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NEW SOUTH WALES
THURSDAY 1ST 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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GRDC Grains Research Update
Thursday March 1st, 2018

Time	Topic	Speaker
9:00 AM	Welcome	
9:10 AM	**Using the drivers of phenology in wheat varieties to better manage frost risk in a variable climate**	*Felicity Harris (NSW DPI)*
9:35 AM	**Matching phenology, environment and variety to optimise wheat yield. When is it too early?**	*Rick Graham (NSW DPI)*
10:05 AM	**Chickpea: temperature and other factors affect flowering, pod set and yield**	*Andrew Verrell (NSW DPI)*
10:30 AM	Morning tea	
11:00 AM	**Chickpea water use efficiency.** Neutron probes, where and when chickpeas draw water from and manipulating biomass	*Kerry McKenzie (DAF Qld)*
11:30 AM	**Chickpeas, wheat and *P. thornei* build up and decline in the farming system. Chickpeas - a dangerous combination of susceptibility and only moderate tolerance**	*Kirsty Owen (USQ)*
12:00 PM	**What's new in grain storage?** ProFume® fumigations, fumigating large silos and latest trials on grain protectants	*Philip Burrill (DAF Qld)*
12:35 PM	Lunch	
1:25 PM	**Spray quality data for nozzles are changing to better reflect the impact of formulation and adjuvants on droplet size. What are the implications for you?**	*Bill Gordon (Nufarm)*
1:55 PM	**Setting the farm up for broadband connectivity** – prerequisites for on-farm automation. Grower experience in installing a 50 MB/sec broadband system. What was done, how and why?	*Nick Gillingham (Keytah)*
2:25 PM	Close	

Contents

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Understanding drivers of phenology to increase grain yield of wheat

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Keywords

phasic development, sowing time, flowering time, photoperiod, vernalisation

GRDC code

DAN00213 Grains Agronomy and Pathology Partnership, GRDC and NSW DPI

Call to action/take home messages

- Variation in phenology had a significant effect on the grain yield potential of wheat varieties in response to sowing date across growing environments of the northern grains region (NGR).
- The variation in phenology of genotypes is largely due to interactions between genetic responses to vernalisation and photoperiod and growing environment, which determines genotype adaptation.
- High grain yields can be achieved from a range of genotype x sowing date combinations; however there is variation in genotype responses across environments of the NGR.
- Whilst flowering time is important in maximising grain yield potential, pre-flowering phases can have a significant influence on grain yield.

Background

There are a range of commercial cultivars suited for sowing across the northern grains region (NGR), which vary in phenology from slow developing winter types to fast developing spring types, providing growers with flexibility in their sowing window. The adaptation and yield potential of wheat is dependent on matching phenology and sowing time of varieties to ensure flowering and grain formation occurs at an optimal time. In most environments, this is defined by decreasing frost risk, and increasing water and heat stress. The optimal flowering time varies across environments of the NGR, therefore providing growers with an understanding of the drivers of phenology will enable them to tailor suitable combinations of genotype and sowing date to minimise exposure to abiotic stresses and achieve maximum grain yield.

This paper discusses the influence of phenology on yield responses to sowing time for wheat genotypes across five environments of the northern grains region (NGR). These results are part of a project aimed at optimising grain yield potential in the NGR co-invested by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

Phasic development of wheat

The grain yield of wheat is determined by three main components: spike density, grains per spike and individual grain weight. The timing and duration of development phases in wheat is directly related to the formation of specific grain yield components and overall grain yield. During early vegetative development, leaves and tillers are initiated (spike density), prior to the transition to the reproductive stage, when spikelet development commences. Spike growth and differentiation continues in conjunction with stem elongation up until flowering (grains per spike). After flowering, and during the grain filling phase, the embryo develops, producing a viable seed; this coincides with the establishment of grain weight.

Phasic development in wheat is primarily controlled through varied responses to vernalisation (*Vrn*) and photoperiod (*Ppd*) genes. Generally, accumulated temperature accelerates development of all phases, whilst there is an additional effect of vernalisation in some genotypes. Genotypes responsive to vernalisation require a period of cold temperatures to progress from vegetative to reproductive development. Vernalisation accumulates most rapidly in the range 3-10°C, but can accumulate at a slower rate up to 17°C. The direct influence of vernalisation is to alter the length of the vegetative phase, however it can also indirectly affect the duration of subsequent phases. Wheat is a long-day plant; therefore the rate of development is increased with longer day-lengths. However, individual genotypes of current commercial varieties have varying levels of responsiveness to photoperiod, and a large number of Australian cultivars are insensitive to photoperiod. In photoperiod sensitive genotypes, short-day (SD) conditions prolong the vegetative phase and delay the transition to reproductive development, whilst long-day (LD) conditions decrease time to reproductive phases. Flowering time is generally regulated by *Vrn* and *Ppd* genes; there is also an additional effect of a third level of genes, the earliness *per se* (*Eps*) genes. These have been identified as having a fine-tuning effect on flowering time, though these are less associated with regional adaptation of genotypes.

2017 results

In 2017, field experiments were conducted across eight sites in the NGR, in central and southern QLD, northern NSW and southern NSW. This paper presents results from five sites: Wagga Wagga, Trangie, Edgeroi, Wellcamp and Emerald. A range of genotypes with varied development (and with different combinations of *Vrn* and *Ppd* genes) were sown across from late April to late May, with an additional early April sowing at the Wagga Wagga site.

The optimum genotype and sowing date combination for achieving maximum grain yield varied significantly across the five sites (Figure 1). Optimal flowering time was substantially earlier and spanned longer in the northern sites compared to the Wagga Wagga site in southern NSW. In 2017, grain yields were maximised when the sowing date x genotype combinations flowered mid-late July at Emerald, late August-mid September at Wellcamp, mid-late August at Edgeroi and Trangie and early October at Wagga Wagga.

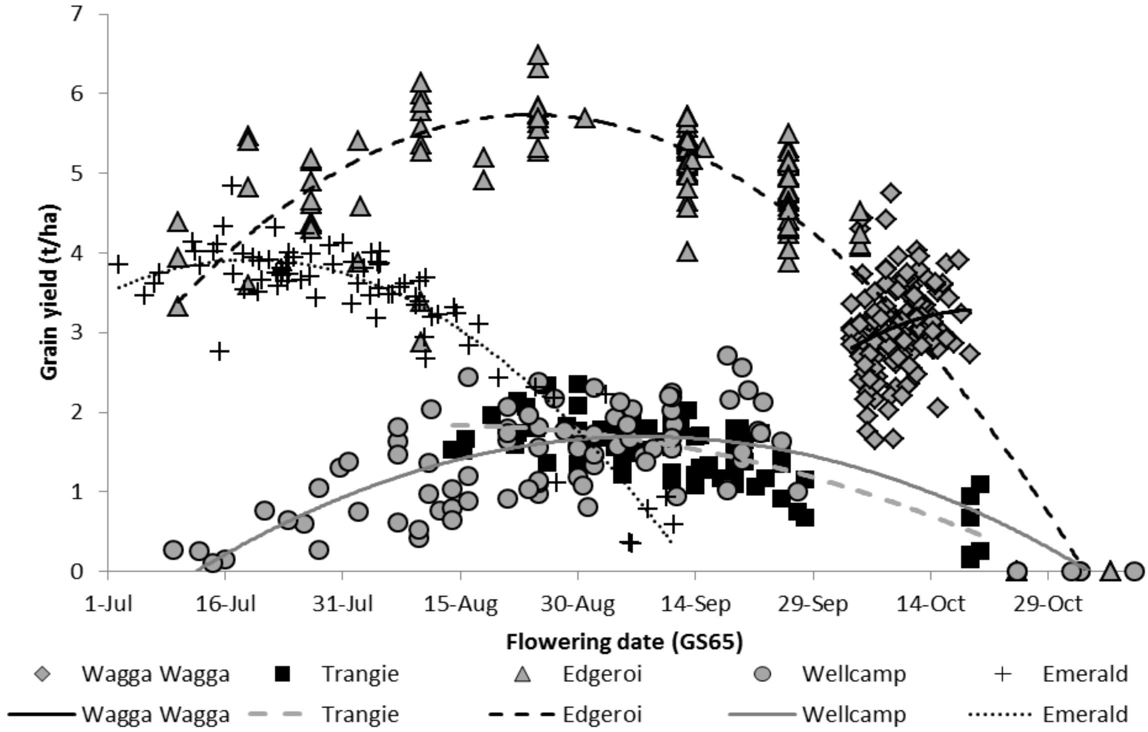

Figure 1. Relationship between flowering date and grain yield of genotypes across sowing dates at five sites in 2017.

Wagga Wagga site

The flowering window at Wagga Wagga was directly influenced by early stem frost damage in 2017. This resulted in significant tiller death and late regrowth of tillers in faster developing genotypes, consequently affecting uniformity of maturity in plots. Flowering dates are expressed as 50% of emerged spikes with visible anthers, as such many of the recorded flowering dates reflect later tillers and do not account for early tiller losses. Faster developing genotypes had lower tiller survival (proportion of tillers which produced a spike) at early sowing dates, whilst the slower developing genotypes, which remained vegetative for longer, were exposed to less frost events and were able to maintain tillers and stabilise flowering time.

Trangie site

The grain yield responses to flowering time at the Trangie site were largely influenced by below average rainfall, recording the driest growing season (April to September) in 2017 (Decile 1). In this warmer environment, winter genotypes flowered much later than the optimal flowering window, as a result yield was severely penalised (EGA_Wedgetail⊕) or not attained (Manning⊕ and RGT Accroc⊕).

Edgeroi site

The optimal flowering window at Edgeroi, as determined by grain yield response in 2017 (Figure 1), was broadly representative of this environment, highlighting the potential for frost risk whilst also underlining the impact of heat and moisture stress. In 2017, this was determined by a combination of abiotic stresses, including frost in August and early September, below average growing season rainfall April to October (195 mm) and temperatures ≥ 30°C in mid-late September. Consequently, the highest yields were achieved by combinations of sowing date x genotype which flowered during this optimal flowering window. The winter types with strong vernalisation responses, for example

Manning⦶, did not flower until late October, even when sown early, which was too late to achieve grain fill in this environment.

Wellcamp site

The optimal flowering window identified for Wellcamp (Figure 1), was generally representative of this environment. In 2017, the site was particularly influenced by cooler temperatures and significant frost events in July-September, and high temperatures throughout the flowering window. Grain yield was also influenced by a hail storm on 24 October, just prior to harvest. Generally, wheat is sown from late May to June for the Inner Downs region, due to increased risk of frost damage, and later onset of heat risk.

Emerald site

The flowering response observed at the Emerald site in 2017(Figure 1) was generally representative of the sowing dates in that environment. The optimal flowering window at Emerald is largely driven by high risk of heat stress August onwards, rather than early frost risk in most seasons. The winter genotypes such as RGT Accroc⦶, Manning⦶, EGA Wedgetail⦶ and Longsword⦶ did not achieve harvestable yield across any of the sowing dates, whilst some slower developing genotypes, such as LongReach Kittyhawk⦶, Sunlamb⦶, Sunmax⦶ and EGA Eaglehawk⦶ did measure grain yield, the Emerald environment favoured mid-fast spring genotypes which flowered within the optimal flowering window and attained the highest grain yields in 2017.

Preliminary results from 2017 indicate some variation in pre-flowering development phases of genotypes with respect to environment and sowing time across the experimental locations in the NGR (Figures 2 and 3). This may have implications to the variation in the flowering grain yield responses in Figure 1, as well as information regarding suitable phenology drivers for different environments. For example, at the Emerald site, winter type EGA Wedgetail⦶ was unable to saturate its vernalisation requirement to progress from the vegetative stage in the first sowing time (TOS1). Start of stem elongation (GS30) was recorded in TOS3 and for 2 of 3 replicates in TOS2 (Figure 2). In contrast, the extended vegetative phase of EGA Wedgetail⦶ at the Wagga Wagga site enabled a level of frost damage avoidance during the stem elongation phase, and recorded consistent flowering dates across sowing dates within the optimum flowering window.

