**System NUE (kg grain N/kg N used)**
Wheat-X-X-Sorghum	203	251	0	0.81
Wheat-X-X-Maize	151	72	62	1.23
Wheat-X-X-Cotton	142	121	28	1.06
Fababean-X-X-Sorghum	259	189	23	1.22
Fababean-X-X-Maize	212	93	92	1.15
Fababean-X-X-Cotton	211	116	28	1.47
Canola-X-X-Sorghum	176	189	0	0.93
Fieldpea-X-X-Sorghum	186	205	0	0.91
Chickpea-X-X-Sorghum	227	236	18	0.90
Wheat-Mungbean-X-Sorghum	211	188	23	1.00
Canola-Mungbean-X-Sorghum	177	201	0	0.88
Fababean-Mungbean-X-Sorghum	248	187	46	1.07
Fieldpea-Mungbean-X-Sorghum	182	196	28	0.82
Wheat-X-Chick-X-	233	161	0	1.15
Fababean-X-Wheat-X-	290	181	0	1.61
Fababean-X-Durum-X-	322	249	0	1.29
Canola-X-Durum-X-	202	173	0	1.17
Wheat-X-X-X-	117	72	0	1.63

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Are Australian supply chains getting cheaper?

Peter White, Ross Kingwell, Chris Carter, Australian Export Grains Innovation Centre

Key words

Supply chains, logistics, grain transport, grain handling, ports, regulation, wheat

Call to action / take home messages

The costliness of Australia's export grain supply chains has remained generally stable or decreased slightly in real terms over the past five years.

Complete cost component transparency is often lacking in Australian export grain supply chains, unlike what occurs for some of Australia's competitors, and so perhaps greater or formal monitoring of supply chain costs is required.

Supply chain costs of new, low-cost competitor countries (Russia, Ukraine and Argentina) are likely to decrease further, as their production volumes increase and new infrastructure becomes operational.

Australia needs further improvements in grain yields, greater investment and operational efficiencies in supply chain infrastructure, additional regulatory reform and a greater intensity of cropping in higher rainfall regions to help lower the average cost of its export grain supply chains.

Aims

This paper reports on changes in the costliness of Australia's grain supply chains that principally are devoted to exporting wheat. We also report the wheat supply chain costs of Australia's principal competitors. The purpose of our analyses is to assess how well the Australian export supply chains are serving the interests of Australian farmers and exporters as they strive to compete against other low-cost bulk exporter nations that also serve nearby growing Asian markets.

As background, supply and demand for wheat has expanded rapidly over the past decade, creating opportunities for the Australian grains industry but also opportunities for grain exporters in other nations. Australia now faces significant price competition in many markets. Australian wheat production in 2016-17 reached record levels which tested the capacity of Australia's storage, handling and transport system, but also helped keep downward pressure on wheat prices. Increasingly, wheat export prices are being influenced by low-cost producers in the Black Sea region and Argentina. Russia is now the world's leading wheat exporter and has established a competitive position in Australia's traditional markets. Also, following policy changes in Argentina, their wheat exports have surged. Much of this increased supply has been absorbed by demand growth in Asia and Africa, caused by growing populations, rising incomes and changing consumer preferences.

Method

Australia's export grain supply chains are complex and varied. A range of supply chain options are available in every Australian state, with grain being exported in bulk or containers through 18 ports spread around Australia's coastline. Geographic and logistical constraints affect the movement of grain through each region. Often a mix of transport modes applies, with road and rail services varying in capacity and quality and being subject to a range of state and federal regulations. Further, substantial variation in grain production and quality can occur from year to year, increasing the risks associated with long-lived investments in supply chain infrastructure and affecting the costs and pricing of supply chain services.

This study provides a general description of the main changes that have occurred in Australian supply chains over recent years. We also estimate the trend in supply chain charges compared with

Australia's major competitors. Supply chain costs are based on prices published by supply chain service providers (bulk handlers), weighted by the volume of grain passing through each port catchment zone. Catchment zone maps are published by all the major supply chain service providers. Distances from a receival site to port in each catchment zone are based on the shortest Google Maps® road distance.

Charges listed for services used in this paper do not necessarily reflect the commercial cost of providing the service, but simply represent the costs to growers and exporters who use the service to export grain. Published prices are only a reference and actual charges may, and do, vary depending on negotiations between the user and supplier of the service.

Results

Recent changes in the structure of Australian supply chains

Grain Trade Australia list nearly 200 ordinary trading companies among its Australian membership in 2017. Of these, the top six companies exported about 80% of Australia's wheat from 2013/14 to 2015/16 (ACF, 2017). Cooperative Bulk Handling (CBH) is the largest, exporting about 30% of Australia's wheat followed by Glencore with a 17% share (Figure 1). The remaining four companies: Cargill, GrainCorp, Emerald and Plumgrove/Mitsui, have export shares between 8% and 12% each on average. From 2013/14 to 2015/16 the dominance of the top six exporters declined slightly from 86% down to 76%.

The dominant wheat exporters are also integrated marketing and bulk handling companies. Plumgrove/Mitsui is the only top-six wheat exporter that is not also a bulk handler. Kalish-Gordon *et al* (2016) show the reorganisation of the structure and ownership of Australian supply chains over the past 30 years. The number of major grain handling companies has halved from 11 to six, and, following the deregulation of wheat marketing in 2008, they are all now integrated marketing and bulk handling companies, and four of the remaining six (representing nearly 60% of total wheat exports) are foreign-owned.

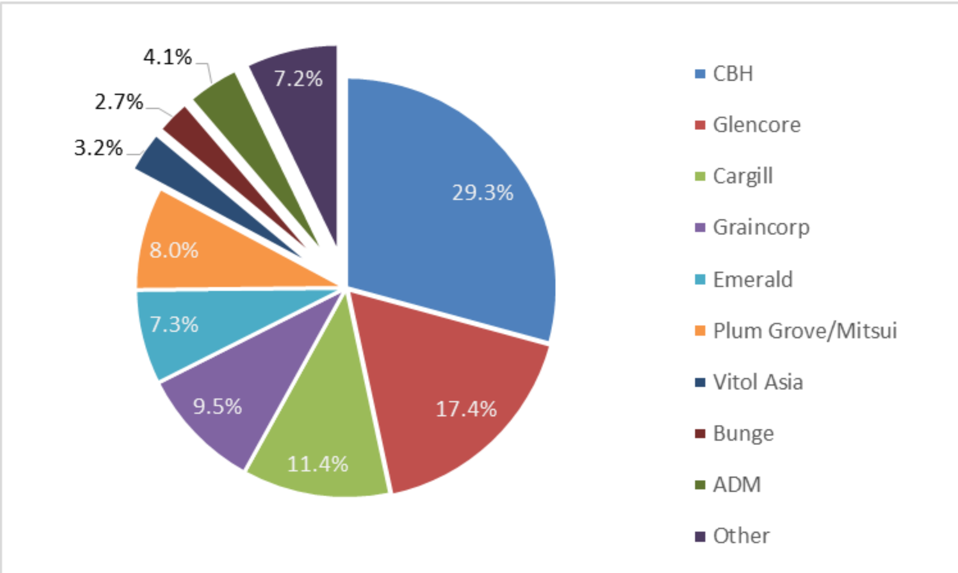

Figure 1. Main Australian wheat exporters (Source: Australian Crop Forecasters (ACF))

Regionally, the presence of the major integrated marketing and bulk handling companies is even more pronounced than indicated by a national market share assessment. The recent entrance of new companies with new port infrastructure into Australian grain supply since 2014 has, so far, only posed a minor threat to the dominant position of incumbents; particularly for CBH in WA, Viterra in SA and Graincorp in Queensland.

Graincorp controls nearly all the port capacity for bulk grain export from Queensland. In WA, the bulk handling division of CBH owns and controls almost all the state's warehouse storage, grain freight and port loading infrastructure, while its trading division marketed 40% of all grain exported in 2015/16. Its next biggest marketing competitor in WA is Glencore which marketed about 17% of the wheat exported from WA in 2015/16.

A similar situation occurs in SA with Viterra, the bulk handling arm of Glencore, controlling over 90% of the state's port export capacity and the majority of its grain receival, storage and transport capacity. Glencore also markets about 36% of all grain exported from SA which is nearly three times its nearest competitor in the state; CBH.

Ownership and control of grain export infrastructure is more diverse in Victoria and NSW, where substantial new port facilities have been established and are operating, but grain handling is still dominated by GrainCorp. In these states Graincorp controls about 50% to 70% of the port and warehouse storage capacity and is also the largest marketer of grain. In 2015/16 Graincorp marketed about 20% of the grain from NSW and about 40% from Victoria.

The difference in the structure of supply chains across Australia is partly driven by the size of the domestic market. Both WA and SA have relatively small domestic markets causing much of their total production to be exported; 88% and 66% for WA and SA respectively during 2006 to 2016. By contrast, in the other wheat producing states (NSW, Qld and Vic) domestic consumption often takes more than 50% of total production. As a consequence, the variation in the volume of wheat exports from WA and SA is lower than for NSW, Qld and Vic which reduces both the cost and risk of grain exports from WA and SA (Figure 2).

Grain storage

The size of the domestic market also influences the proportion of grain stored on-farm which continues to increase across Australia. Industry experts estimate that over that past five years the amount of grain stored in good quality steel silos in NSW, Qld and Vic has doubled. Significant amounts of grain have moved from temporary or poor quality shed storage into higher quality facilities. More than 80% of an average harvest can now be placed in permanent storage on-farm in these states. On-farm storage in SA and WA is at a lower level than in these other state, but continues to grow, albeit at a slower pace. About 240,000 tonnes of permanent storage have been added annually in WA over the past few years and more than 30% of an average harvest can be stored on farm in either permanent or short term storage (e.g. grain bags). The increase in on-farm storage has been driven by growers seeking to increase their marketing options and to facilitate their farms' grain harvest logistics.

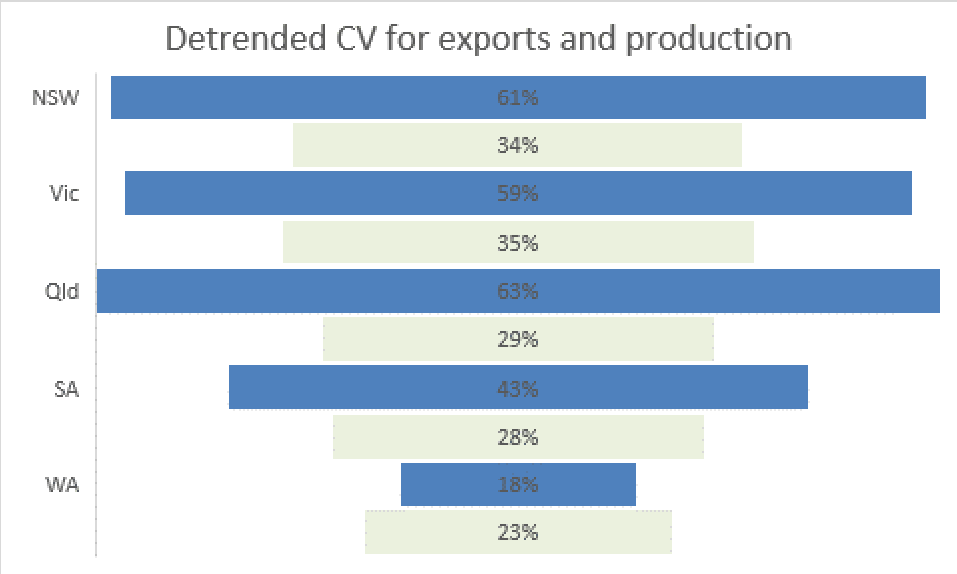

Figure 2. De-trended coefficient of variation in annual wheat production (green/pale bars) and exports (blue/dark bars) from Australian states from 2006 to 2016. Larger annual variation in the volume of exports relative to production (e.g. Qld 63% vs 29%) indicate the extent to which factors other than production influence exports (e.g. domestic consumption)(Source: ABARES and AEGIC).

