NORTH STAR
NEW SOUTH WALES
WEDNESDAY 25TH JULY 2018

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

grdc.com.au

NORTH STAR

GRDC Grains Research Update

Wednesday 25th July 2018

North Star Sports Club

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 am	Welcome	
9:10 am	**Farming systems trials at Narrabri & Billa Billa** – gross margins and $ return/mm water and issues for sequencing cotton in dryland production systems.	*Andrew Erbacher, DAF Qld & Jon Baird, NSW DPI*
9:45 am	**Impact of different summer crops on soil water extraction and subsequent fallow efficiency**.	*Lindsay Bell, CSIRO*
10:10 am	**Farming systems discussion**	
10:25 am	**MORNING TEA**	
10:55 am	**Sorghum row spacing and yield stability in hard finishing seasons.**	*Trevor Philp, Pacific Seeds*
11:20 am	**Tactical crop agronomy for sorghum -** early sowing dates, how early can you sow? How much do hybrids vary in their tolerance to cold and sowing depth?	*Loretta Serafin, NSW DPI*
11:50 am	**Chaff lining / chaff tramlining -** how much can it assist in driving down the seedbank of problem weeds?	*Annie van der Meulen, DAF Qld*
12:15 pm	**New developments in weed management**. o How compatible are stripper fronts with weed seed collection at harvest? o Robots armed with lasers controlling weeds? o Where is microwave and strategic tillage research up to?	*Mike Walsh, University of Sydney*
12:45 pm	**LUNCH**	
1:45 pm	**The Helicoverpa resistance management strategy** – why; what's in it; how will it work? Efficacy data of alternate products and their use at times where Altacor® is not available. Repeated low-rates of NPV to suppress Helicoverpa populations.	*Melina Miles, DAF Qld*
2:10 pm	**Deep P -** when results are examined over multiple years, there has been a big economic response to deep applied P!	*David Lester, DAF Qld*
2:35 pm	**Grower experience with deep P**	*Tom Woods, Billa Billa*
2:50 pm	**Discussion session on deep P**	
3:05 pm	**CLOSE**	

Contents

Compiled by Independent Consultants Australia Network (ICAN) Pty Ltd.
PO Box 718, Hornsby NSW 1630
Ph: (02) 9482 4930, Fx: (02) 9482 4931, E-mail: northernupdates@icanrural.com.au
Follow us on twitter @GRDCNorth or Facebook: http://www.facebook.com/icanrural

Can systems performance be improved by modifying farming systems? Farming systems research – Billa Billa, Queensland

Andrew Erbacher and David Lawrence

Department of Agriculture and Fisheries (DAF), Queensland

Key words

Northern farming systems, rainfall, productivity, profitability

GRDC Code

DAQ00192

Take home messages

- Different farming systems comparisons conducted over 3 years at Billa Billa QLD have shown that the baseline system (wheat-barley-wheat) has so far returned the highest gross margin ($2.77) per mm rainfall.
- Increasing or decreasing cropping intensity has returned similar gross margins, but had low returns in 2016/17 summer.

Project background

While advances in agronomy and the performance of individual crops have helped grain growers to maintain their profitability, current farming systems are underperforming; with only 30% of the crop sequences in the northern grains region achieving 75% of their water limited yield potential.

Growers are facing challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Changes will be needed to meet these challenges and to maintain the productivity and profitability of our farming systems. Consequently, the Queensland Department of Agriculture and Fisheries (QDAF), New South Wales Department of Primary Industries (NSW DPI) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) are conducting an extensive field-based farming systems research program, focused on developing farming systems to better utilise the available rainfall to increase productivity and profitability, with the question;

Can systems performance be improved by modifying farming systems in the northern region?

This research question is being addressed at two levels by the northern farming systems initiative; to look at the systems performance across the whole grains region, and to provide rigorous data on the performance of local farming systems at key locations across the region.

Research began in 2014 with local growers and agronomists identifying the key limitations, consequences and economic drivers of farming systems in the northern region; assessing farming systems and crop sequences that can meet the emerging challenges; and developing the systems with the most potential for use across the northern region.

Experiments were established at seven locations; a large factorial experiment managed by CSIRO at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres by QDAF and NSW DPI (Table 1). Several of these systems are represented at every site to allow major insights across the northern region, while the site specific systems will provide insights for local conditions.

The following report details the systems being studied in Billa Billa (Goondiwindi), how they are implemented locally and the results after the first three years. Data and system performance indicators have been developed to compare performance across sites.