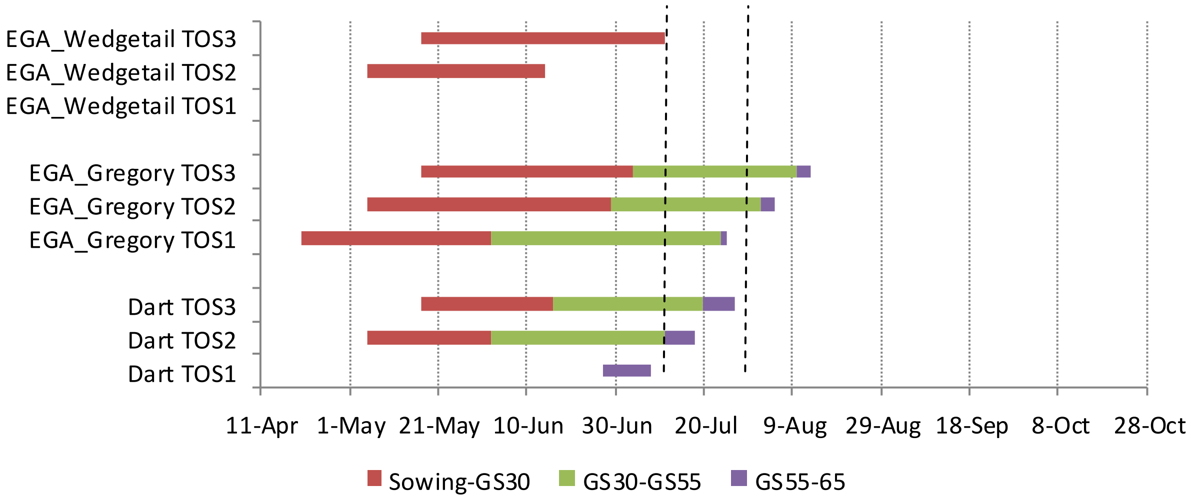

Figure 2. Phasic development in response to sowing time of Dart⦶, EGA Gregory⦶ and EGA Wedgetail⦶ at ***Emerald***. Phase durations measured from sowing to start of stem elongation (GS30), ear emergence (GS55) and anthesis (GS65). Sowing dates: 20 April (TOS1); 5 May (TOS2) and 17 May (TOS3). Dotted lines indicate optimal flowering period in 2017.

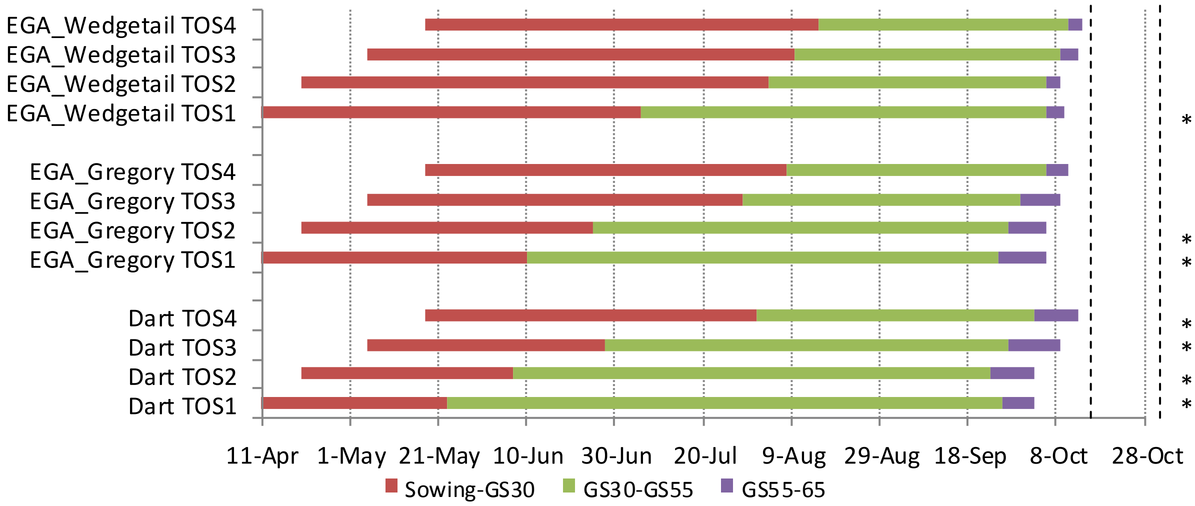

Figure 3. Phasic development in response to sowing time of Dartᶲ, EGA Gregoryᶲ and EGA Wedgetailᶲ at ***Wagga Wagga***. Phase durations measured from sowing to start of stem elongation (GS30), ear emergence (GS55) and anthesis (GS65). Sowing dates: 10 April (TOS1); 20 April (TOS2); 5 May (TOS3) and 17 May (TOS4). Dotted lines indicate optimal flowering period in 2017, asterisks indicate significant frost damage, resulting in late regrowth influencing development.

Yield responses to sowing time

There was genotypic variation in the grain yield responses to sowing time across the five sites in 2017, as indicated for the selected genotypes in Figure 4. Generally, slow developing genotypes favoured southern sites, characterised with a longer growing season and high risk of frost damage. For example, Manningᶲ (winter type with strong vernalisation response) and EGA Wedgetailᶲ (winter type) had highest yields when sown early (indicated by negative slope) at the Wagga Wagga site. However, the vernalisation requirement of these winter types did not suit the warmer environments of northern NSW and QLD, and as such they either had significant grain yield penalties or did not achieve grain yield. The northern sites favoured mid-fast developing spring genotypes sown late April to early May (indicated by negative slope); in contrast, these were better suited to the late-May sowing at Wagga Wagga (indicated by positive slope). Despite the variability across environments, and conditions in 2017, some spring genotypes such as EGA Gregoryᶲ and Suntopᶲ were able to maintain relatively stable grain yields across many sowing dates at some sites (indicated by flatter line). Whilst the general yield responses were similar for some sites, the variability in specific genotype responses across the sites suggests there are differences in suitability of genotypes across growing environments of the NGR.

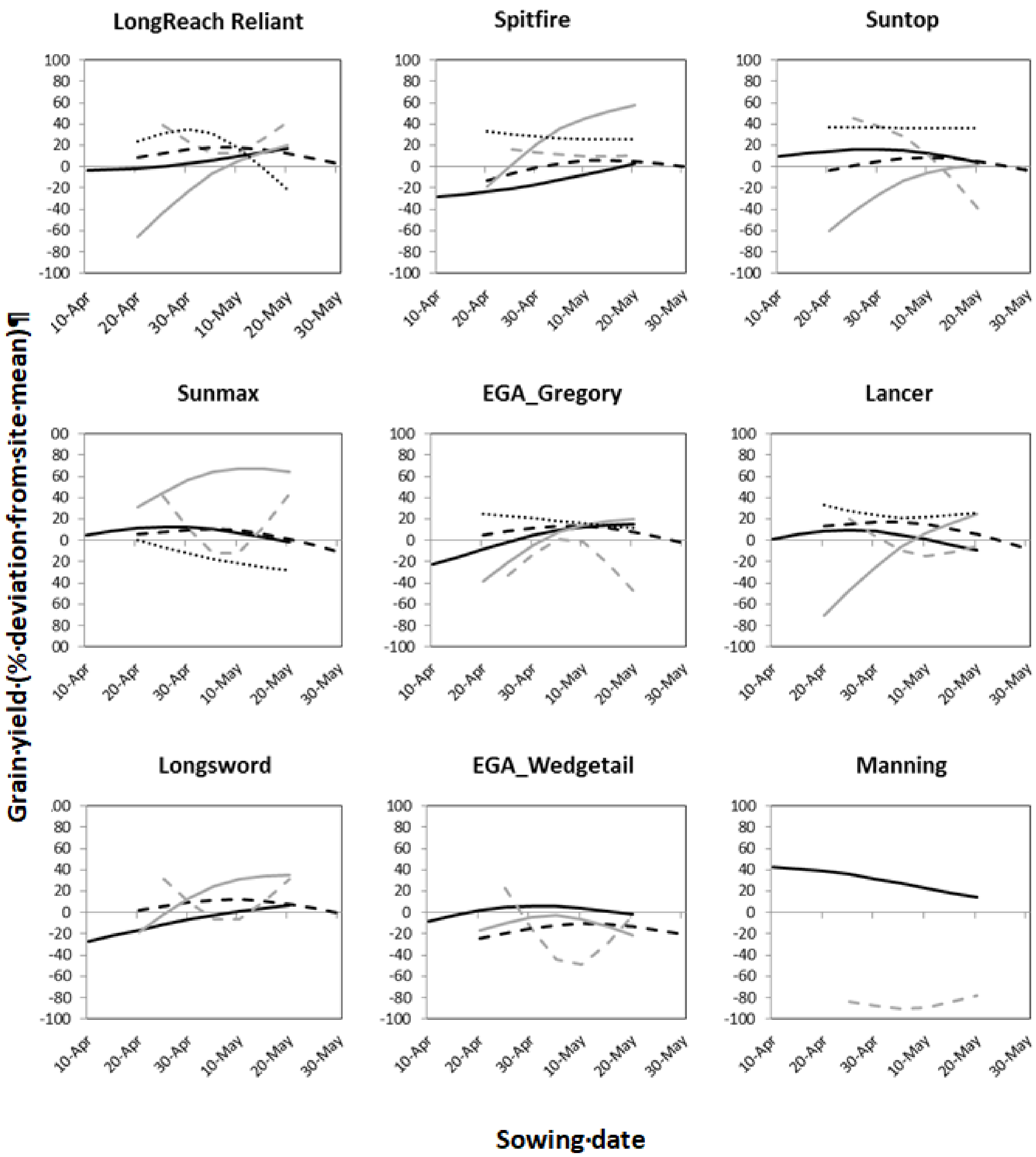

Figure 4. Grain yield response to sowing date in **2017** for selected genotypes across five sites in the Northern Grains Region (black line =Wagga Wagga; grey dash line= Trangie, black dash line= Edgeroi, grey line= Wellcamp, dotted line= Emerald). Grain yield response is presented as deviation from site mean as a percentage for each site. Site means were: Wagga Wagga – 3.07t/ha; Trangie – 1.52t/ha; Edgeroi – 4.98t/ha; Wellcamp – 1.33t/ha; Emerald – 2.93t/ha. (LongReach Relianⓓ, Spitfireⓓ, Suntopⓓ, Sunmaxⓓ, EGA_Gregoryⓓ, Lancerⓓ, Longswordⓓ, EGA_Wedgetailⓓ and Manningⓓ are protected under the Plant Breeders Rights Act 1994.)

Summary

Our data showed that genotypic variation in phenology had a significant effect on the grain yield potential of wheat varieties in response to sowing date across growing environments of the northern grains region. Genotypes varied in responses to vernalisation and photoperiod genes, which influenced early phasic development in addition to flowering time across the sites. Matching variety and sowing date to achieve an optimal flowering time for each growing environment is the most effective management strategy in minimising effects of abiotic stresses. In southern NSW, winter types can be sown early and regulate flowering to minimise effects of early frost damage and later, heat and moisture stress. However, in northern NSW and QLD, winter types are not able to saturate vernalisation requirements and the shorter growing season favours mid-fast spring types which are generally regulated by responses to photoperiod.

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The research undertaken as part of this project is made possible by the significant contributions of growers and is a co-investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP).

We acknowledge the support of NSW DPI and QDAF and their cooperation at Wagga Wagga Agricultural Institute, Tamworth Agricultural Institute, Trangie Agricultural Research Station and Emerald Agricultural College.

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

Matching phenology, environment and variety to optimise wheat yield

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Notes

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 messages

- 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.