Warehouse storage capacity is undergoing significant change, with the major bulk handlers undertaking a planned 50% or more reduction in the number of receival sites. Old and inefficient sites are being closed whilst simultaneous upgrades are being made to several remaining prime sites. However, the charges for receiving grain across the receival networks are not substantially differentiated between sites, despite the cost to bulk handlers of receiving and storing grain at some inefficient sites reportedly being more than twice the receival fees. Viterra is an exception as they classify sites as either Tier 1 or Tier 2, the latter attracting a 6% higher fee to receive grain. Differential transport charges from receival sites to port have been a surrogate mechanism bulk handlers use to attract grain to more efficient sites. In WA and SA where transport charges are listed, transport charges from efficient sites can be up to15% lower than those from less efficient sites. In Qld, NSW and Vic, despite lack of transparency in some key components of supply chain costs, cost differences are typically reflected in the price offered for the grain at the receival site.

Transport

Australia has 18 grain ports, most located a relatively short distance from production areas, although average distance to port is substantially shorter in SA at about 140 km compared with the average in NSW at 400 km. Shorter distances reduce the cost of transportation and increase the viability and flexibility of road transport. Appropriate investment and regulation of freight networks to optimise the different advantages of road and rail transport will be important for Australia, especially as technologies and requirements of grain transport evolve.

Long term climate trends appear to be shortening the average distance to port by increasing cropping intensity in high rainfall zones closer to the coast. This is supported by recent evidence from the ABS indicating the crop area is declining in some regions such as the northern parts of the WA cropping zone and eastern parts of NSW (Hughes *et al*, 2017). If these trends continue then grain supply chains will be affected, both in terms of the location of major infrastructure and the cost of grain transport to port.

Over the past four years the average share of rail has remained more or less unchanged, despite closure of some rail lines. The closure of two rail lines in SA's Mallee district saw about 180,000 tonnes of grain move from rail to road, however operational efficiencies in the other parts of the SA rail network saw a slight increase in the proportion of grain transported by rail so that overall the modal share of grain transport to port in SA remained at about 50%. The closure of Tier 3 lines in WA and has seen the shift of some grain onto road transport. By contrast, the upgrade of rail lines in NSW and Victoria has seen some grain return to rail.

Road transport continues to become more competitive with rail over time. BITRI (2017) list a range of reasons for this including: the age and capacity of variable rolling stock, improved roads, weather events closing rail lines or restricting train speeds, and larger trucks. For example, the average truck size delivering into some receival networks has increased by about 20% from 2009/10 to 2016/17, reducing freight costs and the total number of vehicle journeys. BITRE also state that deregulation of grain export marketing has seen smaller shipments being moved on diverse pathways by a broader range of bulk handlers and export marketers which similarly favours road over rail.

Ports and regulation

Significant changes have occurred in the provision and regulation of port services over the past five years. The greatest additional export capacity has been added in NSW where an additional 4 million tonnes of capacity was added through construction of the Quattro terminal at Port Kembla and the Newcastle Agri-terminal. Construction of the Bunge terminal in WA added a further 0.5 million tonnes of export capacity in WA but this represents less than 5% of the export capacity already operated by CBH. Similarly, new mobile loaders operating at Port Adelaide and Geelong provided new, but, relatively minor extra capacity.

With the deregulation of wheat exports in 2008, provision was made for the Access Test to regulate export terminals. This test lapsed in 2014 to allow wheat exports to revert to normal regulation using general competition law and an agreed voluntary code of conduct. However, after industry consultation and review, the Wheat Export Marketing Act (Access Test) was replaced with the Port Terminal Access Code of Conduct in September 2014. This new mandatory code has slowed the normalisation of wheat export regulation in Australia. In addition, exemptions have created a more diverse set of regulations. Currently all terminals operated by Viterra in SA, as well as three ports operated by GrainCorp (Mackay and Gladstone in Qld and Portland in Vic) are subject to the full provisions of the code, while the remaining port terminals in Australia are exempt from significant parts of the mandatory code. In its 2017 Bulk Wheat Monitoring Report the ACCC stated that further exemptions were not, at that time, being considered and that the retention and improvement of the mandatory code was essential.

One advantage of the mandatory code has been that port terminal service providers have moved away from fixed capacity systems, such as the relatively costly auction system, to more flexible systems allocating capacity via long term agreements. This change has occurred more rapidly where port terminals were exempted from the full provision of the mandatory access code. Capacity allocation arrangements are likely to continue to evolve over time, particularly where exemptions to the code have been granted. As yet though, changes in port regulations have not been reflected in much change to port terminal access fees.

We are of the view that consideration could and perhaps should be given to expanding the monitoring of grain supply chains currently undertaken by the ACCC, to include grain transport and storage services. By illustration, effective monitoring of supply chain services has been shown in Canada to increase confidence in the integrity of service providers and to encourage reduced regulation that then stimulates greater flexibility and innovation for service providers.

Costs

Cost estimates for the major components of supply chains in Australia and its competitors are listed in Table 1 based on AEGIC and GRDC research from 2013 to 2017. The cost components vary from year to year due to a range of factors including exchange rates, yields, the relative proportion of grain exported from each catchment zone in Australia and assumptions underlying the estimates. Despite this variation, supply chain costs are consistently about 30% to 35% of the total costs for all countries and all years, except for Canada. Total Australian supply chain costs are higher than most of its competitors, except for Canada, yet some components of Australian supply chains are generally competitive i.e. port charges. Transport from upcountry receival sites to port and port charges are the highest components of supply chain costs in all countries and typically represent 55% to 70% of total supply chain costs. These are costs growers have least control over, and these costs can be greatly affected by government policy, labour costs, regulation and investments by private firms and governments. Labour and energy are the two biggest input costs for bulk handlers. Hence, greater automation in the handling and transport of grain holds the potential to significantly reduce these costs; but such automation requires reliable, affordable regional telecommunication infrastructure, as well as regulatory change.

Table 1. Estimated supply chain costs in Australia and other wheat export competitors from 2013 to 2017. Numbers in parenthesis indicate the proportional contribution to total supply chain costs Source: AEGIC and GRDC (nd-no data).

	2013	2014		2015/16	2016		2017	
Dollars per tonne	Australia	Canada	Australia	Ukraine	Russia	Australia	Argentina	Australia
Cartage farm-site	8.9 (12%)	10.7 (10%)	8.9 (11%)	4.3 (8%)	3.5 (6%)	7.8 (9%)	2.9 (5%)	7.8 (11%)
Upcountry handling	11.9 (16%)	15.2 (14%)	14.4 (17%)	7.7 (14%)	9.2 (16%)	18.4 (22%)	13.2 (21%)	10.4 (15%)
Storage	6.8 (9%)	17.7 (16%)	8.9 (11%)	2.9 (5%)	5.1 (9%)	9.0 (11%)	1.4 (2%)	5.0 (7%)
Transport upcountry to port	21.6 (29%)	46.8 (44%)	27.8 (33%)	13.3 (23%)	15.5 (28%)	26.7 (32%)	29.5 (47%)	23.6 (33%)
Port charges	21.2 (29%)	13.9 (13%)	21 (25%)	23.8 (42%)	22.4 (40%)	19.9 (24%)	15.5 (25%)	21.7 (30%)
Levies and check-offs	2.9 (4%)	3.0 (3%)	2.8 (3%)	4.9 (9%)	0.10 (<1%)	2.8 (3%)		2.8 (4%)
Total supply chain cost	**73.3**	**107.3**	**83.8**	**56.9**	**55.8**	**84.6**	**62.5**	**71.3**
Production cost	**nd**	**139.1**	**157.1**	**133.0**	**121.1**	**148.3**	**140.0**	**148.8**
Supply chain proportion	**nd**	**0.44**	**0.35**	**0.30**	**0.32**	**0.36**	**0.31**	**0.32**

In Australia, charges for grain transport from up country receival to port have decreased on average by about 8% in nominal terms over the past five years, based on scheduled fees published by CBH and Viterra in WA and SA. Assuming an annual inflation rate of about 1.8%, then in real terms this represents a reduction in cost of about 12-13%. The published fees however may not simply reflect transport costs but also incorporate efficiency improvements at receival sites as well as the pricing policy of bulk handlers that aims to influence the delivery preferences of growers. However, offsetting these reduced costs is the fact that, on average, most growers now need to travel further from their farms to deliver grain to fewer receival sites.

Fees for port services over the past five years have remained flat in nominal terms or have increased slightly. Considering inflation, the overall the real price of these services has decreased slightly or remained flat. However, the structure of port service fees varies considerably between bulk handlers and between years, so simple pricing trends are difficult to estimate (see figure from ACCC, 2017).

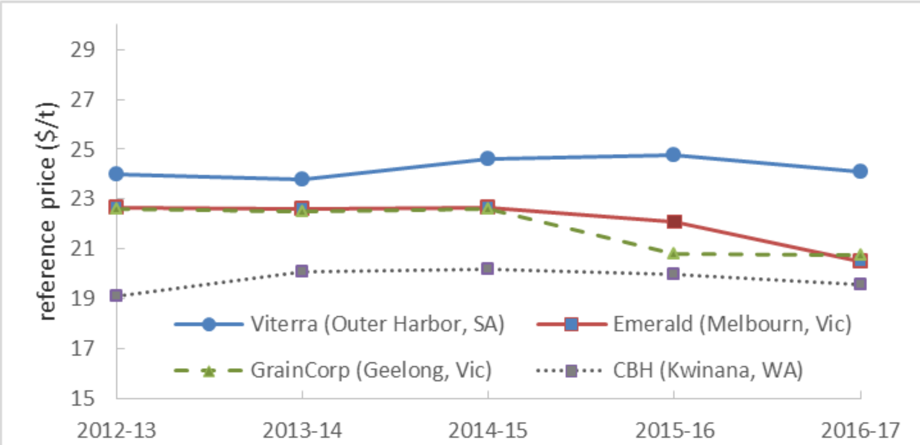

Figure 3. Reference price schedules of major port service providers. (Source: ACCC, 2017)

Conclusion

There is variation in the costliness of Australia's export grain supply chains, with costs varying spatially and temporally. Over the last several years in Australia, most export grain supply chains have slightly reduced their costliness in real terms. Further improvements in grain yields, greater investment in infrastructure, and improvements in operation, regulatory reform and a greater intensity of cropping in higher rainfall regions will all help lower the average cost of Australia's export grain supply chains. These improvements are essential to help preserve the international competitiveness of Australian grain exports, especially when acknowledging Australia's grain export competitors are continuing to drive down their costs through major investments in on-farm and post-farm improvements.

Acknowledgments

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References

ACCC (2017). Bulk wheat ports monitoring report 2016–17. Australian Competition and Consumer Commission. Canberra, ACT Australia. Available at https://www.accc.gov.au/publications/serial-publications/bulk-wheat-ports-monitoring-reports/bulk-wheat-ports-monitoring-report-2016-17

BITRE (2017) Trainline 5 Statistical Report, Bureau of Infrastructure, Transport and Regional Economics and Australasian Railway Association. Department of Infrastructure and Regional Development, Canberra, Australia. Available at https://bitre.gov.au/publications/2017/files/train_005.pdf

Hughes, N., Lawson, K., & Valle, H. (2017). Farm performance and climate: climate adjusted productivity on broadacre cropping farms. Australian Bureau of Agricultural and Resource Economics and Sciences Research Report 17.7, Department of Agriculture and Water Resources. Canberra, Australia.

Kalisch-Gordon, C. McKeon, D., Whiteley, C. Southan, M. Price, C. and MacAulay, G. (2016). State of the Southern Region Grains industry and Challenges to Innovation and Growth. Grain Growers Ltd, Sydney and Canberra, Australia.

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Deprive weeds of sunlight and space - crop competition research in the northern grains region.

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Key words

crop competition, barnyard grass, sowthistle, feathertop Rhodes grass, row spacing, crop density, wheat, chickpea, mung bean, soybean

GRDC code

US00084

Call to action/take home messages

- Growing a competitive crop can significantly reduce weed numbers, biomass and seed production in crop while providing increases in grain yield.
- Growing faba bean and chickpea at a narrow row spacing of 25cm and a high plant density of 70 and 80 plants/m^2 respectively significantly reduced sowthistle biomass and seed production while increasing crop yield.
- Growing wheat at narrow row spacing of 25cm and a high density of 120 plants/m^2 significantly reduced awnless barnyard grass density, biomass and seed production while increasing crop yield.
- Narrow row spacing (25cm) in mung bean and soybean could lead to reduced weed growth and increased crop yield.
- The critical time of weed removal in mung bean and soybean occurs at later stages of crop growth in narrow (25cm) compared to wide rows (75cm).