Table 1. Summary of the regional farming systems being studied at each location in the northern farming systems initiative.

System	Regional sites					
	Emerald	Billa Billa	Mungindi	Spring Ridge	Narrabri	Trangie x2 (Red & Grey)
Baseline – represents a typical zero tillage farming system	*	*	*	*	*	*
Higher nutrient supply – as for the 'baseline' system but with fertilisers for 100% phosphorus replacement and nitrogen targeted at 90% of the yield potential each season	*	*	*	*	*	*
Higher legume - 50% of the crops are sown to legumes	*	*	*	*	*	*
Higher crop diversity – a wider range of crops are introduced to manage nematodes, diseases and herbicide resistance		*	*	*	*	*
Higher crop intensity – a lower soil moisture threshold is used to increase the number of crops per decade	*	*		*	*	*
Lower crop intensity – crops are only planted when there is a near full profile of soil moisture to ensure individual crops are higher yielding and more profitable		*	*	*	*	*
Grass pasture rotations – pasture rotations are used to manage soil fertility. One treatment has no additional nitrogen fertiliser, while the other has 100 kg N/ha/year to boost grass production		Grass (+/-N)				
Higher soil fertility (higher nutrient supply <u>plus</u> organic matter) - as in the high nutrient system but with compost/manure added	*	*				
Integrated weed management (incl. tillage) – this system is included at Emerald where crops, sowing rates, row spacings and 'strategic tillage' are included to manage weeds and herbicide resistance	*					

Billa Billa - 2015 to now

The Billa Billa site is located 50 km north of Goondiwindi on the Leichhardt Highway. The soil is a grey vertosol. The original belah and brigalow trees were cleared and the paddock used as a long-term pasture before being developed for crops in the late 1990s. The previous paddock management has meant there was 360 kg N/ha available at the beginning of the trial.

The paddock grew chickpeas in 2014, so was quite bare prior to commencing the trial in autumn 2015. All of the systems were planted to wheat in the first season to provide stubble cover, yielding 4.7 t/ha. After harvesting this crop, the higher soil fertility system had 75 t/ha of compost broadcast across it to supply an additional 10 t/ha of carbon to this system, which increased the soil carbon by 27% in the top 30 cm of soil. Deep phosphorus was then applied to all of the cropping systems supplying 70 kg P/ha applied in the form of Granulock® Z. After 2015, rotations in the different systems have been quite diverse (Figure 1).

The baseline system was planted to barley in 2016, wheat in 2017 and is planted to chickpea in 2018 (Figure 1).

The summer of 2015-16 was dry with storm rain contributing to the majority of the profile moisture accumulation. The higher crop intensity system triggered an opportunity to be double cropped to mungbean on 15 January. The next effective rainfall this crop saw was after spraying out, so yielded 0.35 t/ha (Figure 2). This double-cropped mungbean crop was planted with the same starting water as the baseline system, which was held in fallow over summer and planted to barley in 2016. This gave the higher crop intensity system a fallow efficiency advantage of 71% versus 30% in the Baseline system(Figure 5). However, differences in the timeliness of in-crop rain had a major impact on the yield outcomes of the mungbean and barley crops (Figure 2).

Autumn 2016 was also dry, requiring faba bean and field pea to be deep sown in the higher legume and higher crop diversity systems respectively. Baseline, higher nutrient supply and higher soil fertility systems were planted to barley on 1 June (Figure 1), with the season remaining quite wet until November. The faba bean and field pea crops matured in early October, and had a wet harvest with a full profile of water, allowing a double crop opportunity in both of these systems. However, the barley in 2016 (baseline, higher nutrient supply and higher soil fertility systems) lodged and put out late tillers, so was harvested mid-November with weather damaged grain. Grain yields averaged 6.3 t/ha for barley and 3.45 t/ha for faba bean and field pea (Figure 2). The yield per mm of water used (water use efficiency) of the two pulse crops were similar to each other, but lower than the barley grown in the same season (Figure 5).

Differences in the economics of the systems to date have largely been driven by the high yields of the 2016 winter crops (Figure 3). The high starting available nitrogen levels at this site has allowed the baseline, higher nutrient supply and higher soil fertility systems to grow 11 t/ha of cereal grain over the first two years, without the expense of nitrogen fertiliser. As such, these three systems have been the most profitable, with the only difference being a higher starter P fertiliser rate in the two higher nutrient systems.