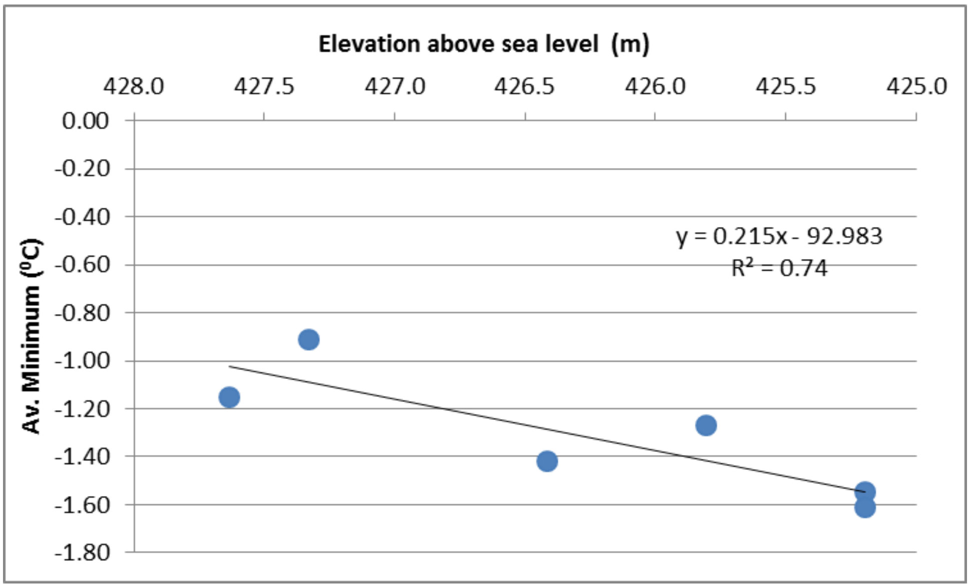

Figure 1. Effect of slope on average minimum temperature (7/7 – 8/8/2017) at ground level at the Tamworth Agricultural Institute (TAI)

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.

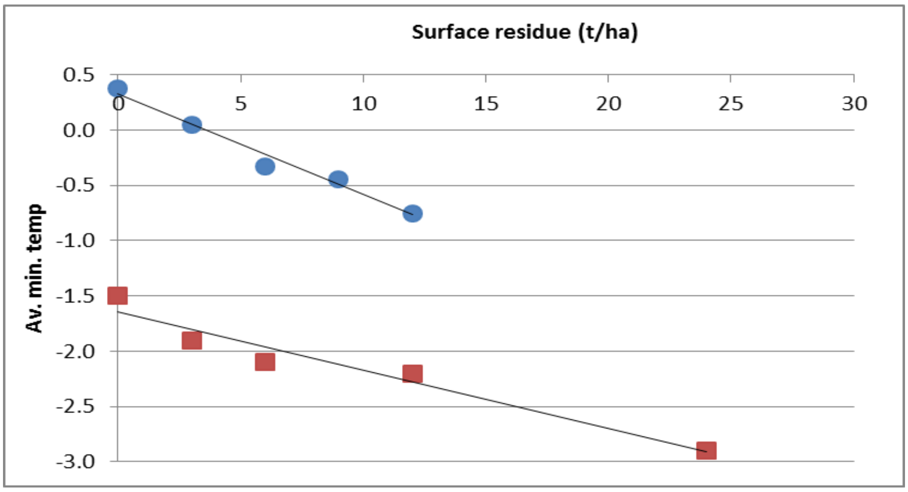

Figure 2. The effect of surface residue loading on average minimum temperature at the residue surface at Rowena (●) and TAI (■) in the chickpea crop

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.

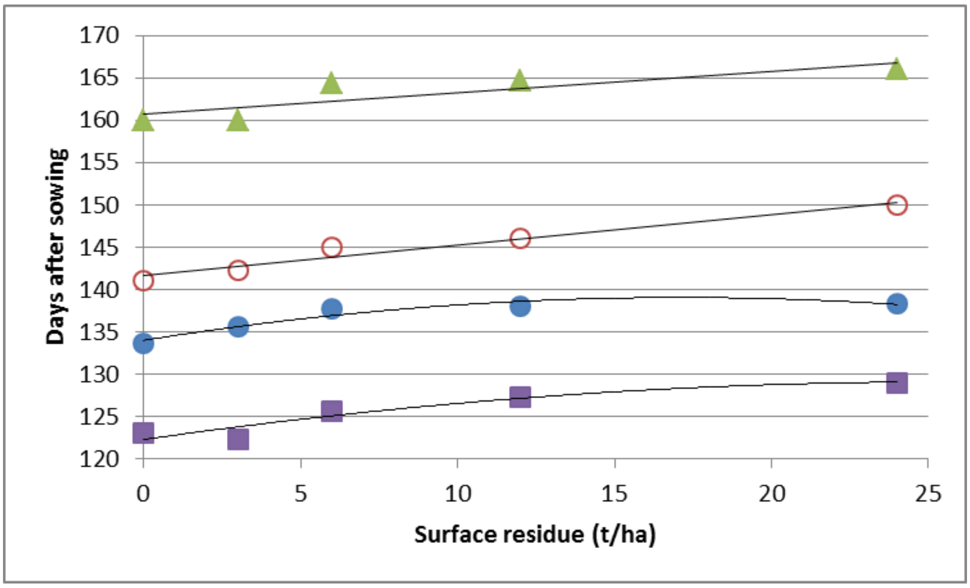

Figure 3. The effect of surface residue loading on the time taken (days after sowing) to reach 20% flower (■), 1st pod (●), 50% pod (○) and flowering cessation (Δ).

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⁽ᵈ⁾	110	126	132
Flat residue	PBA HatTrick⁽ᵈ⁾	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⦶, while the bare soil treatments led to earlier 1st podding. CICA1521, a fixed line, is substantially earlier at flowering than PBA HatTrick⦶, 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⦶.

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.

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

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Key words

chickpea, phenology, heat, chilling, prebreeding

GRDC code

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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°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°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°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.

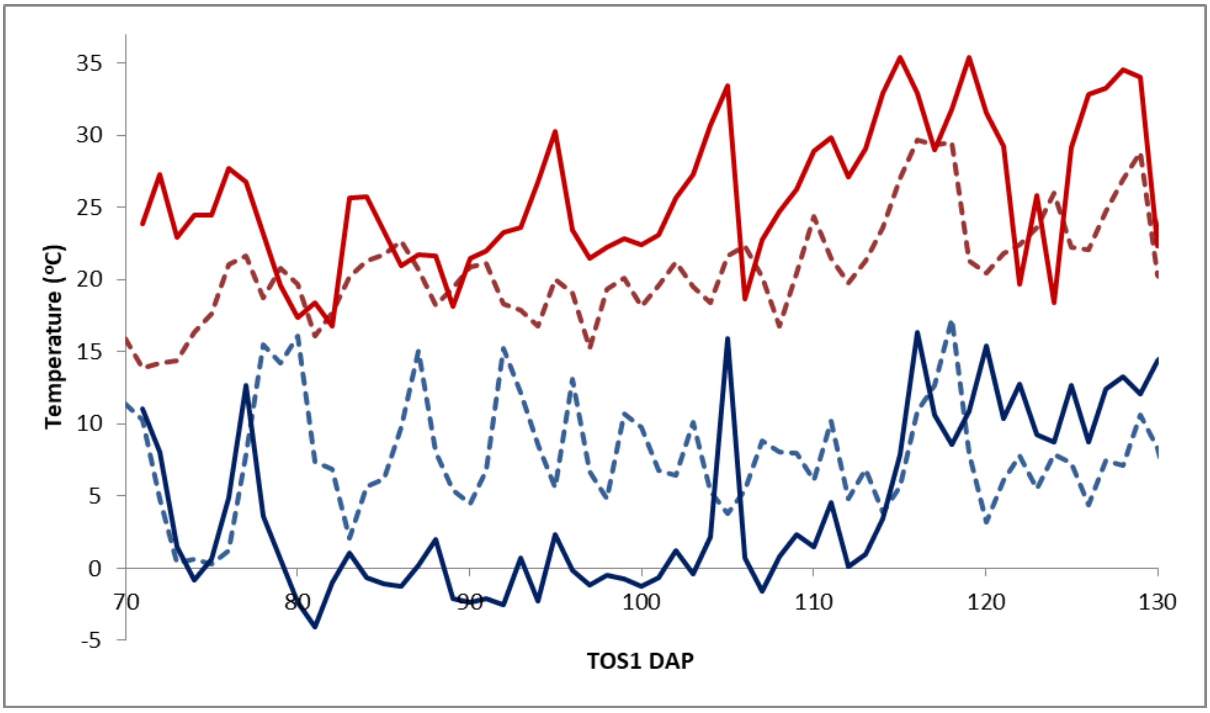

Figure 1. Temperature profiles for the two experimental seasons before and during the reproductive phase. Dotted lines = 2016 daily minimum and maximum temperatures; solid lines = 2017 daily minimum and maximum temperatures.

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.

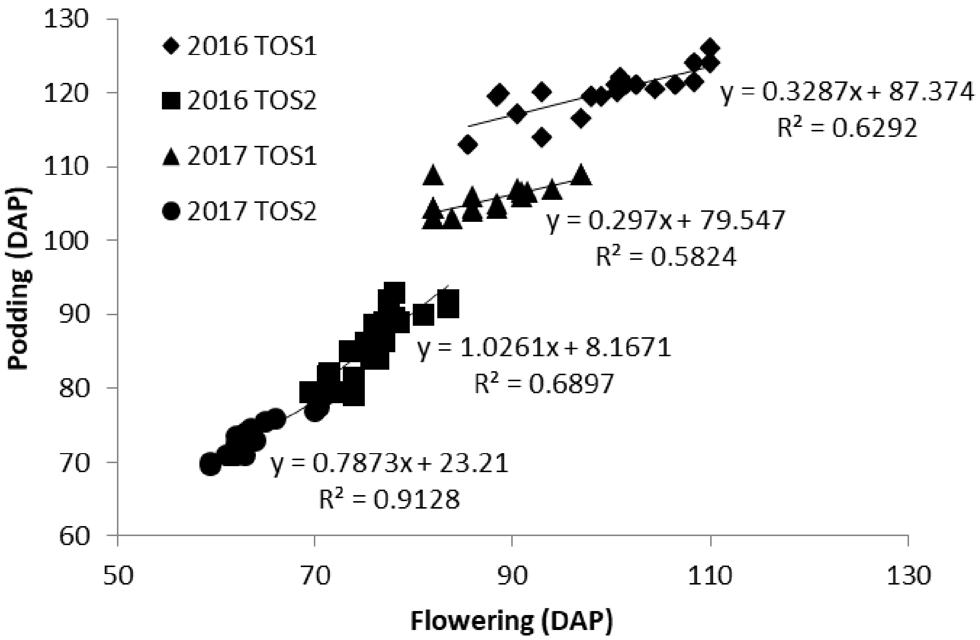

Figure 2. Correlations between the flowering and podding dates of genotypes in two contrasting seasons

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°C) 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 HatTrickᶲ	86	63	105	72	19	10
PBA Monarchᶲ	82	64	105	74	23	11
PBA Pistolᶲ	82	60	103	70	21	10
PBA Seamerᶲ	82	62	103	71	21	9
PBA Slasherᶲ	82	62	105	71	23	10
PBA Strikerᶲ	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 HatTrickᶲ and the earliest podding lines, and 7 days difference in the flower-pod interval, were observed. Podding dates of PBA Slasherᶲ and PBA HatTrickᶲ 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.