Introduction

Crop competition is widely accepted as an important tactic for suppressing weed growth and development while maintaining crop yield. Agronomic choices influence crop competition, including crop species and cultivar, row spacing and crop density. All these cultural control tactics have been shown to impact on the control of in-crop weeds.

This paper outlines recent research conducted by the Queensland Department of Agriculture and Fisheries (QDAF) and the University of Queensland (UQ) on important crop competition factors in key crops and for key weed species. The first component of the paper describes QDAF research in winter crops on the impact of crop row spacing and density in chickpea and faba beans on common sowthistle (*Sonchus oleraceus*) and early emerging awnless barnyard grass (*Echinochloa colona*) in wheat. The second component of the paper describes UQ research on the effect of row spacing, seeding rate and weed infestation period in mung beans and soybeans and the effect on Rhodes grass.

1. Crop competition in winter crops (QDAF)

Background

Awnless barnyard grass and common sowthistle are common weed species infesting crops in the northern region, contributing an estimated $14.7 and $4.2 million in crop revenue loss each year (Llewellyn *et al.* 2016). Both species have been confirmed as having glyphosate resistance and common sowthistle also has resistance to chlorsulfuron in Queensland.

Awnless barnyard grass is recognised as a summer dominant weed, predominantly emerging in mid-spring to mid-autumn. However, recent observation has seen the weed emerge earlier to infest winter crops prior to harvest. This earlier emergence takes place at a crop growth stage when post emergence in-crop herbicides are not an option and when residual herbicides are no longer persistent.

As part of a five year GRDC project, we have evaluated the effect of crop row spacing and density on the presence and growth of common sowthistle in faba beans and chickpea, and in wheat on early emerging awnless barnyard grass.

Three field experiments were conducted in 2017 at the QDAF Hermitage Research Facility near Warwick, Queensland;

(i) Faba beans with common sowthistle,

(ii) Chickpeas with common sowthistle, and

(iii) Wheat with awnless barnyard grass.

Materials and methods

The faba bean (*cv.* PBA Warda⦶) and chickpea (*cv.* PBA HatTrick⦶) experiments were planted on the 15th May and an equal number of sowthistle seed per plot were distributed in weedy plots the day after. The target crop densities were 15, 30 and 60 plants/m^2 planted at row spacing of 25 and 50cm. In both experiments a crop-free + weeds treatment was included and for each row spacing x crop density treatment combination, there were both weedy and weed-free plots. The sites were irrigated to promote crop and weed emergence and any non-target weeds were manually removed.

The third experiment with wheat (*cv.* Longreach Lancer⦶) was planted 27th July at target plant densities of 75, 100 and 125 plants/m^2 at row spacings of 25 and 50cm. The site had a natural infestation of awnless barnyard grass and was watered (16th August) to encourage awnless barnyard grass emergence. A crop-free treatment was included, but there were no weed-free treatments. Any non-target weeds were manually removed.

In each experiment, data was collected on weed emergence, weed biomass and seed production and crop yield. Weed measurements were made close to crop maturity at approximately 1 to 2 weeks before crop harvest. For faba beans, these measurements were taken on the 9th October, for chickpea the 30th October and for wheat the 12th December 2018.

Results

Faba bean experiment

The faba bean plant densities were 21, 41 and 70.5 plants/m^2, which exceeded the target populations of 15, 30 and 60 plants/m^2 respectively. Actual crop densities have been used in analysing the data, and for density comparisons, values of 20, 40 and 70 plants/m^2 are used.

Sowthistle density was not affected by crop density or the absence of crop (crop-free treatment) with density ranging from 17-35 plants/m^2. However, there were significantly more sowthistle present in 50cm row spacing treatments than 25cm treatments with on average 30 and 22 plants/m^2

respectively. Therefore, narrow row spacing reduced either the emergence of sowthistle or survival of emerged sowthistle.

Sowthistle biomass was 33% lower at 25cm row spacing when compared with the 50cm row spacing, and biomass was over 440% greater in the crop-free treatment compared to the 50cm spacing, and over 660% more biomass than in the 25cm row spacing (Figure 1a). Crop density also affected sowthistle biomass, with biomass significantly greater at a crop density of 20 plants/m^2 than at 50 plants/m^2, and greater at 50 plants/m^2 than at 70 plants/m^2 (Figure 2a).

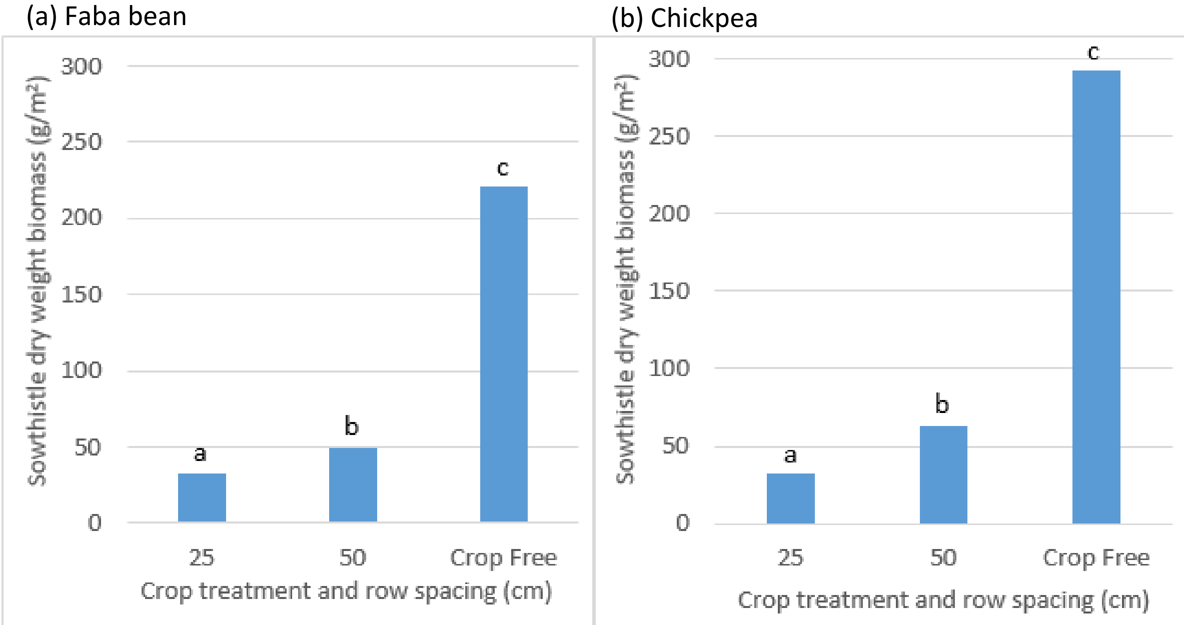

Figure 1. Sowthistle dry weight biomass (g/m^2) as influenced by (a) faba bean and (b) chickpea row spacing (cm) and the absence of crop. Sowthistle biomass was assessed close to crop maturity on the 9th and 30th October 2018 respectively. Bars with a different letter within a crop are significantly different at a 5% significance level.

Sowthistle seed production was least when faba bean was grown at the combination of 25cm row spacing and density of 70 plants/m^2 with seed production greatest at a combination of 50cm row spacing and density of 20 plants/m^2 (Figure 3a). Sowthistle seed production was 36% less at 25cm crop row spacing when compared with the 50cm row spacing (Figure 4a) and seed production in the crop-free treatment averaged almost 591,000 seeds/m^2, which was significantly higher than cropped treatments. Sowthistle seed production was also greater at a crop density of 20 plants/m^2 compared to 40 plants/m^2, and greater at 40 plants/m^2 than at 70 plants/m^2 (Figure 5a).

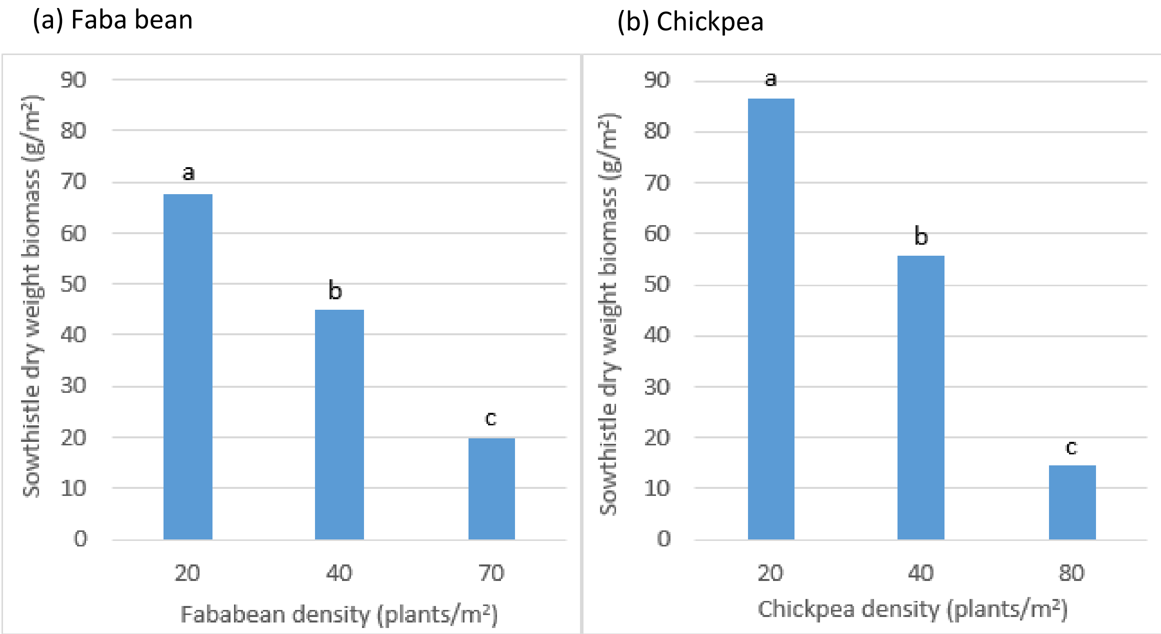

Figure 2. Sowthistle dry weight biomass (g/m^2) in response to (a) faba bean and (b) chickpea plant densities (plants/m^2). Sowthistle biomass was assessed close to crop maturity on the 9th and 30th October 2018 respectively. Bars with a different letter within a crop are significantly different at a 5% significance level.

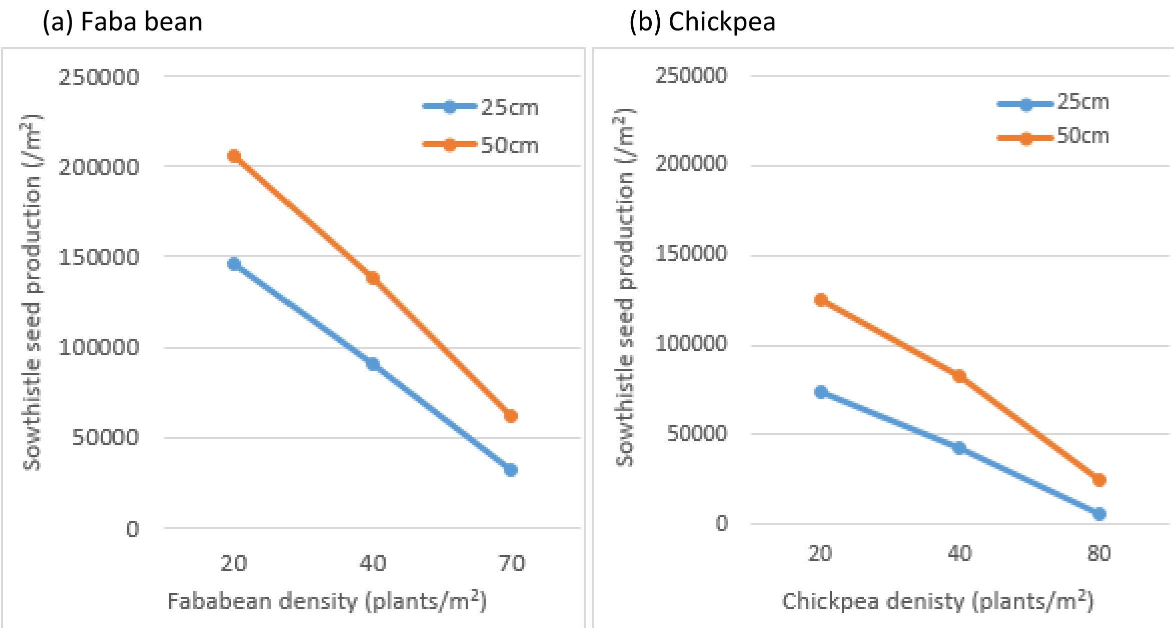

Figure 3. Sowthistle seed production (/m^2) in response to (a) faba bean and (b) chickpea row spacing (cm) and density (plants/m^2). Sowthistle seed production was assessed close to crop maturity on the 9th and 30th October 2018 respectively.