The higher legume and higher crop diversity systems were both planted to pulses in winter 2016 that yielded similarly to each other, but the value of faba bean vs field pea meant the faba bean income and $/mm was similar to the much higher yielding barley, whereas the field pea was quite a bit lower (Figure 3 & 4). The pulse crops in 2016 appear to have fixed nitrogen despite the high starting N. They have similar nitrogen removed in the grain to the barley crops but have an extra 50 kg N/ha left in the soil profile post-harvest. Add to this, the early maturity date of the pulses left an extra 150 mm plant available water, which provided an opportunity double crop. However the dry summer that followed provided poor returns on that double-crop.

The lower intensity and higher intensity systems were planted to sorghum on 15 October, with 200 mm and 120 mm plant available water (PAW) respectively. With only 80 mm in-crop rainfall, these crops were low yielding at 1.5 t/ha and 0.8 t/ha (Figure 2). These yields both lined up with the APSIM predicted yield for the driest 10% of years, for their starting plant available water.

Apart from the 2015 wheat crop that is common to all systems, this sorghum crop was the only crop grown in the low crop intensity system from November 2015 to May 2018, whereas the higher crop intensity system grew three crops to achieve similar cumulative gross margins, with a fourth (sorghum) crop putting the higher crop intensity system slightly ahead. The major commonality in these two systems, that is different to the other systems, is all the crops grown after the initial wheat crop have had received below average in-crop rainfall. Two of these crops were grown in the driest 5 % of seasons for Goondiwindi. As a result the higher crop intensity and lower crop intensity systems are providing the lowest economic returns to date.

After 2016 winter crop was harvested with a full profile of water, the higher legume and higher crop diversity systems were planted to mungbean and sorghum respectively at the next planting opportunity, which wasn't until December (Figure 1). With no effective rainfall before flowering, the mungbean yielded 0.15 t/ha, whereas the sorghum held on to take advantage of autumn rain for a yield of 1.5 t/ha, harvested in July.

The three systems that grew barley in 2016 were all planted to wheat in May 2017. The higher crop intensity system was also double-cropped to wheat at the same time. This crop received 25 mm rainfall prior to maturity, but received a further 83 mm before it could be harvested. The fallowed systems (baseline, higher nutrient supply and higher soil fertility) yielded 1.7 t/ha on average and the double cropped wheat (higher crop intensity) yielded 1.4 t/ha. These systems had similar crop water use efficiencies (WUE) of 12.5 kg/mm on average (Figure 5). The difference in yield is reflecting differences in starting plant available water.

The mungbean grown in the higher legume system had only dried the top 30 cm of soil, so was one rainfall event off being planted to wheat. With the dry winter this did not eventuate, but 80 mm of rain in October allowed it to be planted to spring sorghum with a good profile of plant available water. This sorghum was looking good with 200 mm of in-crop rain, but a dry January capped the yield at 2.9 t/ha with 40% screenings.

The wet spring in 2017 allowed the higher intensity system to be double-cropped again to sorghum. This crop had a dry start, but 150 mm in February and March allowed it to tiller again for a yield of 2.4 t/ha, harvested in May.

Six systems have been planted to winter crops in 2018 (Figure 1). Higher crop diversity has been planted to canola and lower crop intensity to wheat, both after long fallows. Baseline, higher nutrient supply and higher soil fertility were planted to chickpeas after a short fallow and higher legume double-cropped to chickpeas. This leaves only higher crop intensity in fallow, having received no rain from sorghum harvest to the end of June 2018.