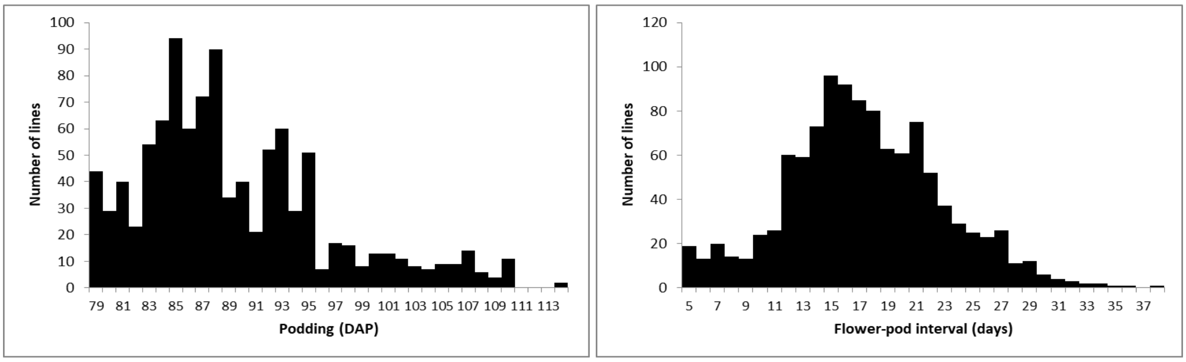

Figure 3. Histograms showing distribution of podding and flower-pod intervals amongst a range of >1000 diverse genotypes including closely related *Cicer* species and wild lines.

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.

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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

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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ⓓ, PBA Boundaryⓓ and the now released PBA Seamerⓓ (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).

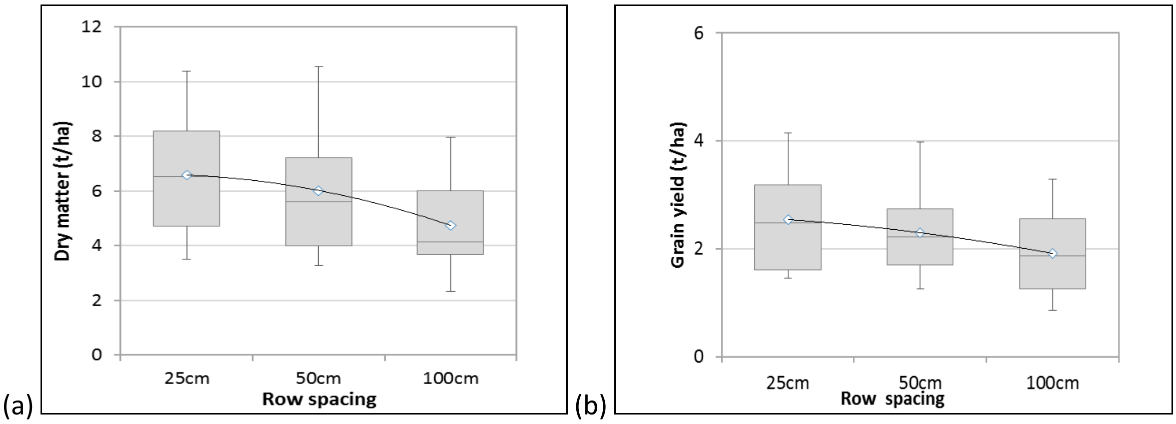

Figure 1. Summary of 12 chickpea sites from 2014 and 2015 [diamond marker indicates average across all sites and the trend line for the 3 row spacings]. (a) shows the effect of row spacing on dry matter production and (b) final grain yield. Row spacing has a larger effect on dry matter production than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

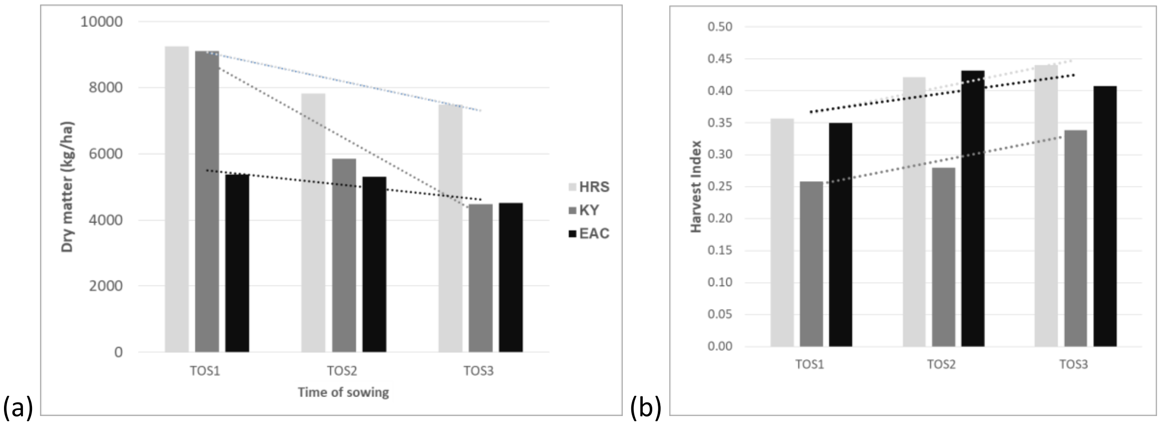

Figure 2. Time of Sowing (TOS) trials in 2015 at 3 sites; Hermitage [HRS], Kingaroy [KY] and Emerald [EAC]. All sites had a decreasing trend for dry matter production when planted later in the season (a). Harvest Index (HI) improves with later sowing dates as dry matter is reduced (b).

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.

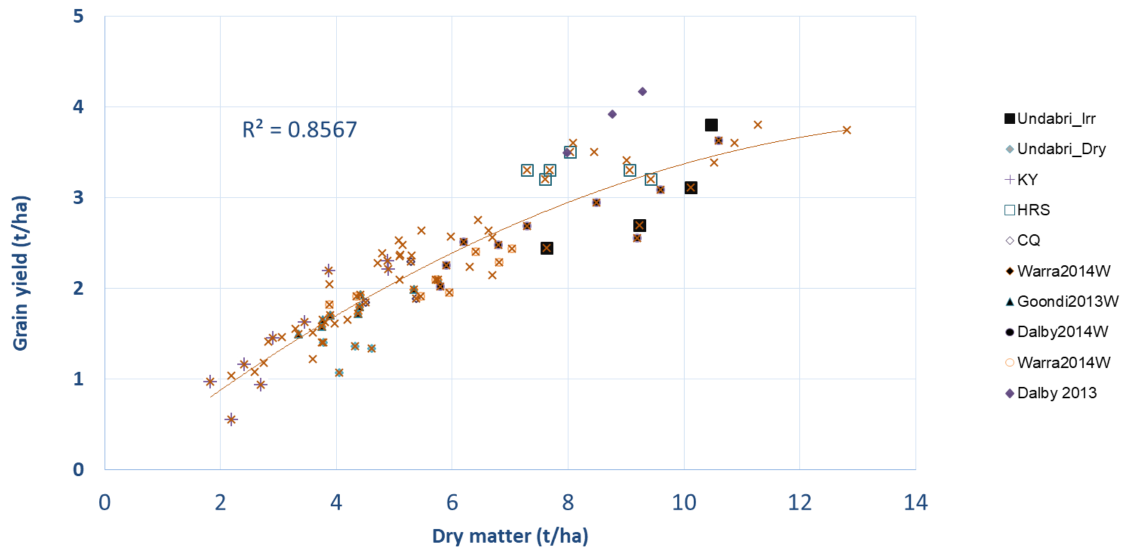

Figure 3. The relationship ship between dry matter production and grain for chickpea trials at 10 sites over 3 years

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.

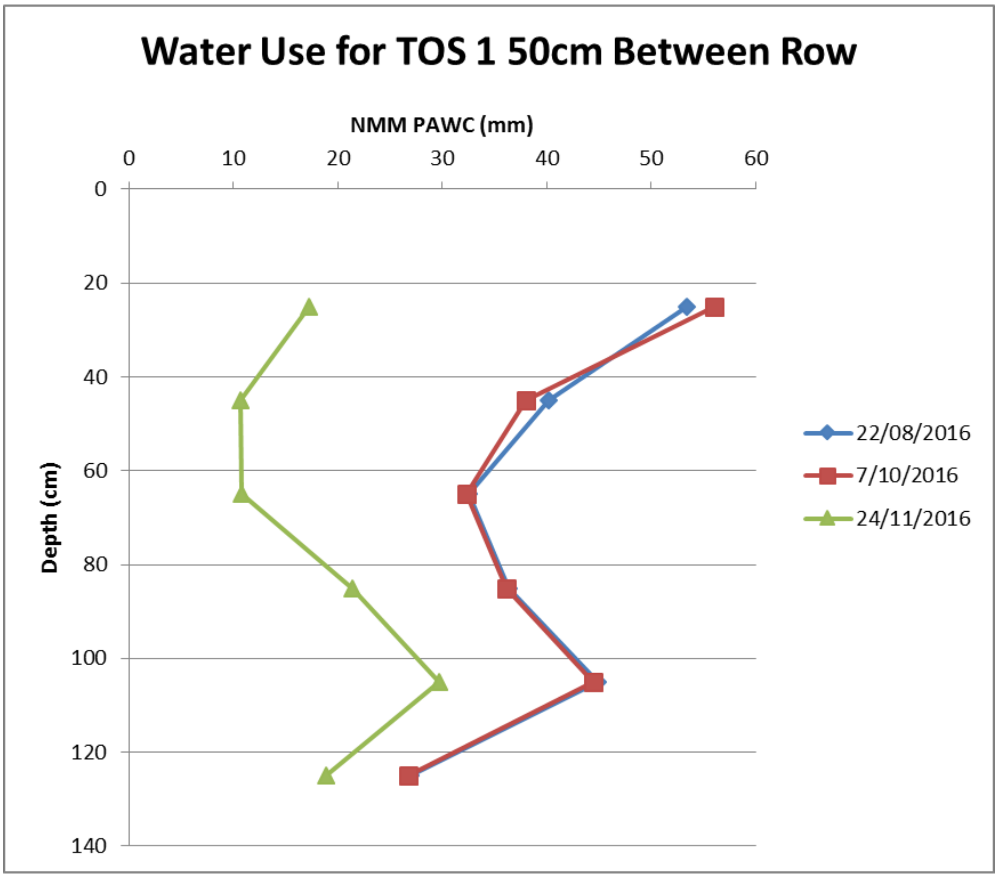

Figure 4. Soil water use as measured by neutron moisture meter at Hermitage Qld. at 3 times during the growing season. Access tube was in the middle of 2 rows planted 50 cm apart.

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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A special thanks to the generous farmer co-operators who have hosted field trials.

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Chickpeas, wheat and *Pratylenchus thornei*: build-up and decline in the farming system. Chickpeas – a combination of susceptibility and moderate tolerance

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Key words

chickpea, wheat, root-lesion nematodes, *Pratylenchus thornei*, susceptibility, intolerance, yield loss

GRDC codes

DAV00128, USQ00019, DAW00245

Call to action/take home messages

- Chickpea varieties range from moderately susceptible to susceptible to the root-lesion nematode, *Pratylenchus thornei*.
- Growing chickpeas will increase populations of *P. thornei* that will carry-over to infest following crops, however, chickpea varieties may not suffer yield loss.
- *Pratylenchus thornei* populations at the time of planting and the tolerance of a wheat variety determine the degree of yield loss at the end of the season.
- Look closely at your crop rotations or sequences and consider the impact of growing susceptible crops, such as chickpea and wheat that will increase *P. thornei* populations thereby limiting crop variety choice in future seasons.

Background: *Pratylenchus thornei* in the northern grain region and their management

The root-lesion nematode *Pratylenchus thornei* is found in soils in two-thirds of fields in the northern grain region. The nematode feeds and reproduces in the roots of plants and can cause yield loss because it reduces the ability of roots to take-up water and nutrients. Populations of the nematode build-up under susceptible crops, are able to survive fallow periods and carry-over into the next cropping season. There are no registered chemical control methods to reduce *P. thornei*. When *P. thornei* is present in fields at damaging populations (greater than 2/g soil), management relies on:

1) growing tolerant crop varieties that do not suffer yield loss, and
2) increasing the number of resistant crops in the cropping sequence to reduce populations.