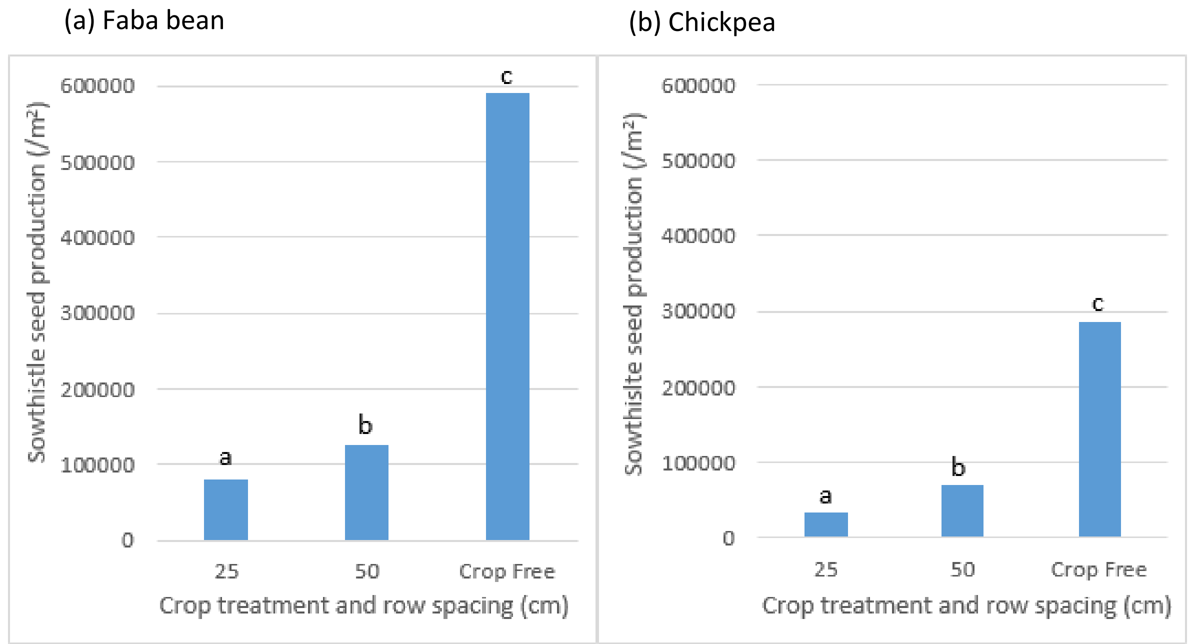

Figure 4. Sowthistle seed production (/m^2) in response to (a) faba bean and (b) chickpea row spacing (cm) and the absence of crop. Sowthistle seed production was assessed close to crop maturity on the 9th and 30th October 2018 respectively. Bars with a different letter within a crop are significantly different at a 5% significance level.

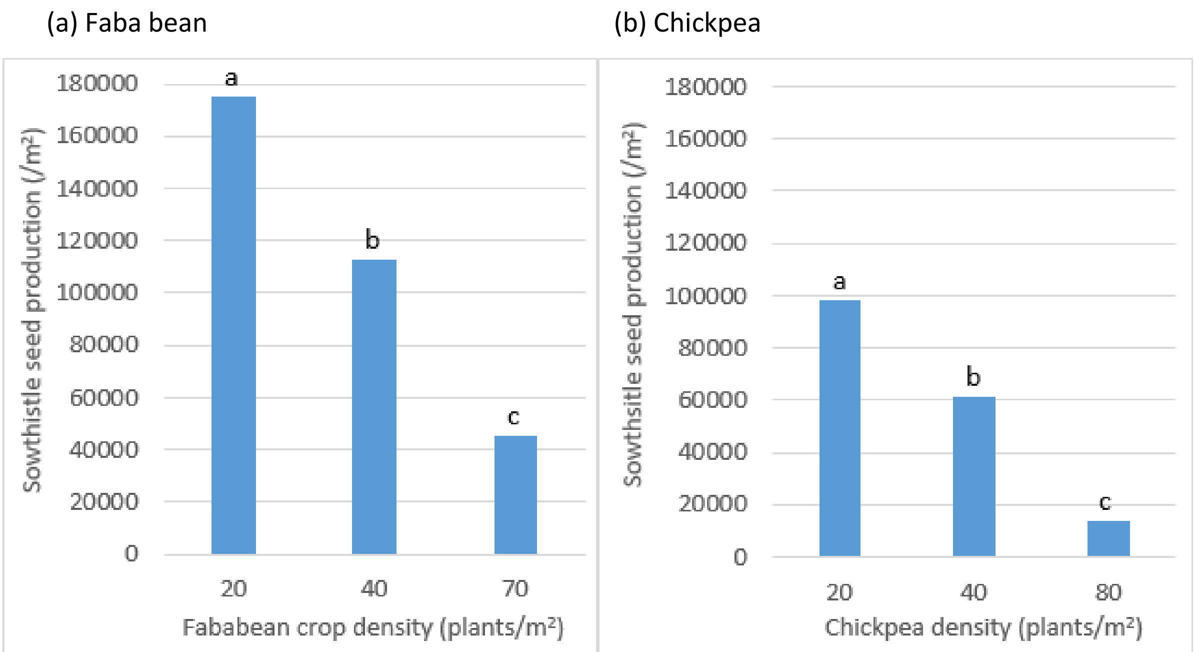

Figure 5. Sowthistle seed production (/m^2) as influenced by (a) faba bean and (b) chickpea plant densities (plants/m^2). Sowthistle seed production was assessed close to crop maturity on the 9th and 30th October 2018 respectively. Bars with a different letter within a crop are significantly different at a 5% significance level.

Crop yield was not different between row spacing treatments. However, crop yield was significantly less in the presence of weeds (Figure 6a), with 11% less yield in weedy treatments. In the absence of weeds, crop density did not affect crop yield. However, in the presence of weeds, there were significant increases in yield with each increase in crop density above 20 plants/m^2 (Figure 7a).

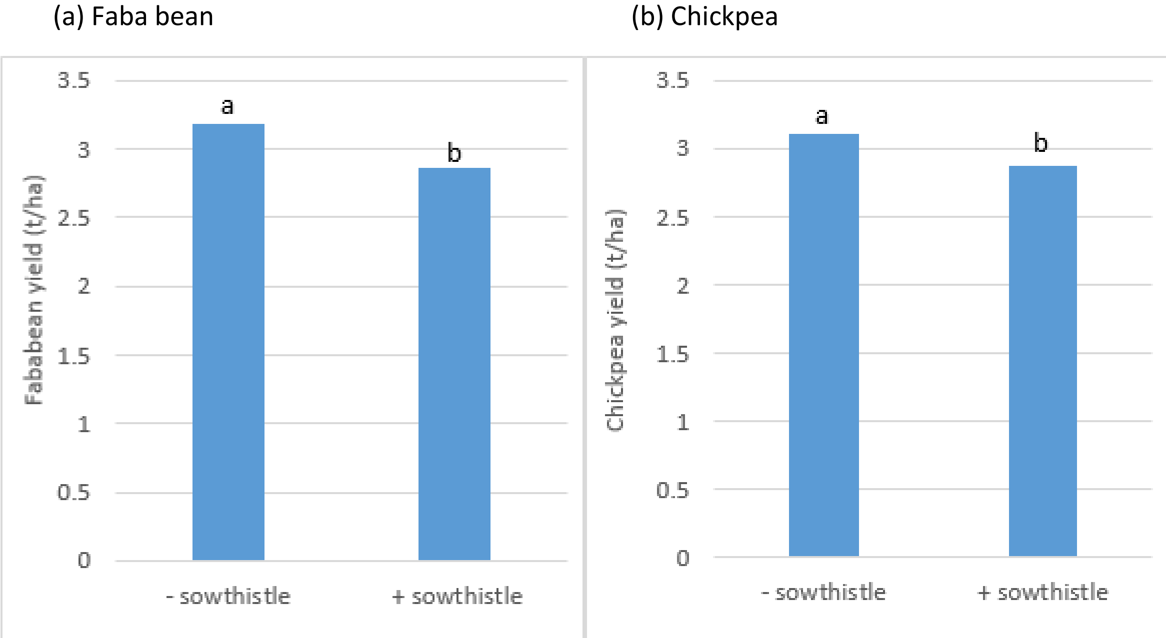

Figure 6. (a) Faba bean and (b) chickpea yield (t/ha) in the presence or absence of sowthistle. Bars with a different letter within a crop are significantly different at a 5% significance level.

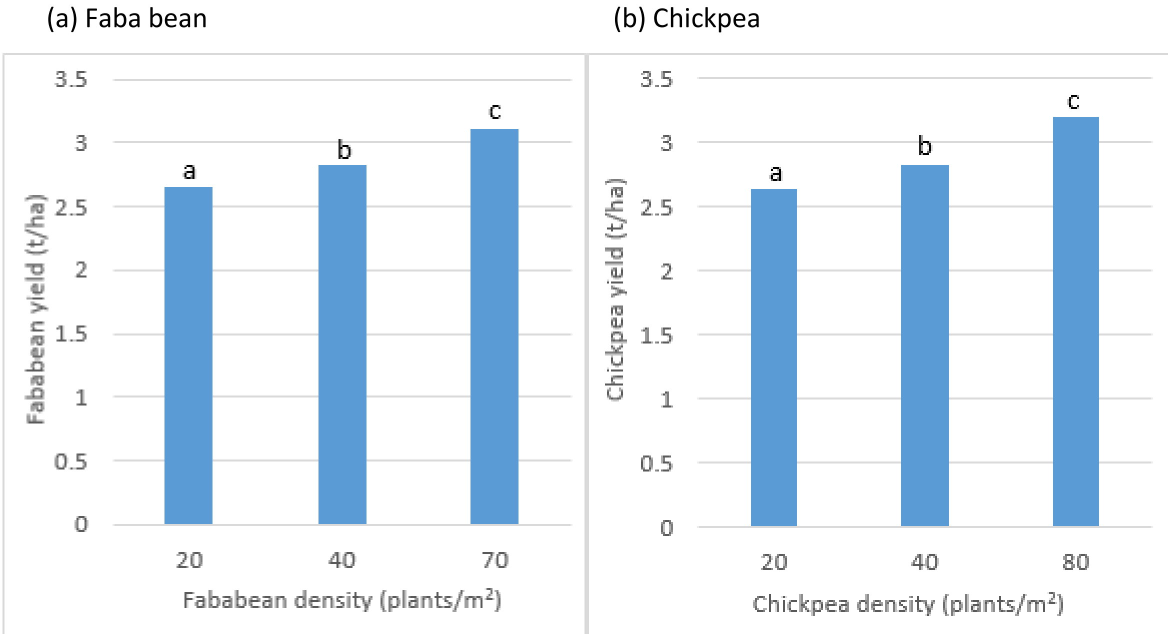

Figure 7. (a) Faba bean and (b) chickpea yield (t/ha) at increasing plant density (plants/m^2) when infested with sowthistle. Bars with a different letter within a crop are significantly different at a 5% significance level.

Chickpea experiment

The chickpea plant densities were 22.6, 40 and 79.5 plants/m^2, which exceeded the target populations of 15, 30 and 60 plants/m^2 respectively. Densities of 20, 40 and 80 plants/m^2 are used in the analysis and presentation of results.

Sowthistle density ranged from 12 – 30 plants/m^2 and was consistent across the site with no significant difference between treatments.

Sowthistle biomass was 50% less in the 25cm row spacing treatment when compared with the 50cm treatment, and the crop-free weed biomass was over 460% greater than in the 50cm treatment, and over 900% more than in the 25 cm row space treatment (Figure 1b). In addition, crop density impacted on sowthistle biomass with biomass significantly greater at a crop density of 20 plants/m^2 than at 50 plants/m^2, and greater at 50 plants/m^2 than at 80 plants/m^2 (Figure 2b).