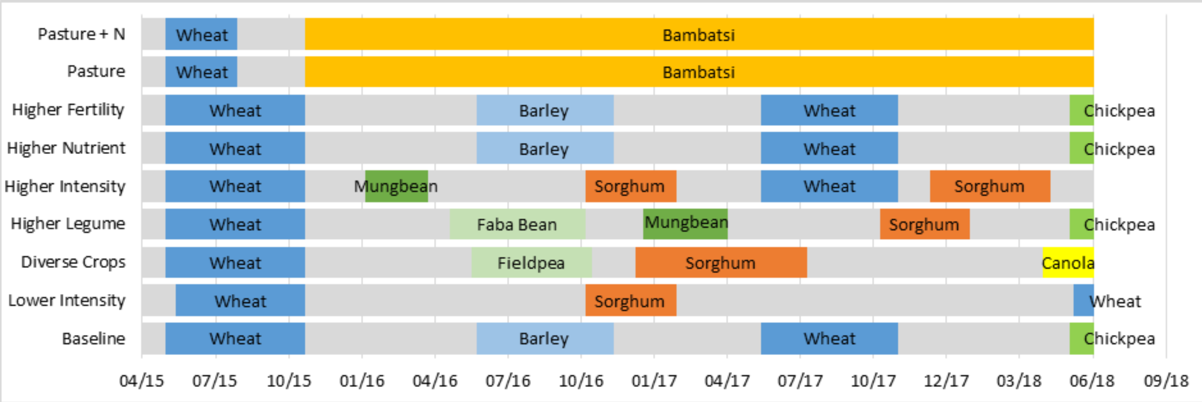


Figure 1. Crops grown at the Billa Billa farming systems trial, presented on a time scale. The coloured sections are planting to harvest of each crop, and the grey bars are fallow periods.

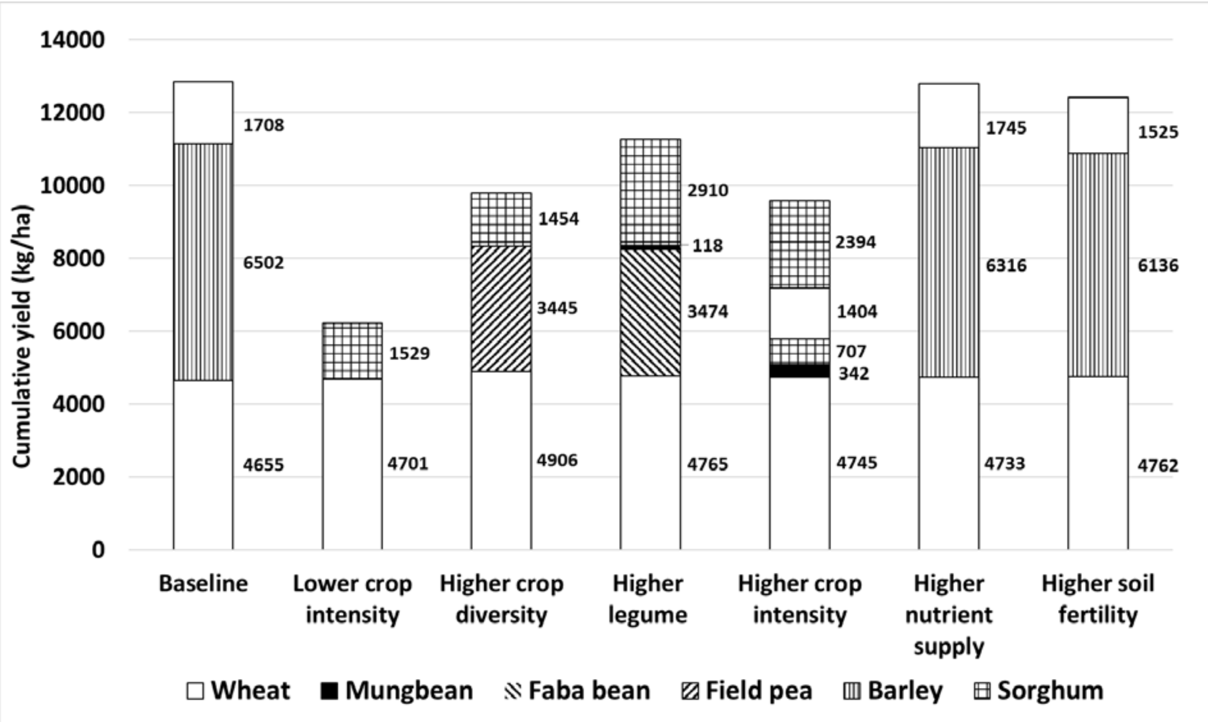


Figure 2. Cumulative grain yields of the seven grain systems at the Billa Billa farming systems trial