When *P. thornei* populations are reduced to very low populations, crop variety choice is expanded and farm profits are maximised.

Definition of tolerance and resistance

- **Tolerance** is the ability of a plant to produce good yields in the presence of *P. thornei*. Its opposite is intolerance.
- **Resistance** is the ability of the plant to prevent nematode reproduction. Its opposite is susceptibility.

Crop varieties can be tolerant but susceptible, that is they produce good yields, but allow the nematode to increase in population. The ideal combinations for management of *P. thornei* are varieties that are tolerant AND resistant.

Resistance and tolerance of chickpea

Repeated two-year experiments to determine the tolerance and resistance of chickpea varieties were conducted at Formartin, Queensland in 2014-15 and 2015-16. In the first year of each experiment, the wheat varieties QT8343 (moderately resistant to *P. thornei*) and Kennedy⏀ (susceptible to *P. thornei*), were grown to establish low or high *P. thornei* populations in a replicated, randomised block design. In the second year of each experiment, varieties or advanced lines of chickpea, and wheat varieties with moderate resistance and susceptibility were planted following the established design. Nematode populations were determined by PreDicta®B tests at planting and at harvest in the second year of the experiment.

Before planting in the second year of the experiments, average *P. thornei* populations after growing the susceptible wheat cv. Kennedy⏀ were 14/g soil and after the resistant cv. QT8343, 5/g soil. In the second experiment, populations were 29/g after cv. Kennedy⏀ and 7/g soil after QT8343.

Tolerance or yield loss

Average yield across all chickpea varieties was reduced by 6.5% when grown on the high *P. thornei* populations compared to the low populations (*P*=0.05), however, no differences in yield loss were detected between varieties. Average yield for chickpea varieties on the low *P. thornei* populations was 2.77 t/ha and 2.59 t/ha after the high *P. thornei* populations.

The take home message from these experiments is that chickpea varieties are generally moderately tolerant to *P. thornei*.

Resistance or nematode reproduction in chickpea

Populations of *P. thornei* increased after growing chickpea varieties compared to the initial *P. thornei* populations present at planting (Pi) which was 7/g soil averaged over both experiments (Figure 1).

Pratylenchus thornei populations at harvest ranged from 8/g soil for cv. PBA HatTrick⏀ to 28/g soil for cv. Kyabra⏀ (Figure 1). Populations were significantly greater (*P*=0.05) than wheat cv. QT8343 after chickpea cvs CICA0709, PBA Seamer⏀, PBA Boundary⏀, CICA1313, CICA1007 and Kyabra⏀. Populations increased by 1.2 to 4.3 times compared to the moderately resistant wheat control. In contrast, for the very susceptible wheat control cv. Strzelecki⏀, populations at harvest were 67/g soil, or a 10-fold increase compared to the moderately resistant wheat control.

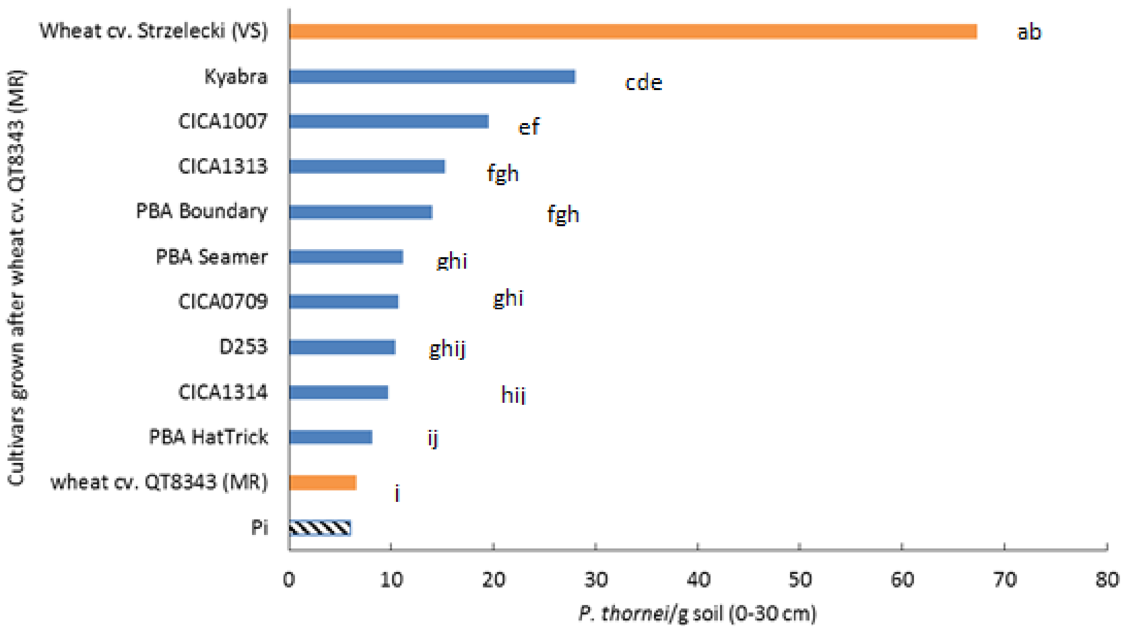

Figure 1. Populations of *Pratylenchus thornei*/g soil at 0–30 cm soil depth after harvest of chickpea varieties compared to wheat cv. QT8343 (moderately resistant) and wheat cv. Strzelecki⦶ (very susceptible). Initial *P. thornei* populations at planting are shown by the hashed bar. Results from combined experiments from two seasons. Bars followed by the same letter are not significantly different (*P*=0.05). (Strzelecki⦶, Kyabra⦶, PBA Boundary⦶, PBA Seamer⦶ and PBA HatTrick⦶ are protected under the Plant Breeders Rights Act 1994.)

Take home message on chickpeas and P. thornei

Chickpeas generally have a good level of tolerance to *P. thornei* but because most chickpea varieties are susceptible to *P. thornei*, populations of the nematode will increase to attack future crops. Consider the impact of growing chickpeas in your crop sequences if you are trying to reduce *P. thornei* populations or keep them at low levels.

Wheat yield loss response curves

Several two-year field experiments to determine the impact of increasing *P. thornei* populations on the yield of wheat varieties that range from intolerant to tolerant have been conducted in Queensland at Formartin and Westmar. This paper reports results from 2017 at Westmar in a very dry season.

In the first year of the experiment, four varieties of wheat that ranged from resistant to susceptible to *P. thornei* were planted to establish a range of *P. thornei* populations. The design was a randomised complete block with four replicates. In the second year before planting, soil samples were collected from each plot (at 0–30 cm) and *P. thornei* populations determined by PreDicta®B. Then, six wheat varieties were planted so that each variety was exposed to a range of *P. thornei* populations (Table 1).

Table 1. Wheat varieties grown in the second year of the experiment at Westmar, Queensland, the range of *P. thornei* populations for each variety before planting and yield loss during that season

Variety	Tolerance[a]	*P. thornei*/g soil at planting		Max. yield loss[b]
		Min.	Max.	%
Suntop⟑	MT-T	0.7	29.4	ND[c]
EGA Gregory⟑	MT-T	0.6	28.5	13
LongReach Spitfire⟑	MT-MI	0.4	24.1	23
Lang⟑	MI	1.1	20.4	59
LongReach Lincoln⟑	I	1.0	28.0	81
Strzelecki⟑	I-VI	1.2	19.2	64

[a]MT-T, moderately tolerant-tolerant, MT-MI, moderately tolerant-moderately intolerant; MI, moderately intolerant; I, intolerant; I-VI, Intolerant-very intolerant. Ratings from nvtonline 2018.

[b]Yield loss was calculated for the minimum and maximum *P. thornei* at planting from the yield response curves for each variety (Figure 2).

[c]ND, none detected.

Results from Westmar

Despite the dry seasonal conditions which restricted yield potential of each variety, there was a significant ($P<0.001$) negative relationship between yield of each wheat variety and *P. thornei* populations at planting except for Suntop⟑ (Figure 2).

Suntop⟑ was the highest yielding variety (average 1.5 t/ha) and its yield did not change in response to increasing *P. thornei* populations. This is an interesting result because Suntop⟑ has a higher level of resistance than EGA Gregory⟑ which is moderately susceptible to *P. thornei* but both have a similar tolerance rating.

Yield loss at the maximum *P. thornei* population compared to the lowest population for other varieties ranged from 13% for EGA Gregory⟑ to 81% for LongReach Lincoln⟑ (Table 1). The rate of yield loss was greatest at low initial *P. thornei* populations for intolerant varieties such as LongReach Sptifire⟑, Lang⟑, Strzelecki⟑ and LongReach Lincoln⟑ (Figure 2).

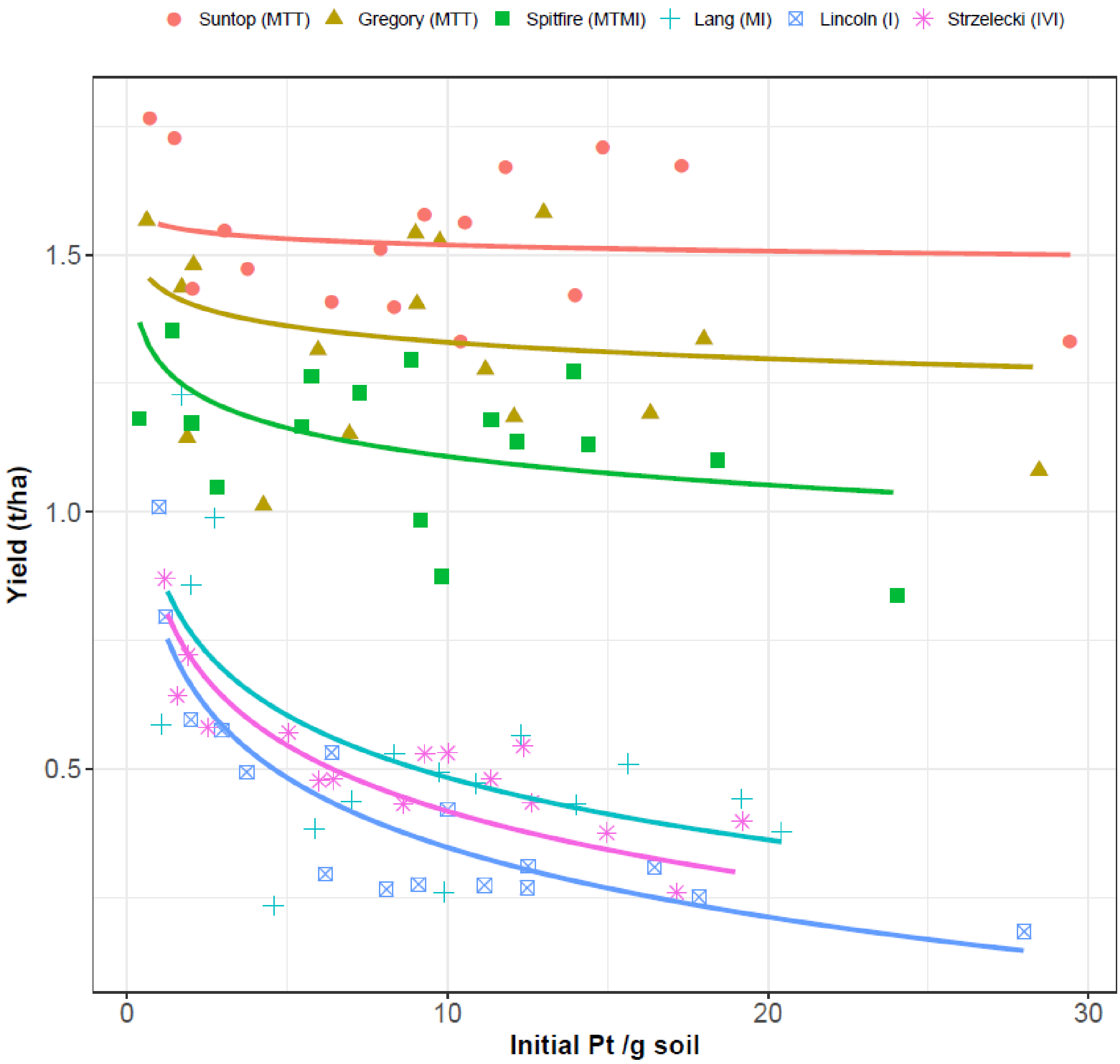

Figure 2. The yield response of six wheat varieties to *P. thornei* populations present at planting (Initial Pt/g soil at 0-30 cm soil depth; backtransformed) at Westmar, Queensland in 2017. There was a significant yield response of each variety to *P. thornei* populations at planting, except for Suntop⏀ to the (P<0.001). Figure provided by Karyn Reeves, Curtin University. (Suntop⏀, Gregory⏀, Spitfire⏀, Lang⏀, Lincoln⏀ and Strzelecki⏀ are protected under the Plant Breeders Rights Act 1994.)