Sowthistle seed production was least when chickpea was grown at the combination of 25cm row spacing and density of 80 plants/m^2 with seed production greatest at a combination of 50cm row spacing and density of 20 plants/m^2 (Figure 3b). Sowthistle seed production was 52% lower at the 25cm row spacing than at the 50cm row spacing and was significantly higher in the crop-free treatment which had sowthistle seed production of 287,000 seeds/m^2 (Figure 4b). Also, sowthistle seed production was influenced by crop density. Significantly more seeds were produced at a crop density of 20 plants/m^2 compared to 40 plants/m^2, and more at 40 plants/m^2 than at 80 plants/m^2 (Figure 5b).

Crop yield was not affected by row spacing. However, crop yield was significantly higher in treatments were weeds were not present (3.1 t/ha) compared with when weeds were present (2.9 t/ha) (Figure 6b). Crop yield was not affected by crop density in weed-free plots. However, was affected by crop density in the weedy plots, where there was a significant increase in yield at the crop density of 80 plants/m^2 over the density of 40 plants/m^2, which had a greater yield than the 20 plants/m^2 crop density (Figure 7b).

Wheat experiment

Wheat density averaged 60, 88 and 105 plants/m^2 and there was a significant difference between crop densities across row spacing. This has been accounted for in the analysis. Actual crop densities have been used in analysing the data, and for density comparisons, values of 60, 90 and 120 plants/m^2 are used.

Growing a competitive crop of wheat significantly reduced the number of barnyard grass plants in crop. Awnless barnyard grass density was significantly affected by crop row spacing (Figure 8) with 71% fewer barnyard grass at 25 vs 50cm row spacing and >280% and >970% more barnyard grass when no crop was present compared to the 50cm and 25cm treatments respectively.

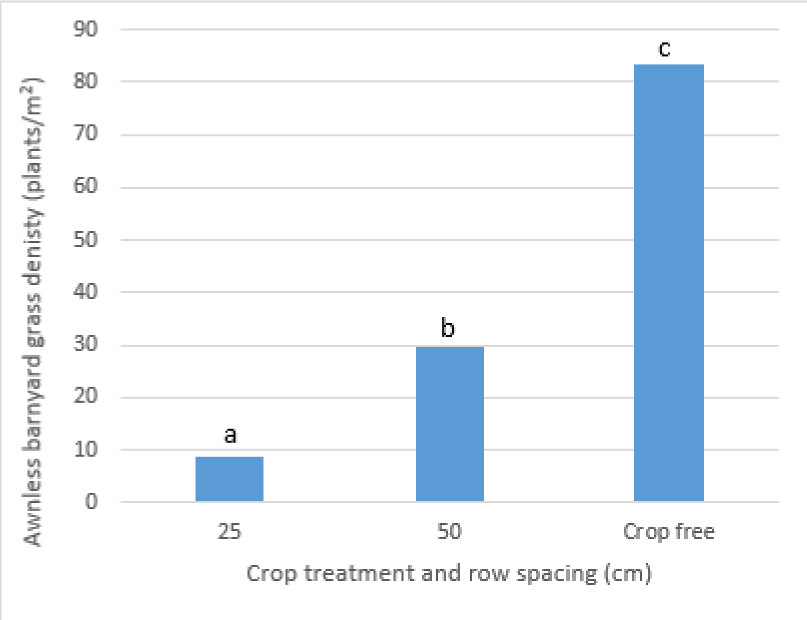

Figure 8. Awnless barnyard grass density (plants/m^2) as influenced by wheat row spacing (cm) and the absence of crop. Density was assessed close to crop maturity on the 12th December 2018. Bars with a different letter are significantly different at the 5% significance level.

Growing wheat at a narrow row spacing significantly reduced barnyard grass biomass (Figure 9) with 70% lower biomass at 25cm row spacing compared with 50cm row spacing. In addition, there was a significantly greater biomass in the absence of a crop with an average biomass production of 93 g/m^2.

There was no impact of row spacing on barnyard grass seed production. However, greater crop density significantly reduced seed production (Figure 10) with greater seed production at 60 plants/m^2 than at 90 plants/m^2 and greater seed production at 90 plants/m^2 than at 120 plants/m^2.

Wheat yield was significantly greater under competitive wheat crops of narrow row spacing and high wheat density (Figures 11a and 11b). Wheat yield was 10% greater at 25cm row spacing compared with 50cm row spacing, and 3% greater at a wheat density of 120 plants/m^2 compared to 90 plants/m^2.

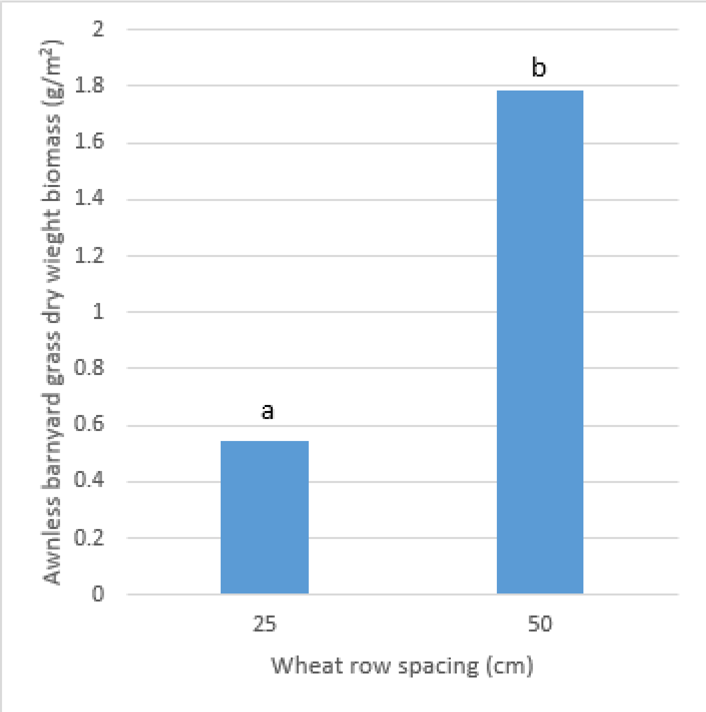

Figure 9. Awnless barnyard grass dry weight biomass (g/m^2) as influenced by wheat row spacing (cm). Bars with a different letter are significant at the 5% significance level.

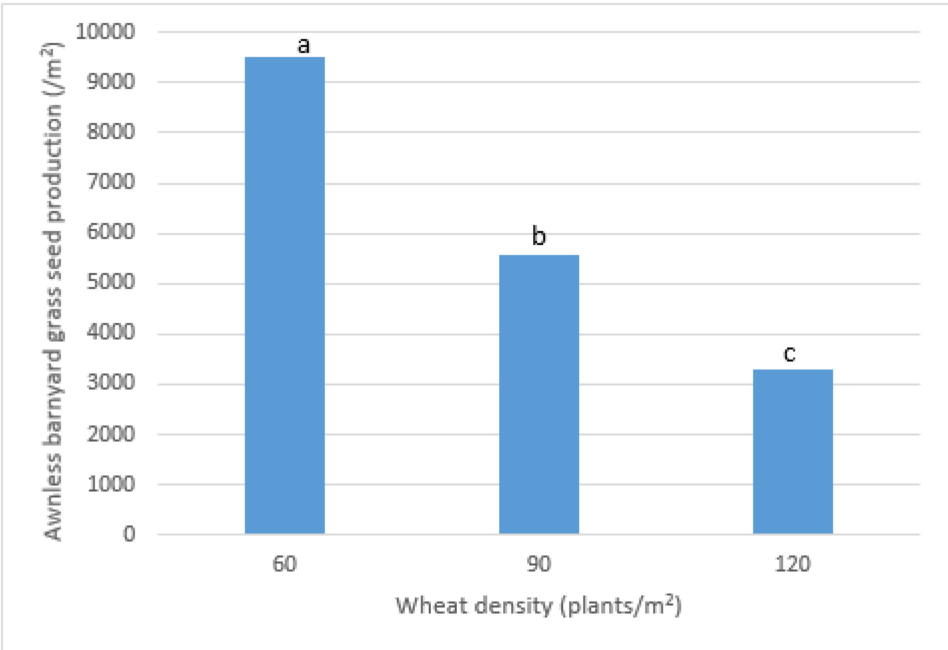

Figure 10. Awnless barnyard grass seed production (seeds/m^2) as influenced by wheat density (plants/m^2). Bars with a different letter are significant at the at the 5% significance level.

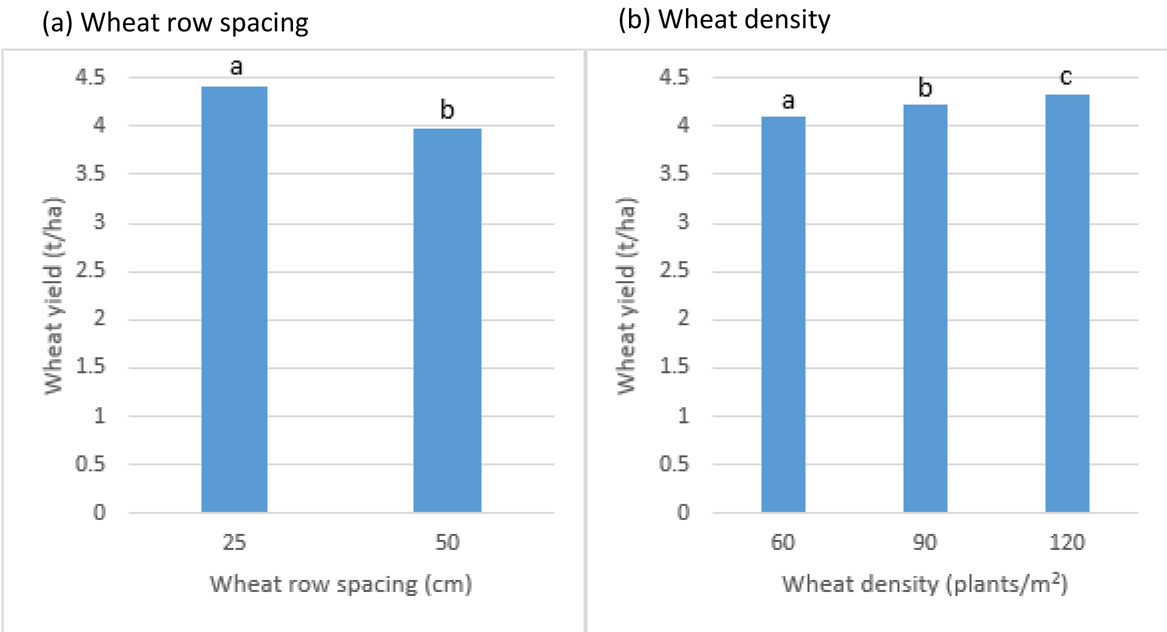

Figure 11. Wheat yield (t/ha) as influenced by (a) wheat row spacing (cm) and (b) wheat density (plants/m^2). Bars with a different letter within each graph are significant at the 5% significance level.

Implications

Results across the three crops; faba bean, chickpea and wheat, show that growing these crops at a narrow row spacing and increased crop density reduced weed biomass and seed production. Additionally, in these trials we generally saw a yield benefit at narrow row spacing and consistently at high crop density.

Current industry recommendation for optimising yield in both faba beans and chickpea is to grow the crops at a density of 30 plants/m^2. In the northern region, there is a trend for both crops to be grown in wide rows of up to 1 metre.

Crop competition can serve as a complimentary tactic for in-crop weed control in combination with in-crop residual and knockdown herbicides. By using these tactics in combination, the pressure is being taken off the herbicide to do all the heavy lifting. As a result, growing a competitive crop can help to prolong the useful life of in-crop herbicides by delaying herbicide resistance. Furthermore, by reducing seed set in crop, future weed populations are likely to be less dense.

Our research highlights the high level of competition that wheat grown at narrow row spacing and high crop density can provide against early emerging summer weed species such as awnless barnyard grass. Increasingly, such weeds are emerging in winter crops at a crop growth stage when residual chemistries are no longer persistent in the soil and when in-crop herbicides are either unavailable or can no longer be applied. Growing a competitive crop will help to reduce these weed numbers and seed production.

The impact of row spacing and crop density on weed control and crop yield will differ with environment (soil types, climate, weed density). To address this issue, multi-site crop competition trials are also being conducted in Wagga Wagga (NSW DPI) and Narrabri (University of Sydney).

Other agronomic factors can also influence the competitiveness of these crops including variety choice, fertiliser placement and precision planting. Each of these factors will be examined in future multi-site trials in both winter and summer crops.