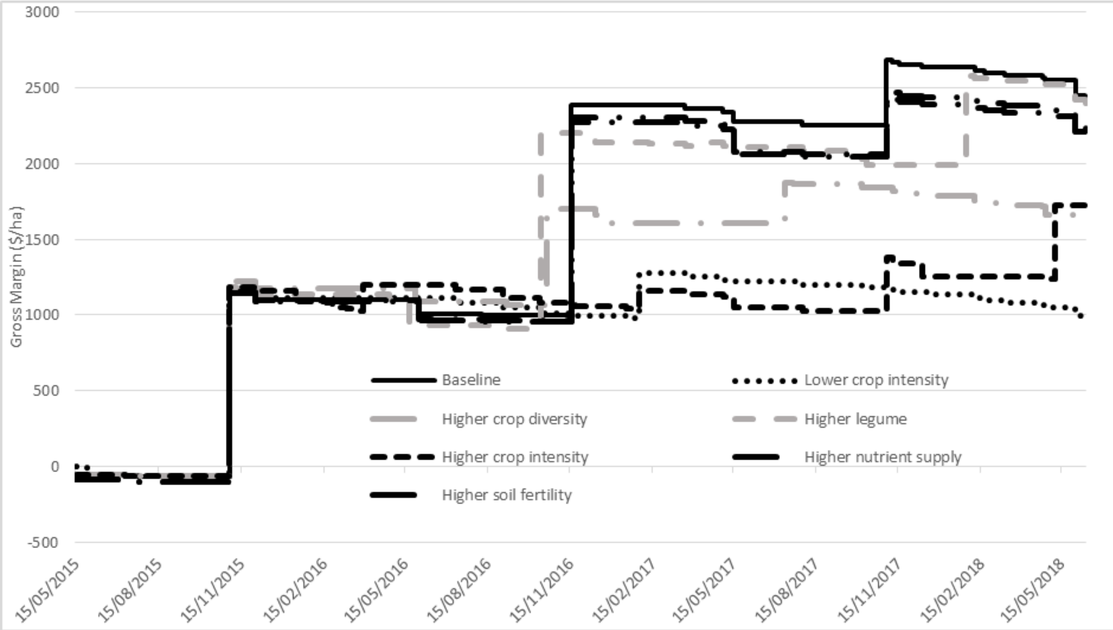


Figure 3. Cumulative cash-flow from the seven grain systems at the Billa Billa farming systems trial. This shows the actual production costs and incomes (based on 10 year average commodity prices), over time for each of the systems.

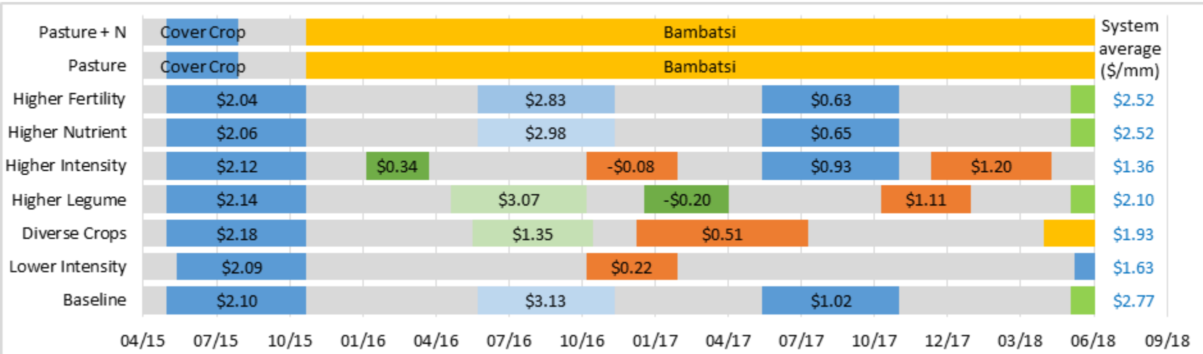


Figure 4. Gross margin per mm of rainfall for each crop grown, including the preceding fallow period, and total for each system (up to the harvest of the last crop). The coloured bars represent the crops depicted in Figure 2.