The take home message on yield response of wheat to P. thornei

Low *P. thornei* populations will maximise profits from wheat production and expand variety choice. Avoid intolerant wheat varieties when *P. thornei* populations are at damaging populations, but be aware that even moderately tolerant varieties may suffer yield loss.

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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 authors would like to thank them for their continued support.

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DAW00245, nematode module, is led by Dr Grant Hollaway (AgVic) and statistical support provided by Dr Karyn Reeves (SAGI-West, Curtin University).

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What's new in grain storage? – ProFume® fumigations, fumigating large silos and grain protectant update

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Key words

grain fumigation, ProFume®, sulfuryl fluoride, storage pest control, large silo fumigation, fumigation recirculation, grain protectant insecticides

GRDC codes

PRB00001, PBCRC3036, PBCRC3150

Call to action/take home message

- ProFume® (sulfuryl fluoride gas) applied by licenced fumigators to control storage pests in cereal grains, is valuable when rotated with phosphine fumigations to manage insect pest resistance.
- ProFume trials show that longer fumigation times of 7-10 days are required to control the full life cycle of storage pest insects when grain temperatures are below 25°C.
- In larger silos (150 – 2000 t) recirculating fumigation gases within the sealed silo using a small fan, helps ensures rapid, uniform distribution of phosphine, or ProFume (sulfuryl fluoride gas).
- Without recirculation during fumigation, it can take 2-5 days before the fumigant gas reaches all areas in a large silo, resulting in significant volumes of grain and insect pests being exposed to low amounts of gas.
- Seek good advice prior to applying any grain protectant treatment. Set up grain protectant spray application equipment to achieve good coverage and the correct dose rate.

Key storage management tools

Fumigations and strategic use of grain protectant insecticides are only two of the five key tools used to maintain grain quality and achieve reliable pest control results. Combined, they form the foundation of successful grain storage. Successful grain storage is crucial to a producer building a reputation as a reliable supplier of quality grain. Key aspects of successful grain storage are:

1. **Aeration**: correctly designed and managed, it provides cool grain temperatures and uniform grain moisture conditions. Aeration reduces problems with moulds and insect pests in storage, plus maintains grain quality attributes such as germination, pulse seed colour, oil quality and flour quality.
2. **Hygiene**: a good standard of storage facility hygiene is crucial in keeping background pest numbers to a minimum and reducing the risk of grain contamination.
3. **Monitoring**: monthly checking of grain in storage for insect pests (sieving / trapping) as well as checking grain quality and temperature. Keep a monthly storage record to record these details, including any grain treatments applied.
4. **Fumigation**: in Australia we now only have gases (fumigation) to deal with insect pest infestations in stored grain. To achieve effective fumigations the storage/silo must be sealable – gas-tight (AS2628) to hold the gas concentration for the required time.
5. **Grain protectants**: used on specific parcels of grain like planting seed held on farm, or bulk grain where potential grain buyers have agreed to its use, grain protectant sprays provide another line of defence against storage pests.

ProFume use in Australia

ProFume (sulfuryl fluoride gas) has only been available for use in Australia for a relatively short time (10 years). Phosphine fumigation products have been used to control grain pests for well over 50 years.

Initially registered and sold in Australia by Dow AgroSciences™, ProFume is now manufactured and supplied by Douglas Products™ based in America. A-Gas Rural® based in South Australia has the importing and distribution rights for ProFume. They also provide specialist product and safety training to licenced fumigators, allowing them to purchase and undertake ProFume fumigations.

One of the main drivers for use of ProFume is the continued development of phosphine resistance in storage pests over the past 30 plus years in Australia. Thankfully, for most grain producers, the current levels of phosphine resistance for most storage pest species still allows for complete control when fumigating in correctly sealed, gas-tight silos and when used as specified on the product label.

About 10 years ago one of the flat grain beetle species, known as the rusty grain beetle *(Cryptolestes ferrugineus)* developed a very high level of phosphine resistance at a number of eastern Australian sites. To control infestations of strongly resistant rusty grain beetles, most bulk handlers and a number of farm storage sites have been able to utilise ProFume.

Figure 1. Flat grain beetles, *Cryptolestes spp.*

When should I consider using ProFume?

- Phosphine fumigation failure. If live flat grain beetles *(Cryptolestes spp)* are found in grain after a well mananaged fumigation, consider using a ProFume fumigation.
- Fumigation resistance management. As for most Ag chemical use, aim for a rotation of products and active ingrediants to combat pests. If phosphine fumigations are often used for pest control at your grain storage facilities, consider a plan to use ProFume® every third year in rotation with phosphine.

Figure 2. ProFume

Key features of ProFume

- ProFume active ingredient is 998 g/kg sulfuryl fluoride. Each gas cylinder holds 56.7 kg.
- Only licenced fumigators with ProFume training can purchase and apply ProFume.
- Registered for use on cereal grains, NOT pulses or oilseeds.
- Requires a gas-tight (sealable silo) storage to hold the specified gas concentrations for the required time.
- Bulk grain treatment costs range from approx. $2-4/t excluding GST, depending on tonnage and travel.
- The 'eggs' of storage pests are usually the hardest life cycle stage to kill with ProFume. Longer fumigation times are required.
- Cooler grain temperatures below 25°C, typical for aerated grain, also require longer fumigation times.
- Fumigation time and grain temperature have the largest impact on successful pest control results with ProFume(see Figure 3).

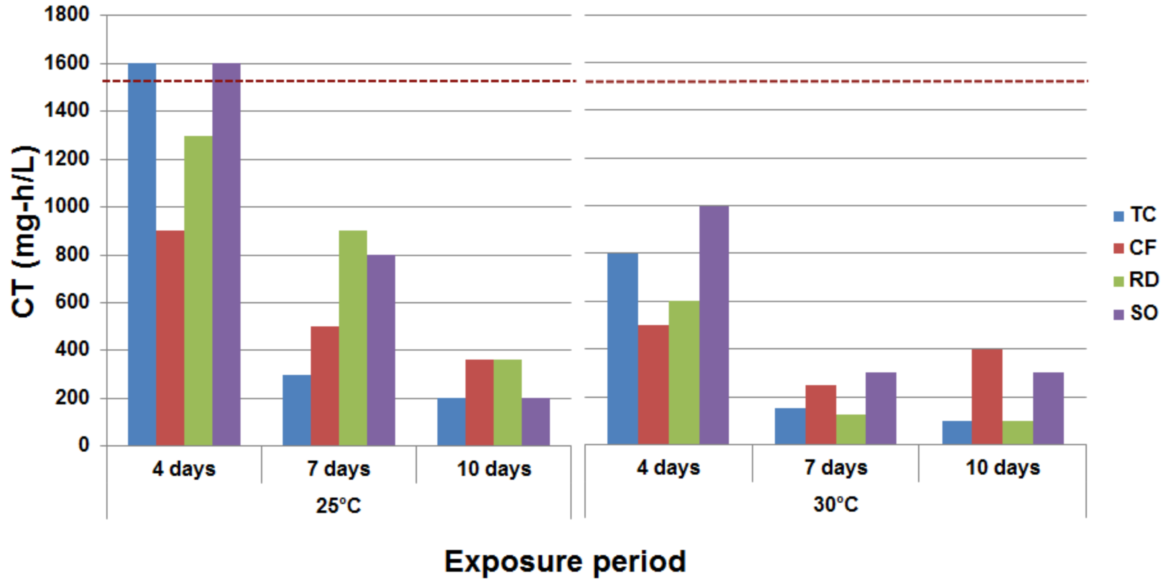

Figure 3. ProFume gas concentrations and time required at 25 and 30°C for complete control of the rust-red flour beetle (TC), rusty grain beetle (CF), lesser grain borer (RD) and rice weevil (SO) (Red dotted line is the 1500 CT limit for grain application)

Achieving reliable results and practical steps for ProFume fumigation

- Use only in gas-tight silos and storages. Pressure test silo, repair any leakage points.
- Avoid last minute, rushed 'short' fumigations. Longer fumigation times in a well-sealed storage provide effective pest control to all life cycle stages including the egg stage.
- Grain at temperatures below 25°C, fumigation times of 7-10 days would be recommended for effective pest control (see Figure 3).
- ProFume (sulfuryl fluoride) is a 'heavy' gas. Its' vapour density = 3.7 (air = 1). ProFume gas is typically applied into the top headspace of a silo. Discuss placement of a sealable fitting at the top of your silo with your licenced fumigator in preparation for fumigation.
- Recent field trials suggest that due to ProFume vapour density, there may be significant benefits to using recirculation during fumigation. This can reduce the tendency for this 'heavy gas' to fall and sit at much higher concentrations at the bottom of the silo or storage, leaving insects at the top exposed to much lower concentrations during fumigation.
- Follow all safety requirements as outlined by the licenced fumigator, including leaving fumigation warning signs and safety tape barriers in place. Aeration fans if fitted on storages simplify the venting requirements following fumigation. After venting and prior to grain movement, fumigators will test gas safety levels and 'clear' the grain. Keep copies of fumigation documentation.

Fumigation of larger silos (150 - 2000 t or greater)

The first step – ensure "gas-tight storage"

To control live insect pests in grain the only registered products in Australia are now a range of gases. Most often various phosphine fumigation products, and sometimes sulfuryl fluoride gas (ProFume). The controlled atmosphere method is also effective, using either carbon dioxide or nitrogen gas, but is mostly used for pest control in organic grains.

For any fumigation to be effective at controlling storage pests, the insects need to be exposed to a given gas concentration "C", for a specified length of time "T". If this "C x T" exposure requirement is not met during the fumigation, it is common to see survival of various insect life cycle stages. With these fumigation failures, live insect pests quickly appear in the grain within days or weeks.

This is why it is critical for Australian grain producers who store grain for more than a month, to have at least two or more sealable, gas-tight storages that meet the Australian silo sealing standard (AS2628).

A storage that is not gas-tight does not allow the fumigation "C x T" exposure level to be reached in all parts of a silo, large or small. Achieving reliable pest control results is not possible with gas leakage and air dilution. As well as not killing the pests, selection and development of resistant insect populations is the additional negative outcome of poor fumigation attempts.

To achieve effective fumigations, silos must be pressure tested to check they are sealed – gas-tight. This ensures they hold high gas concentrations for the required time to kill pests.

Checking a large silo is ready for fumigation – useful equipment for pressure testing

- Portable leaf blower, or small aeration fan, used to add air to silo for pressure tests. High volume, low pressure air is required. Standard air compressors are generally not suited to this task.
- 50 mm poly fitting, including a 50 mm shut-off value, fitted into external section of silo aeration ducting. Using this port to blow air into silo.
- Plastic tube manometer, or better, a digital manometer (e.g. Extech HD 755 Differential pressure manometer 0 – 0.5 psi). Aiming to measure within the range of 0-4 inches water gauge (w.g.) (0-1000 Pa).
- Spray bottle containing water & detergent, to check for leaks. Often you can hear or feel air leaks from large silos during the pressure test.