2. Crop competition in summer crops (UQ)

Background

Mungbean and soybean are nutritionally important grain legume crops in Queensland and New South Wales. In general, these crops are grown using a wide row spacing of up to 1-m. In widely spaced crop rows, weeds have a better chance to flourish due to plenty of available space for capturing light and other resources. Herbicides are widely used to manage weeds in these legume crops; however, there are very limited post-emergence herbicide options. In addition, over-reliance on herbicides has resulted in the evolution of herbicide resistance in several weeds. These issues have forced industry to investigate the role of crop competition in managing weeds. This research investigated i) the effect of row spacing and weed infestation period on weed biomass and mungbean grain yield, and ii) the effect of seeding rate, row spacing and weed infestation period on weed biomass and soybean grain yield.

Materials and methods

Two experiments were conducted in 2015 and repeated in 2016 at the research farm of the University of Queensland, Gatton. The mungbean (*cv.* Jade-AU⚘) experiment was established in a split-plot design with three replications. Main plots were mungbean row spacing (25, 50 and 75 cm) and sub-plots were weed infestation periods: weedy from planting to maturity, weedy from 3 wk after planting (WAP) to maturity, weedy from 6 WAP, and weed-free from planting to maturity. The soybean (*cv.* Soy971) experiment was established in a split-split plot design with three replications. Main plots were seeding rates (40 and 80 kg/ha), sub-plots were row spacings (25 and 75 cm), and sub-sub-plots were four weed infestation periods (same as described above for the mungbean experiment). Rhodes grass (300 seeds/m^2) was used as a model weed to create uniform density across the experiments. Weed biomass (oven-dried) was determined at 12 WAP. Both crops were harvested from a 12-m^2 area and grain yield was converted to kg/ha at 12% moisture content. Data were subjected to ANOVA and means were separated using the least significant difference at 5% (LSD5%).

Results

Mungbean experiment

In both years, weed biomass was influenced by the interaction of row spacing and weed infestation periods (Table 1). Row spacing had no effect on weed biomass when plots were kept weedy from planting to maturity (0 WAP), whereas mungbean planted at 75 cm rows had greater weed biomass when plots were kept weedy beyond 3 WAP. In the 3 WAP weed infestation treatment, weed biomass was reduced by 60-70% in mungbean grown at 25 and 50 cm rows compared with 75 cm rows. In the 6 WAP weed infestation period, these values were 70-92%.

Table 1. Interaction effect of row spacing and weed infestation period on weed biomass in 2015 and 2016 (Chauhan *et al.* 2017).

Row spacing (cm)	Weed biomass (g/m^2)					
	0 WAP	3 WAP	6 WAP	0 WAP	3 WAP	6 WAP
		2015			2016	
25	334	35	5	471	46	6
50	340	46	9	492	58	12
75	357	117	56	508	147	40
LSD 5%		27			39	

[Weed infestation periods: Weedy from planting to maturity (0 WAP), weedy from 3 wk after planting (3 WAP), and weedy from 6 wk after planting (6 WAP)].

Mungbean grain yield was influenced by the interaction of row spacing and weed infestation periods in both years (Table 2). Row spacing had no effect on grain yield in the season-long weedy plots (0 WAP). However, mungbean planted at 25 and 50 cm rows produced higher grain yield than at 75 cm rows when plots were kept weedy beyond 3 WAP. In the weed-free environment also, mungbean planted at 75 cm rows had lower grain yield than at 25 and 50 cm rows, indicating that narrow row spacing may produce higher grain yield even in the absence of weeds. For mungbean sown at 25 and 50 cm rows, the grain yield was similar between the plots kept weedy beyond 6 WAP and weed-free plots. However, this was not the case for mungbean planted at 75 cm rows, suggesting that the critical weed-free periods are longer for mungbean planted at 75 cm rows than at 25 and 50 cm rows.

Table 2. Interaction effect of row spacing and weed infestation period on mungbean grain yield in 2015 and 2016 (Chauhan *et al.* 2017).

Row spacing (cm)	Mungbean grain yield (kg/ha)							
	0 WAP	3 WAP	6 WAP	WF	0 WAP	3 WAP	6 WAP	WF
	2015				2016			
25	360	1240	2010	2203	177	1002	1644	1815
50	305	1000	1890	2025	159	887	1505	1653
75	200	630	1203	1620	113	449	928	1222
LSD 5%	283				212			

[Weed infestation periods: Weedy from planting to maturity (0 WAP), weedy from 3 wk after planting (3 WAP), weedy from 6 wk after planting (6 WAP), and weed-free from planting to maturity (WF)].

Soybean experiment

Weed biomass was not affected by seeding rates or its interaction with other factors. However, it was affected by the interaction of row spacing and weed infestation periods (Table 3). Row spacing had no effect on weed biomass in the season-long weedy plots (0 WAP), whereas plots that were weedy beyond 3 and 6 WAP had greater weed biomass in wider rows than narrow rows. In the 3 WAP weed infestation treatment, 55-58% weed biomass was reduced in soybean grown at 25 cm rows than at 75 cm rows. In the 6 WAP weed infestation period, these values were 80-82%.

Table 3. Interaction effect of row spacing and weed infestation period on weed biomass in 2015 and 2016 (Rasool *et al.* 2017).

Row spacing (cm)	Weed biomass (g/m^2)					
	0 WAP	3 WAP	6 WAP	0 WAP	3 WAP	6 WAP
	2015			2016		
25	366	70	17	837	89	19
75	376	155	84	863	213	105
LSD5%	34			17		

[Weed infestation periods: Weedy from planting to maturity (0 WAP), weedy from 3 wk after planting (3 WAP), and weedy from 6 wk after planting (6 WAP)].

As with the weed biomass, soybean grain yield was not affected by seeding rates or its interaction with other factors. However, it was affected by the interaction of row spacing and weed infestation periods in both years (Table 4). The lowest yield was obtained in the season-long weedy plots of the 75-cm spaced crop and the highest yield was obtained in the weed-free plots of the 25-cm spaced crop. Grain yield was higher in the crop planted at 25 cm rows compared with 75 cm rows in all weed-infestation treatments, except in the season-long weedy treatment in 2016. Soybean yield in narrow rows was 83-121% higher than in wider rows for the plots infested with weeds beyond 3 WAP, 63-65% higher for the plots infested with weeds beyond 6 WAP, and 14-21% higher for the weed-free plots.

Table 4. Interaction effect of row spacing and weed infestation period on soybean grain yield in 2015 and 2016 (Rasool *et al.* 2017).

Row spacing (cm)	Soybean grain yield (kg/ha)							
	0 WAP	3 WAP	6 WAP	WF	0 WAP	3 WAP	6 WAP	WF
	2015				2016			
25	550	1754	2356	2498	89	1934	2655	3043
75	428	959	1448	2191	86	875	1610	2525
LSD 5%	94				114			

[Weed infestation periods: Weedy from planting to maturity (0 WAP), weedy from 3 wk after planting (3 WAP), weedy from 6 wk after planting (6 WAP), and weed-free from planting to maturity (WF)].

Implications

The experiments demonstrated that narrow row spacing in mung bean and soybean resulted in increased grain yield and reduced weed biomass, particularly when weeds emerged beyond 3 and 6 WAP. The results suggest that the critical time of weed removal in these legume crops is likely to occur later in narrow than in wider row crops, indicating that weeds might be allowed to compete with these crops for longer periods in narrow than in wider row crops. We did not evaluate weed seed production in these experiments but we know from other studies that weed biomass correlates well with weed seed production, so reducing weed biomass can be expected to also reduce seed production in weeds. To convince Australian growers to change their row spacing, there is a need to demonstrate the negative effect of narrow row spaced crops on weed growth and their fecundity.

Acknowledgements

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References

Chauhan BS, Florentine SK, Ferguson JC, Chechetto RG (2017) Implications of narrow crop row spacing in managing weeds in mungbean (*Vigna radiata*). *Crop Protection* 95:116-119.

Llewellyn RS, Ronning D, Ouzman J, Walker S, Mayfield A and Clarke M (2016) *Impact of Weeds on Australian Grain Production: the cost of weeds to Australian grain growers and the adoption of weed management and tillage practices*. Report for GRDC. CSIRO, Australia.

Rasool G, Mahajan G, Yadav R, Hanif Z, Chauhan BS (2017) Row spacing is more important than seeding rate for increasing Rhodes grass control and grain yield in soybean (*Glycine max*). *Crop and Pasture Science* 68:620-624.

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The P story so far – an update on deep P research findings

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Key words

phosphorus, starter P, deep P, residual value, placement strategies

GRDC codes

UQ00063, UQ00078

Call to action/take home messages

Depletion of subsoil phosphorus (P) reserves and uncertainty over the benefits of starter P use led to a detailed examination of crop responses to P fertilisers in terms of rates, products and placement over the last 5-6 years. Trials have been conducted at 35 locations from central NSW to CQld. While large crop responses have been recorded at many locations, the impact of seasonal moisture availability (on yield potential and root activity), P placement (starter v deep P, band spacing, amount of soil disturbance), P rate, time of application and product choice will all impact on responsiveness. Residual availability of deep P has generally been excellent, although crop response may be limited by shortages of other nutrients (e.g. N). Data continues to be incorporated into the Deep P calculator to provide an indication of the economic returns from P investment. To access the Deep-P Calculator: http://www.armonline.com.au/deepp/

The trial program

There has been a staggered establishment of sites across the region since mid 2012, with a total of 30 experiments in UQ00063 by the 2016 winter crop season at locations indicated in Fig. 1. These trials consisted of rates of phosphorus (P) fertiliser (0 to 40 or 60 kg P/ha) applied in deep bands (at ~20cm depth), typically at band spacings of 50cm, along with an untilled Farmer Reference treatment. All main plots were then split to annual 'with' or 'without' starter P fertiliser applications at planting at rates ranging from 6 to 10 kg P/ha. Crop choice at each site was dependant on the crop in the surrounding paddock (e.g. crop mix in the establishment years are shown in Table 1), and the residual benefit of the different rates of applied P was tracked through subsequent growing seasons. After the 2017 winter crop harvest, some sites have produced 4 or 5 crops, while some of the newer sites were only in the first or second crop after the initial P application. An extension to UQ00063 will allow the residual value of these later sites in particular to be extended to at least 4 crop seasons, weather permitting, while some of the earlier sites will be in their 5th to 7th crop after P application.

At each site, efforts were made to initially address other potential nutrient limitations, identified by soil testing, by applying a basal application of N, K, S and/or Zn as appropriate. Additional N applications were needed to balance different N additions when the P rates were applied as MAP, but also in response to a likely increase in crop yield potential after overcoming the P constraints. Whilst this initial 'top up' ensured crop responses to applied P should be expressed, problems emerged in later years at some responsive sites, as the higher yield potentials in the plots where P deficiency had been overcome did not have enough N to deliver the higher yield potentials (i.e. P responses were constrained by lack of N). While mainly relevant to grain crops and not pulses such as chickpeas or mungbeans, this problem was often not evident until late in a growing season, or only from observations of sub-optimal grain protein content. That meant that remedial action could only be taken for the next crop in the cycle, and assessment of the residual P benefit may have been compromised in some crop seasons. An example of this is provided later in this paper.

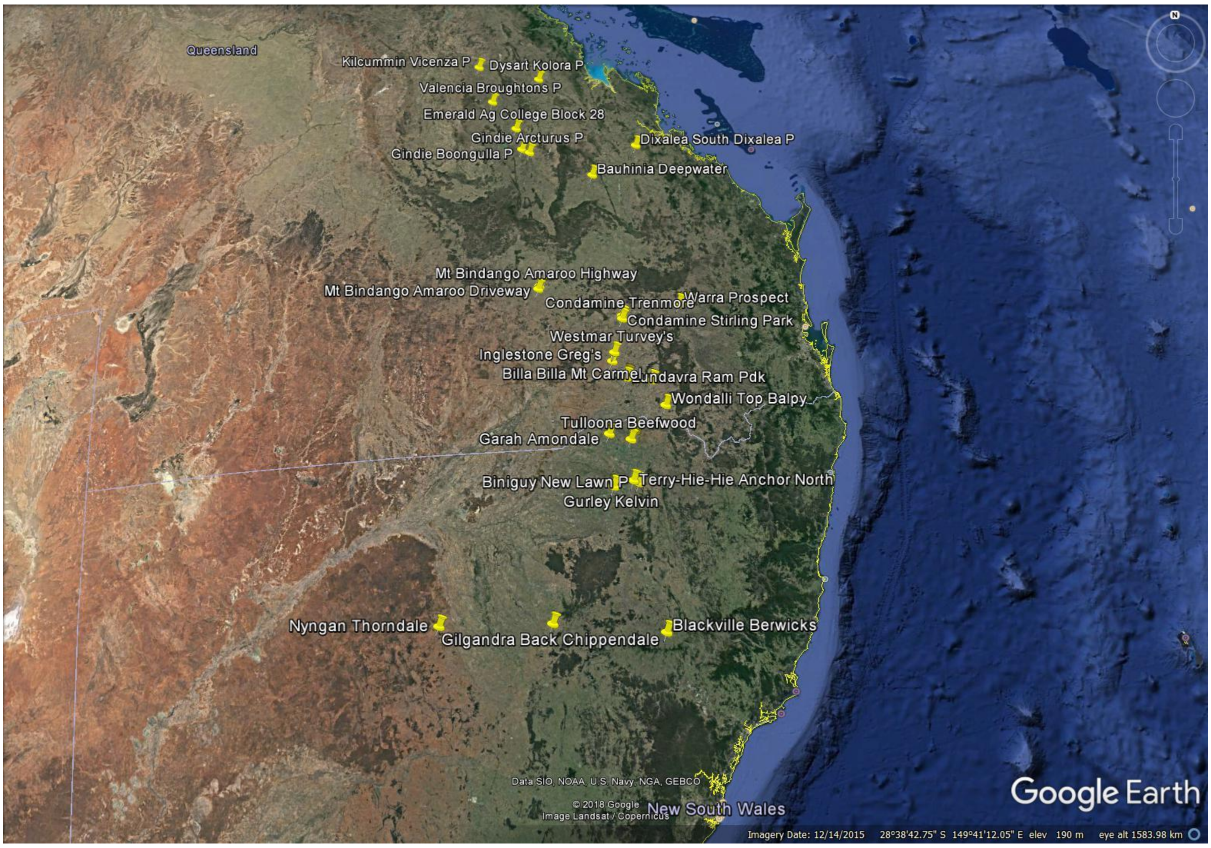

Figure 1. Location of the 30 P trials established from 2012-2017 under UQ00063.

The soil P tests for the 30 P trial sites in UQ00063 are shown in Table 1. Both Colwell and BSES P were higher in the 0-10cm layer than the 10-30cm layer, and BSES P was always at higher concentrations than Colwell P. Based on wheat critical soil test values for starter P responses, the median values would suggest a significant proportion of sites should have been P responsive. Similarly, we had hypothesized deep P responsive sites would have < 10 mg/kg Colwell P and <100 mg/kg BSES P in the 10-30cm layer, so most sites were predicted to respond to deep P.

Table 1. Median, maximum and minimum concentrations of Colwell and BSES P at sites sown to winter cereals (wheat and barley), chickpeas, grain sorghum or other species (sunflower and cotton) in the first year after fertiliser application.

	Colwell P (mg/kg)		BSES P (mg/kg)	
	0-10cm	10-30cm	0-10cm	10-30cm
Winter cereal sites (11)				
Median	19	6	66	18
Range	74-10	22-3	234-22	84-12
Chickpea sites (9)				
Median	17	4	29	12
Range	22-6	6-1	57-13	16-5
Sorghum sites (9)				
Median	14	3	71	15
Range	30-5	6-1	96-8	74-3
Other species (2 - Sunflower, cotton)				
Median	17	7	42	19
Range	19-15	9-4	47-37	30-8

An additional series of trials have been established since 2015 in core sites at Jandowae, Lundavra, Terry Hie Hie and Bellata under UQ00078, with these trials looking at placement strategies (rate*band spacing interactions, liquid v granular fertilisers, form of applied P, degree of soil disturbance/mixing, effect of co-location of different nutrients). Crop choice was again dependent on the host farm crop rotation.

Responses to starter P

Starter fertiliser applications were made at sowing – either by the trial operators with small plot equipment, or by the growers who turned starter fertiliser on and off in planned strip-plot designs. Unfortunately in the latter, starter was not always turned on and off as planned, so there was some loss of starter P contrasts at some trials. Overall, prior to the 2017 winter season (still being processed) there have been 42 site-years with starter P contrasts, split between wheat/barley (17), chickpeas (13) and sorghum (12), with crop responses assessed in relation to the initial pre-trial Colwell P concentration in the 0-10cm layer. To cope with differing yields between sites and seasons, responses were assessed on the basis of relative yield (Yield no starter/Yield with starter), with values <1.0 indicating that the crop responded to starter P application. Responses for each crop species are shown in Fig. 2 (a, b, c) for winter cereals, chickpeas and sorghum, respectively.

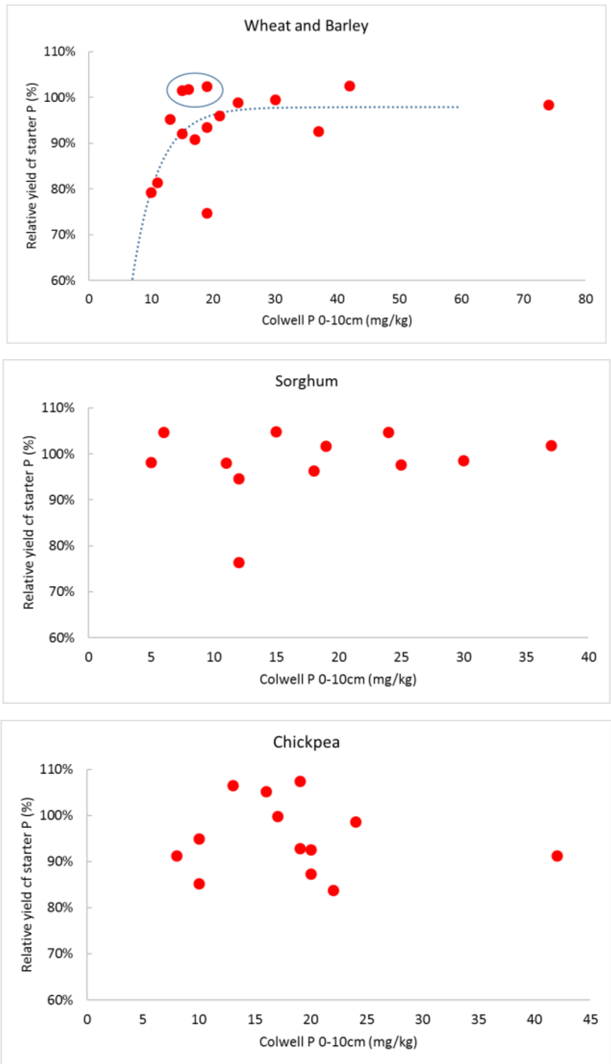

Figure 2. Response to starter P application in winter cereals, chickpea and sorghum crops grown in the UQ00063 trials. Points indicate the relative yield of the plots without starter fertiliser, compared to those where starter P was applied.

There is a relationship that can be developed for the winter cereal crops, although it is poorly defined due to the limited number of sites with very low Colwell P in the 0-10cm. That said, there seemed to be no real evidence of responses to starter P for Colwell P > 15-17 mg/kg – a value somewhat lower than the 20-23 mg/kg suggested from the recent national database analysis (R. Bell *et al.* 2013). More data is needed to better define this relationship.

Despite some quite significant responses to starter P in chickpea (up to 20% yield increases), there is no clear relationship to Colwell P in the 0-10cm layer – possibly because the variable sowing depths between sites and seasons may mean the 0-10cm layer is not always relevant to the developing crop (i.e. it may have been planted below 10 cm!). The data for sorghum shows almost no response to starter P at all, even when Colwell P in the top 10cm layer is very low. The one site where a significant response was recorded was south of Emerald in 2015.

We had intended to undertake separate analyses to look at starter P responses in the presence or absence of moderate-high rates of deep P, to gain some understanding as to whether ameliorating low subsoil P could eliminate the need for starter P – an effective diversion of the current P inputs in the cropping system from smaller annual starter P applications to occasional larger deep P applications. However, given the limited responses to starter P across all crops this has so far been inconclusive.

Responses to deep P

Deep P applications were made using either mono-calcium phosphate (TSP), or more commonly mono ammonium phosphate (MAP) with equilibration of the N inputs for the different rates using urea. The responses to deep P (Figure 3) have been assessed relative to the nil P treatments that received tillage and background nutrient inputs, so any yield increases are directly attributable to P addition only. Comparisons between the deep P treatments and the 'As is – Farmer Reference' condition were also made, with the relative performance of the deep P treatments generally greater than when benchmarked against the nil P, but responses in these instances could be due to soil disturbance, other background nutrients or the deep P input. There were 19 winter cereal and 19 chickpea site years of data, and 17 for sorghum, prior to the 2017 winter season.

As indicated in Figure 3 below, all crops responded to deep P when subsoil P (in the 10-30cm layer) was low. There are a range of responses to deep P for any given soil P concentration, which were due to a combination of other yield constraints (e.g. a lack of water!) or an ability to access P from relatively enriched topsoil layers (i.e. wet years). As an example, ignoring the red point which represented a trial with low N, failing to apply deep P resulted in yield penalties of 10-25% for a Colwell P of 2 mg/kg. It is difficult to make more definitive conclusions from the data at this stage (e.g. which species is the most responsive to deep P applications?), because the crops were grown on different sites, in different seasons with differing access to topsoil P, and with different deep P sources in some cases. For example, for sites where subsoil Colwell P was $\leq$5 mg/kg, the average yield loss due to low subsoil P from all site-years is 8% for wheat and chickpea crops but 13% for sorghum. It is impossible to tell whether this is because sorghum responds more to deep P than the other species, or because 90% of the sorghum crops were responding to deep P applied as MAP while for wheat and chickpea only 45-55% of the sites had MAP and the rest TSP.

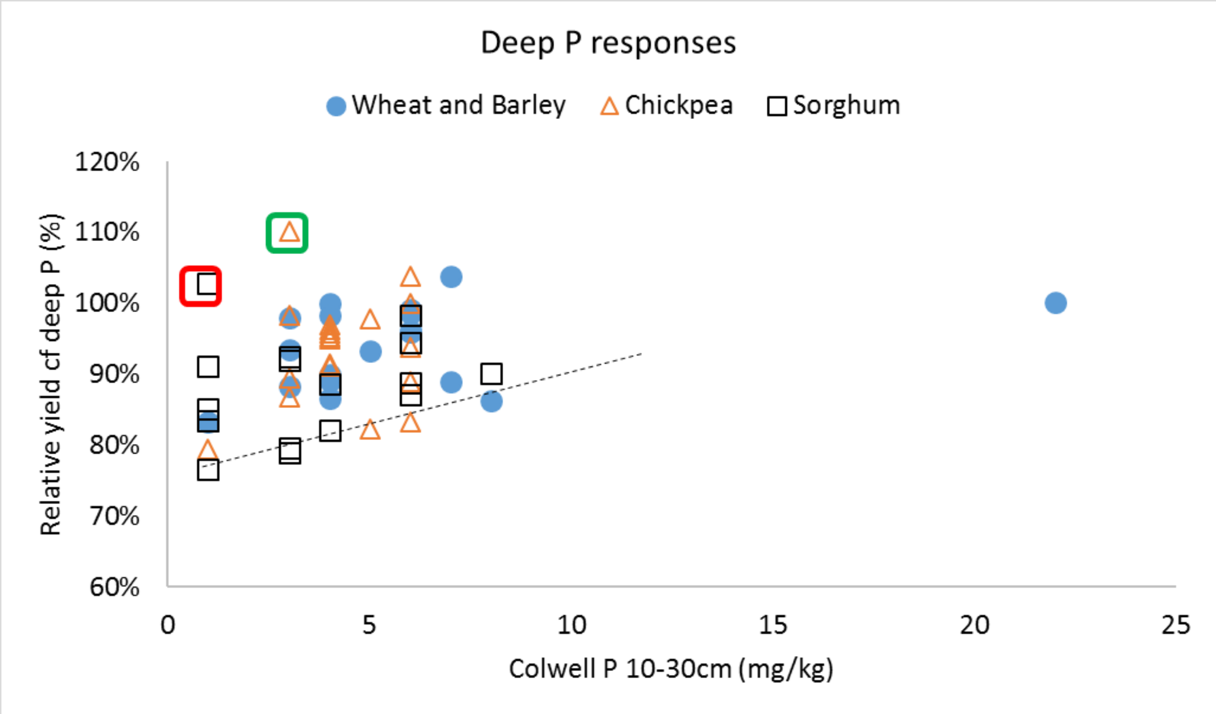

Figure 3. Response to deep P application in winter cereals, chickpea and sorghum crops grown in the UQ00063 trials. Points indicate the relative yield of the plots with starter fertiliser but no deep P, compared to those where starter P and deep P was applied, and represent both fresh and residual P responses. Points in the upper LHS of the curve (red and green squares) are where deep P was applied too close to the planting date, or where the site was N limited.