Pressure test – methods

New silos should be pressure tested by the silo supplier or manufacturer when completed on site. They should pass the Australian standard test (AS2628) to show they are sealable to a standard to allow for effective fumigations.

Sealable silos should then be pressure tested at least once a year to check for suitability for fumigations. Ideally pressure test when a silo is full of grain. This places grain pressure on all silo surfaces and outlets, which is the condition the silo is in when you are fumigating.

Pressure tests should not be conducted in the heat of the day, when the sun is heating the silo's external steel surfaces and warming / expanding the air inside the silo. The pressure test results under these conditions are meaningless. Ideally test in the early morning before the silo is being warmed. A windy day is also difficult, as silo surfaces are pushed around. Hook up the digital manometer, or plastic tube manometer to the silo when the silo is fully sealed. This will quickly show if pressures inside the silo are stable. If stable, a reliable pressure test can be conducted to test the silo seal quality and for any leakage points.

For small silos the pressure tests can be carried out by using a short burst (5 – 15 seconds) from the small aeration fan fitted to the silo. For larger silos a portable leaf blower to push air into the silo via a fitted 50 mm port can be used to initially pressurise the silo for a test. The pressure decay (250-125 Pa) can be checked using one of three options - the silo's oil bath relief valves, a length of 20 mm clear plastic tube in a "U" shape with water in it (manometer), or a digital manometer connected to the silo. See GRDC Fact Sheet: "Pressure testing sealable silos". http://storedgrain.com.au/pressure-testing/

Common leakage points for large sealable silos

- Silo roof vents not sealing – maintenance or design problems.
- Silo grain fill point at top of silo not sealing – damaged rubber seals on lid, or sealing plate.
- Grain outload auger at base of silo – leaking seal plate.
- Bottom silo access manhole into silo - damaged seals, or poor design.
- Sealing plate covers for the aeration fan's intake, often poor design.
- External aeration fan ducting, or the aeration fan itself not well sealed.
- For all cone based silos, weight of grain in the silo can break the seal of the bottom outlet – poor design.

Fumigation recirculation – why is it important for fumigation of larger silos > 150 t

During fumigation, phosphine gas is typically liberated over 5-6 days from tablets or blankets that have been placed in the silo. This gas however only moves slowly, taking about 24 hours to travel 6m through grain.

If you are fumigating a medium to large silo (150 – 2000 t) the gas may take 2-5 days to reach all parts of the silo. In large silo fumigations this may result in some grain, at the furthest distance from tablets, only getting 6 days of phosphine gas instead of the required 10 days or longer exposure period. Six days is not enough time to kill all the life cycle stages of the pests.

One example of a typical phosphine fumigation required to kill all pests, is a minimum of 200 ppm phosphine gas concentration for at least 10 days. See horizontal blue line in Figure 4 below.

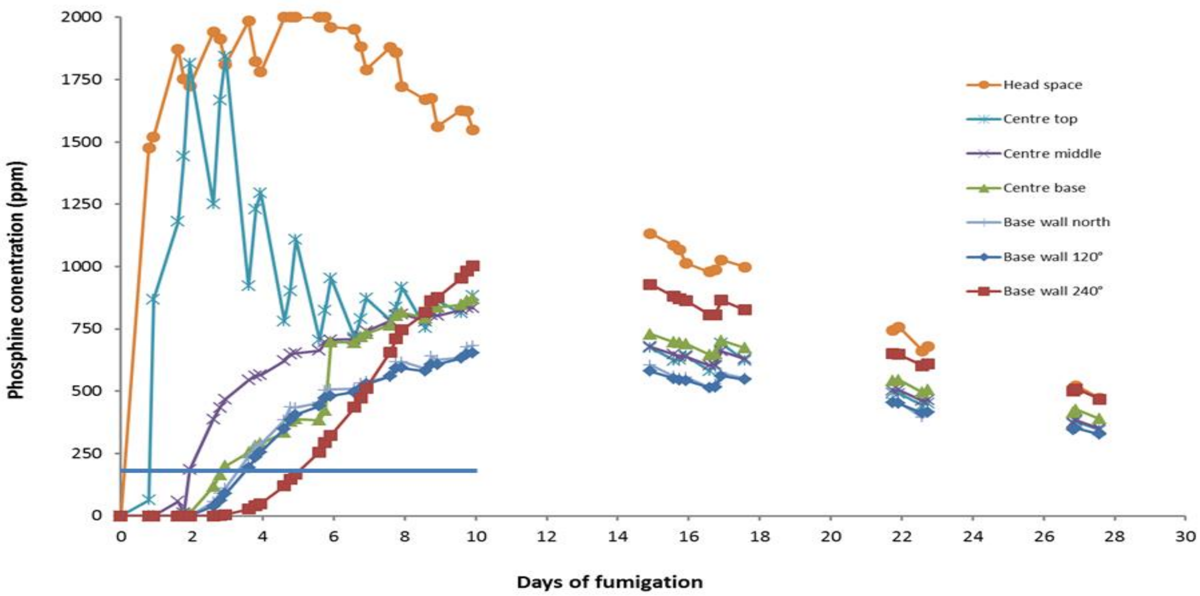

Figure 4. Phosphine gas concentrations at 7 points in a silo during fumigation of 1420 t of wheat. Phosphine blankets were placed in the silo headspace with no recirculation. It took as long as 5 days for all grain at the silo base to reached at least 200 ppm gas concentration.

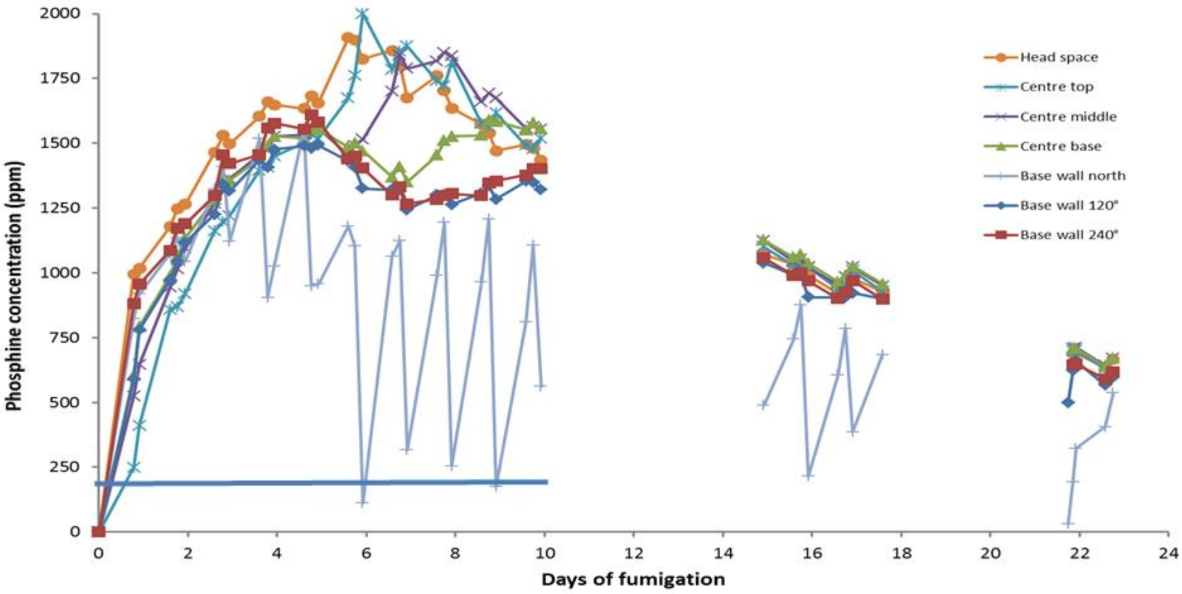

Figure 5. Phosphine gas concentations in a silo (1420 t wheat) where a small fan was used to draw gas from blankets in the silo headspace and pump it into the silo base via aeration ducts for the first 5 days of fumigation. Gas concentration in all areas of the silo reached over 800 ppm within the first 24 hrs.

Figure 6. A small fan (F370 – 0.37 kW) used during the first 5 days of fumigation to recirculate phosphine to give rapid uniform gas distribution in 1423 t wheat. See Figure 5.

Options for fumigation recirculation

- For all fumigation recirculation systems, the sealable silo needs to be gas – tight so there is no gas leakage during the fumigation. In Figure 4, "Base wall north" shows the impact of a leak at the silo manhole, causing large daily fluctuations in gas concentrations.
- Phosphine blankets or tablets can be placed in the 'silo headspace' along with a small fan connected to the headspace via 90 mm pipe plumbing coming down the silo wall from the

roof. Phosphine gas is drawn from the headspace and pumped into the base of the silo via both aeration ducts (see Figure 5).

- For ground level application of tablets or blankets, a sealable 'phosphine box' can be plumbed into this system, either a moveable box, or mounted permanently on each silo.
- Using a fan to force the phosphine gas movement around in silos during fumigation is generally recommended, rather than relying on a passive 'thermosiphon' approach. For medium and large silo fumigations, 150 t or greater, or silos storing smaller grain sizes (e.g. millets, canola, lentils etc.) that reduces air movement, fan force recirculation rather than thermosiphon is advised. Fan forced recirculation may also assist where the grain type (e.g. oilseeds) typically absorbs higher amounts of phosphine during fumigation.

Equipment for fumigation recirculation

- Sealable silo - gas tight, that passes a pressure test.
- Plumbing pipes (90 – 100 mm) from silo roof to ground level. Use quality pipe, fittings and seals that will ensure many years of safe, gas- tight fumigations.
- Small fan (e.g. Downfield F370 - 0.37 kW) to recirculate air. In most case this fan size will be suitable for both small & large silos. In trials (Fig. 4 & 5) this fan size provided a complete silo air change every 12 hours for the full silo holding 1420 t of wheat.
- Fittings for fan intake and outlet. Flexible hoses (50 – 100mm) couplings and gate valves.

Fumigation recirculation - operations

- Pressure test the silo to check for leaks.
- Follow all label directions and place tablets / blankets in the 'headspace' or 'phosphine box'.
- Run small recirculation fan for first 5 days of fumigation. Leave silo sealed for remaining days of fumigation exposure period as label requires (e.g. 7, 10, 20 days).

Notes

There are benefits to using the silo 'headspace' to locate the blankets or tablets. The large surface area of grain in the headspace provides safe, large easy access for liberated gas to penetrate and diffuse into the grain.

Licenced fumigators commonly choose to use 'gas' formulations of phosphine to undertake fumigations in large silos and other storage types, rather than using the solid phosphine formulations of blankets or tablets. An example is Cytec's ECO$_2$FUME® containing 20g/kg phosphine in carbon dioxide handled in 31 kg liquefied gas cylinders. While applying the full dose of phosphine gas on day one into a storage has benefits, in many cases the use of a recirculation systems is valuable to provide rapid, uniform gas concentration distribution throughout the storage.

Warning

Always seek advice from a suitably qualified professional before fitting fumigation recirculation systems to silos / storages. Some systems that are currently sold are not recommended because of unsafe design features. Phosphine is not only a toxic gas, but can be flammable and explosive if restricted in a small area, or used in a manner that causes gas concentrations to rise quickly to high levels. Follow label directions and seek advice.

Grain protectant sprays update

Warning

Grain protectant notes below do not apply to the grains industry in Western Australia where their use is restricted. In all cases, product labels are to be used to determine correct use patterns.

When to use grain protectants

- Grain protectant sprays are not to be used to disinfest grain. When live insects are detected, fumigation in a sealed silo is required for effective control.
- Typically, protectant sprays are applied to clean cereal grain at harvest time as grain is augered into storages, providing storage pest protection for 3-9 months. Protectants are effective at controlling insects as they invade or emerge from eggs within grain during storage.
- With many domestic and export markets seeking grain supplies which are "pesticide residue free" (PRF), always talk to potential grain buyers / traders prior to applying grain protectant sprays.
- With the exception of some chlorpyriofs-methyl products in lupins in Victoria only, NO protectant sprays can be applied to pulses and oilseeds.