If we used the lower (more responsive) boundary of the trial data combined for all crop types (dashed line in Fig. 3) as an indicator of the potential crop responses to deep P in favourable seasons, this analysis would suggest that 90% of maximum yield potential (the value normally used to define a critical soil test concentration) will be achieved when Colwell P in the 10-30cm layer is ~10 mg P/kg. This agrees quite well with the original predictions at the beginning of this project in 2012.

Optimum application rates and residual value of applied P

To explore these effects we use case studies from 2 sites – one at Dysart (deep applied in Aug 2013, crop 4 harvested in 2017 winter) and the other at Wondalli (deep P applied in May 2013 and crop 4 harvested in 2017). Both sites were responsive to deep P, and responses are still evident in the 4th crop after application.

It is difficult to tell whether the P response is diminishing over time, or whether the rate required to reach P-unlimited yields is changing, due to other variables like seasonal conditions and N availability. In the first 3 crop years of sorghum, 20 kg P/ha was enough to reach maximum yields, but the P response was increasing all the way to the top rate (40 kg P/ha) in the chickpea crop in season 4. While this would suggest that the residual benefits of the lower P rates were diminishing by the 4th crop, this ignores the fact that yields of sorghum (crop 3, and to a lesser extent 2) were constrained by N availability, so the full potential P response may not have been able to be expressed. When a legume crop (chickpea) was grown in season 4, low N was less likely to be limiting crop performance, and the P response was very strong (and very profitable!). Further site-years with higher N inputs will help explore this response. However, to date the combination of tillage and deep P has produced an additional 700 kg/ha of sorghum in crop 1, 550 kg/ha of sorghum in crop 2, 450 kg/ha sorghum in year 3 and >850 kg/ha of chickpeas in year 4.

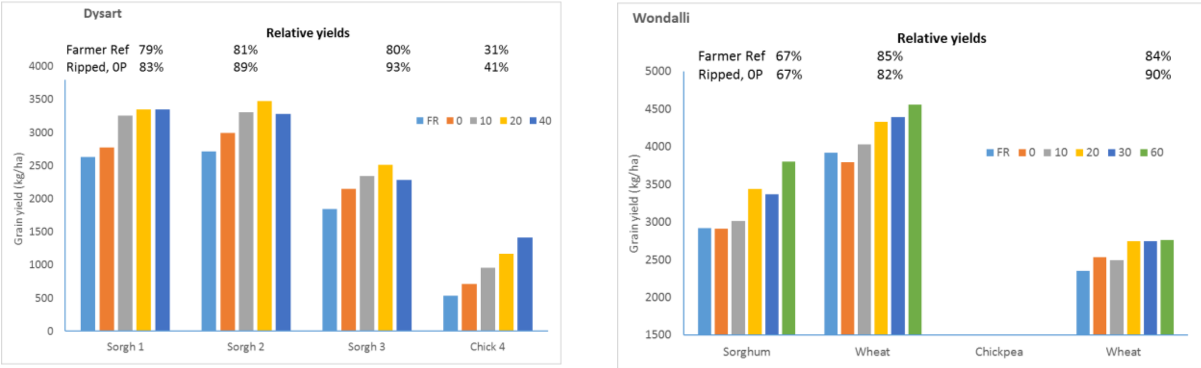

Figure 4. Grain yields at deep P sites at Dysart and Wondalli for the first 4 crop seasons after deep P application in 2013. Deep P was applied as MAP at rates ranging from 0 to 40 (Dysart) or 60 (Wondalli) kg P/ha, and each site had an unripped Farmer Reference (local practice) treatment as a benchmark.

There was no evidence of N limitations at Wondalli, although this site did lose its chickpea crop in season 3 due to the wet conditions in 2016. At this site, yields increased with increasing P rate up to 60 kg P/ha in the initial sorghum and subsequent wheat crops. However, while there were significant P responses in the 2017 wheat crop, there was no yield increase to rates >20 kg P/ha. The very dry seasonal conditions and water-limited yields in this season may have limited any response to higher P rates, so again, further site-years are needed to determine how long the residual effects last. To date, the combination of tillage and deep P has produced an additional 880 kg/ha of sorghum in crop 1, 650 kg/ha of wheat in crop 2 and 400 kg/ha of wheat in year 4.

When do I re-apply?

As more growers and advisors start deploying deep P strategies in their fields, this question is asked more frequently. Unfortunately there are no easy answers, other than the use of test strips with accurate yield monitoring. The amount of time and effort to effectively sample the subsoil layer to account for residual fertiliser bands, and assess the P bioavailability, would suggest soil sampling will not be the answer. Even a budgeting approach will not provide reasonable estimates. This is because, experimentally, we are unable to identify whether additional P uptake or removal by the crop accurately reflects fertiliser P recovery, as most crops are capable of proliferating roots in a P band and so can preferentially take P from the band while sparing P from the surrounding soil. We do not have any tracers that we can put into a P band to indicate fertiliser P recovery over a series of crop seasons, although Phil Moody and the group at DSITI are evaluating some options in the lab at present.

We are currently in year 1 of a 3 year extension to UQ00063 where we will continue to monitor a number of the more recently established sites as well as some of the longer term ones, and that may provide better estimates of the likely length of residual P benefits.

Products, placement strategies, timing

This remains an area of active research in both Qld and NSW under the co-funded UQ00078 GRDC project. Research has so far showed that

- There seems to be no advantage to be gained by using liquid v granular forms of MAP, as has been reported on the calcareous soils of the Eyre Peninsula in South Australia, and recent results from the NSWDPI site near Bellata have suggested the liquid MAP was actually inferior to the granular product.
- Studies have not been able to demonstrate an interaction between P rate and P band spacing (i.e. in band concentration), so the important thing is to get enough P into the subsoil layers in a

way that is practical but maximizes the chances of crop P recovery. Current recommendations for band spacings of 40-50cm therefore remain valid.

- To date, there has been no evidence of benefits of co-locating P and Zn in deep P bands, as there were suggestions that improved P uptake may limit Zn acquisition – possibly through a less extensive mycorrhizal network. However these effects have only been observed in sorghum crops in UQ00063, and as yet the specific P-Zn trial sites have not hosted a sorghum crop.
- The question of type of P fertiliser (MAP or TSP in particular) is currently the subject of trials sown in 2017 winter in NSW and in 2017/18 summer in Qld, and will also form a component of research conducted by a new postdoctoral appointment at UQ commencing in early 2018.
- Trials have also shown that there are no obvious negative impacts of combining MAP and KCl in deep bands in sites where both P and K are limiting, and that in this case, the root proliferation associated with the P band will encourage root activity and K uptake. Again, further work on the interaction between these products at different in-band concentrations and in different soil types will be undertaken by the UQ postdoctoral appointment from early 2018.
- Finally, trials are in the process of being established in Qld to explore the impact of amount of soil disturbance/mixing and the volume of soil enriched with P and K fertilisers on crop nutrient uptake. This will involve comparing discs, tynes and strip tilling units for their efficacy in making P available to the crop, and help to provide better guidance on the type of fertiliser rig required. A particularly interesting observation from this authors recent study tour to Europe and the UK has been the impact of voids/large pores on root branching and proliferation. This is illustrated in X-ray CT images produced in the University of Nottingham for maize and wheat (Fig. 5). Their results suggest that if the deep placement operation leaves large voids around the fertiliser bands and/or there is insufficient time and rain to allow profile reconsolidation, the chances of achieving the vigorous root proliferation needed to get good fertiliser uptake may not occur.

Conclusions

Research to better understand the effects of low subsoil P, agronomic strategies to overcome these limitations and the implications for fertiliser P management across northern cropping systems has come a long way. Rudimentary but functional diagnostic indicators of when to use starter and deep P fertilisers are becoming available, guidelines for effective application methods to address P limitations are developing, and economic assessments of the profitability of deep banding in a cropping system are showing strong returns in low P fields. Factors that limit deep P response include the availability of other nutrients (particularly N) and a lack of plant available water, both of which can restrict the achievement of higher yield potentials. The quantum of deep P response is also affected by seasonal conditions that impact on root activity in different parts of the soil profile, so obtaining benefits under some seasonal conditions will remain somewhat problematic. This risk is countered by the excellent residual value of deep P that is being documented in field trials, allowing the benefits of applications to occur across a rotational sequence rather than solely in the year of application.

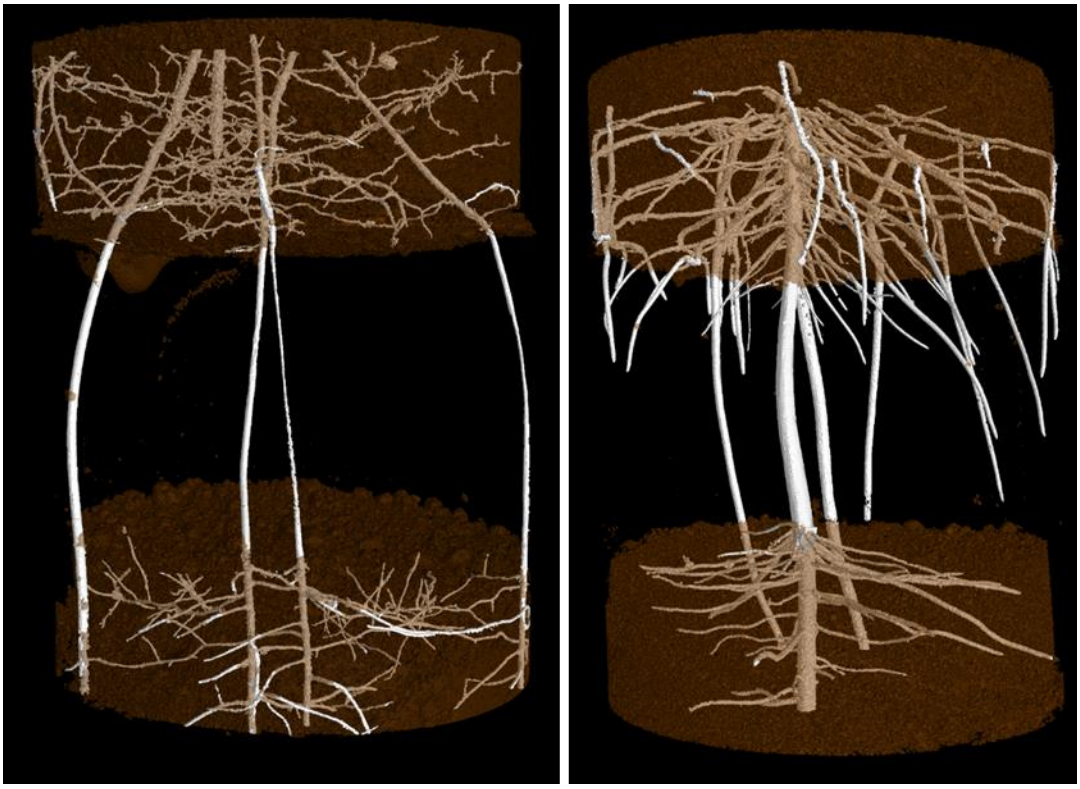

Figure 5. Impact of soil voids/air gaps on localized root branching in maize (left) and wheat (right). Image supplied by Prof Malcolm Bennett, University of Nottingham, and is reproduced from Morris et al (2017) Shaping Root Architecture. Current Biology, 27, R919–R930.

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References

Bell, R., Reuter, D., Scott, B., Sparrow, L., Strong, W., Chen, W., (2013), Soil phosphorus-crop response calibration relationships and criteria for winter cereal crops grown in Australia, Crop and Pasture Science: an international journal for crop and pasture science, 64, 5, pages 480 - 498.

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