Common 'on-farm' uses for grain protectants

- Planting seed held on-farm – wheat, barley, oats.
- Grain held for an extended time in non-sealable storages (not suited for fumigation) and grain buyer has agreed to grain protectant use that is in line with directions for use on the registered product label.
- Grain held on-farm as feed for livestock with agreement from livestock agent or buyer and is in line with directions for use on the registered product label.

Grain protectant choices

Examples of two products, which include a partner product, to control the main storage pest species:

1. **Conserve Plus™ Grain Protector** – a.i. 100g/L spinosad, 100g/L s-methoprene. Used in combination with a compatible product such as chlorpyrifos-methyl (Reldan™), fenitrothion or deltamethrin

   For label and details on product use, see: http://www.conserveonfarm.com.au/en

   Recent key recommendations:

- Always add the OP partner to Conserve Plus so rice weevil (*Sitophilus oryzae*) is controlled.
- Spray equipment calibration and application care are critical to achieve correct dose and uniform coverage on grain.
- If treated grain is exposed to light, for example a semi open grain shed, cover the grain surface with a tarp or 80 - 90% shade cloth. Sunlight breaks down Conserve Plus over time
- Take care to read notes on the web site (above) and seek advice when purchasing Conserve Plus.

2. **K-Obiol® EC Combi**, synergised grain protectant – a.i. 50g/L deltamethrin, 400g/L piperonyl butoxide. Used in combination with an organophosate (OP) partner e.g. chlorpyrifos-methyl or fenitrothion.

   For label and details on product use, see: https://www.environmentalscience.bayer.com.au/K-Obiol/About%20K-Obiol

Key recommendations

- To control rice, maize and granary weevils (*Sitophilus spp.*) add a recommended partner (e.g. OP) to the tank mix.
- To ensure effective pest control and that MRL's are not exceeded, calibrate spray equipment and aim for even treatment / coverage on grain.
- Grower users are required to complete a brief (approx. 60 minutes) online training course to be an 'approved user' prior to purchase of K-Obiol® EC Combi. See above web site.

Insect resistant management

If possible, aim to rotate chemical active ingredients for storage pest control at your storage facility. An example, two years use of Conserve Plus™ product combination, followed by one or two years of K-Obiol® EC Combi.

Please read and follow all label recommendations and ensure that the product is registered for use in your state prior to application of any product.

Application for grain protectants

Grain protectant application requires care to achieve the correct dose and uniform grain coverage. This leads to effective pest control results and ensures MRL's are not exceeded. See Figure 7 below.

- Auger's grain transfer rate. Ensure you have good understanding of the grain flow rate, tonnes per hour, for the particular height the auger will be operating at.
- Calibrate your spray application unit with water and check appropriate nozzles and spray pressure are used to achieve the required application of 1 litre of spray mixture per tonne of grain.

Figure 7. Spray application equipment designed for good coverage by applying treatment at two points in the auger

Further information

GRDC booklet – Fumigating with Phosphine other fumigants and controlled atmospheres
http://storedgrain.com.au/fumigating-with-phosphine-and-ca/

GRDC Fact sheet – Pressure testing sealable silos - http://storedgrain.com.au/pressure-testing/

A-Gas rural – ProFume® - https://www.agasaustralia.com/products-services/a-gas-rural-fumigation-supplies-services/products/profume/

GRDC video – Fumigation recirculation http://storedgrain.com.au/fumigation-recirculation/

Dow™ AgroSciences - Conserve Plus™ Grain Protector http://www.conserveonfarm.com.au/en

BAYER CropScience - K-Obiol® EC Combi https://www.environmentalscience.bayer.com.au/K-Obiol/About%20K-Obiol

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Spray quality data for nozzles – Implications for use and advice

Bill Gordon, Nufarm Australia

Key words

spray application, spray quality, adjuvants, droplet size

Call to action/take home messages

Advisors and growers need to critically evaluate the claims made on adjuvant labels or in technical literature about the products they plan on using, as well as the spray quality data for nozzles supplied by their manufacturers for legal compliance, efficacy and drift control.

Ensure growers select nozzles based on current spray quality information, such as the GRDC nozzle selection guide, 2017.

Why do we use adjuvants?

The primary purpose of adding an adjuvant to the tank mix should be to improve efficacy.

This may be achieved through different mechanisms, such as;

- increasing spread of the droplet on the leaf surface,
- modifying the leaf cuticle to improve penetration,
- adjusting the pH of the solution to reduce interactions with cations in the water or on the leaf surface,
- reducing evaporation to allow more time for the product to enter the target,
- reducing undesirable interactions between products in the tank mix, or
- improving droplet retention by reducing droplet bounce or shatter.

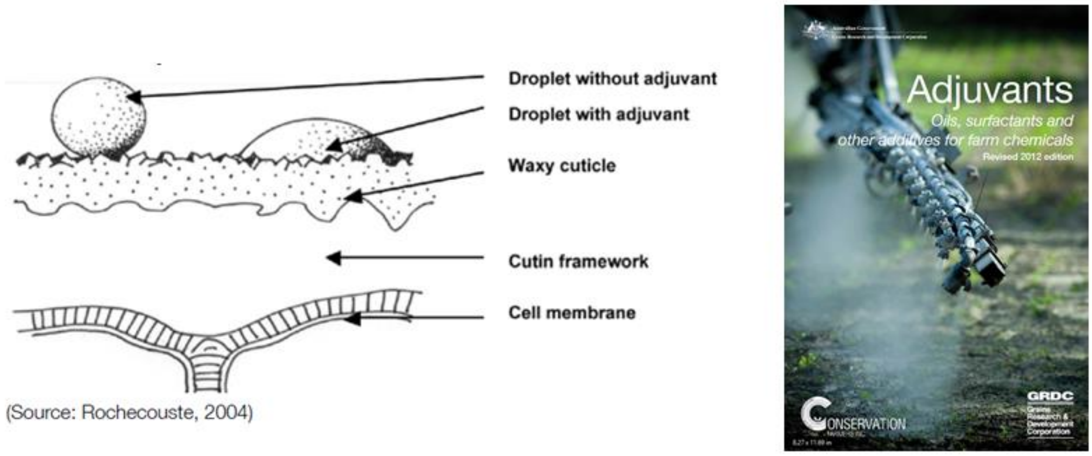

Figure 1. Behaviour of droplets on a leaf surface (with and without an adjuvant).
Source: Adjuvants – Oils, surfactants and other additives for farm chemicals, GRDC 2012.

To change the behaviour of the spray solution, or of a droplet on the leaf surface, the physical and chemical properties of the spray solution usually need to be modified in some way. The most obvious effect of adding an adjuvant to the spray solution is a change in the dynamic surface tension.

Lowering the surface tension causes droplets to spread on the leaf surface, which can increase contact with the leaf surface, improving uptake. However, reducing surface tension of the spray solution can also modify how the droplets themselves are formed as they leave the nozzle, typically reducing their size (compared to water alone).

Table 1. Typical dynamic surface tension values (dynes/cm) for some common adjuvant types

Water alone	72 dynes/cm
Water + Collide™ 700 / LI 700®	48-49 dynes/cm
Water + Wetter 1000 (non-ionic) products	32 dynes/cm
Water + an organosilicone (penetrant)	22-23 dynes/cm

One of the main factors influencing the droplet sizes produced by a nozzle is the nozzle design itself, that is some nozzles are coarser or finer than others. The spray solution also has an influence, where products with a lower dynamic surface tension tend to produce finer droplets than product with a higher dynamic surface tension. Other factors including viscosity and solution temperature can also impact on how droplets are made through various nozzles. Typically, the more uniform the pattern is as is begins to break up, the more uniform the range of droplet sizes produced will be (compare the uniformity of the emulsion in figure 2, to the other solutions).

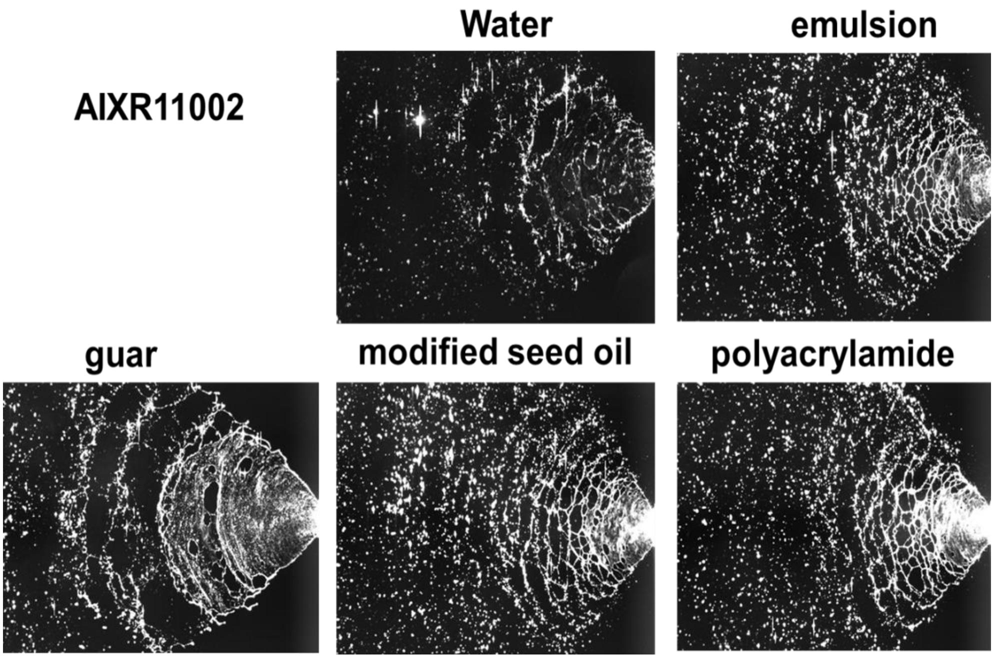

Figure 2. Effect of various adjuvant types on a TeeJet® AIXR11002 at the same pressure.
Source: University of Queensland, C-START

Spray quality according to various standards

Spray quality is not a direct measurement of drift, but a measurement of the range of droplet sizes produced by a nozzle. Spray quality data may be reported by nozzle manufacturers against a couple of different standards including the British Crop Protection Council (BCPC) or the older American Society for Agricultural Engineers (ASAE) Standard S572, which are both mentioned on some Australian labels.

Both the BCPC and older ASAE standards report spray quality based on water alone being sprayed through the nozzle.

More recently the ASAE has changed its name to the American Society for Agricultural and Biological Engineers (ASABE) and has adopted a new standard for spray quality known as the ASABE S 572.1. The new standard requires that testing of pre-orifice and air induction nozzles include the addition of a 40 dynes/cm adjuvant to water as the test solution. This has been designed to provide data that better reflects the spray quality that a typical tank mix may produce, rather than water alone. As a result, recent nozzle charts (see figure 3) may show spray qualities that may appear to be finer than older charts that may still be in circulation. It is important that nozzles are selected based on the best available data.

OLD	Hypro	pressure (bar)	1.5	2	3	4	5	6	7	8
	Gaudian Air 110-025	Spray Quality ASAE S572	XC	VC	C	C	C	M	M	M

NEW	Hypro	pressure (bar)	1.5	2	3	4	5	6	7	8
	Gaudian Air 110-025	*Spray Quality ASABE S572.1*	XC	VC	C	M	M	M	M	M

Figure 3. Comparing old and new spray quality data for the same nozzle.
Source: GRDC Grownote – Spray Application for Grain Growers, 2017.

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Connecting to our farming future

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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™ 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.

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Setting the farm up for broadband connectivity

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