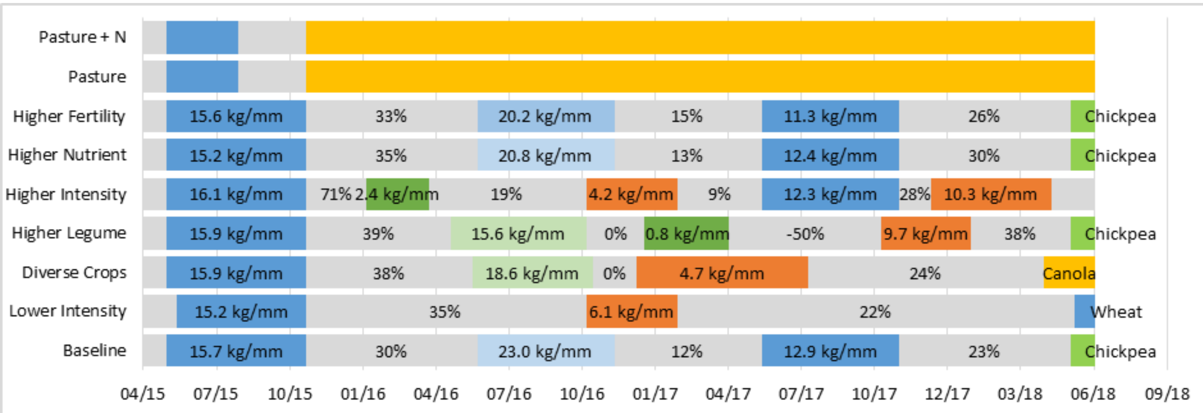


Figure 5. Crop water use efficiency and fallow efficiency, overlaid onto the crop durations represented in Figure 2. The value in the coloured bars is the kg of grain produced per mm of plant available water used + in-crop rainfall. The value in the grey bars is the proportion of rainfall available at planting of the next crop.

Table 2. Grain pricing used in calculations based on median prices over the past ten years, less $40/t cartage costs, for selected crops

Crop	$/t	*Crop*	$/t
Barley	218	Mungbean	667
Canola	503	Oat	400
Chickpea	504	Pasture Grass	150
Cotton	1090	Pasture Legume	150
Durum	269	Sorghum	221
Fababean	382	Sunflower	700
Fieldpea	350	Vetch	150
Maize	281	Wheat	269

Acknowledgement

This trial is part of a collaboration between the Grains Research Development Corporation (GRDC) Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and Commonwealth Science and Innovation Research Organisation (CSIRO). DAQ00192.

Contact details

Andrew Erbacher
DAF Qld
Ph: 07 4671 6711
Mb: 0475 814 432
Email: andrew.erbacher@daf.qld.gov.au

® Registered trademark

Farming systems site report – Narrabri, northwest NSW

Jon Baird and Gerard Lonergan

NSW Department of Primary Industries, Narrabri, NSW

Key words

Northern farming systems, water limited yield potential, nematodes

GRDC code

DAQ00192

Take home messages

- The baseline, high nutrients, high intensity and high legume systems resulted in the highest grain production at Narrabri. With differences in gross margins of the four systems due to the grain value of the crop choice in 2016. High intensity (wheat-canola-wheat) had highest gross margin, baseline and high nutrient (wheat-chickpea-wheat) the second and third highest gross margin and the high legume system (wheat-faba bean-wheat) the lowest gross margin of the top four systems.
- The baseline, high nutrients, high legumes and high intensity systems had the greatest crop water use efficiency in 2016 and in return the highest system gross margin per mm of rainfall. The low intensity system (which contained a summer cotton crop) had lower water use efficiency than the high diversity but greater system gross margin per mm due to the value of the summer crop in the low intensity system and frost damaged 2017 canola crop in the high diversity system.
- *Pratylenchus thornei* numbers were higher after a chickpea crop compared to faba bean and field pea in 2016, while canola and cotton reduced *P. thornei* numbers in the same season. The higher *P. thornei* numbers after the 2016 chickpea crop have continued through to December 2017 (post the 2017 wheat crop).
- There was no difference in wheat yield (2017) following chickpea, faba bean or canola grown in 2016.

Project background

While advances in agronomy and the performance of individual crops have helped grain growers to maintain their profitability, current farming systems are underperforming; with only 30% of the crop sequences in the northern grains region achieving 75% of their water limited yield potential.

Growers are facing challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Changes will be needed to meet these challenges and to maintain the productivity and profitability of our farming systems. Consequently, The Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and CSIRO are conducting an extensive field-based farming systems research program, focused on developing farming systems to better use the available rainfall to increase productivity and profitability, with the question;

Can systems performance be improved by modifying farming systems in the northern region?

This research question is being addressed at two levels by the northern farming systems initiative; to look at the systems performance across the whole grains region, and to provide rigorous data on the performance of local farming systems at key locations across the region.

Research began with local growers and agronomists in 2014 to identify the key limitations, consequences and economic drivers of farming systems in the northern region; to assess farming systems and crop sequences that can meet the emerging challenges; and to develop the systems with the most potential for use across the northern region.

Experiments were established at seven locations; a large factorial experiment managed by CSIRO at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres by DAF and NSW DPI (Table 1). Several of these systems are represented at every site to allow major insights across the northern region, while the site specific systems will provide insights for local conditions.

The following report details the systems being studied in Narrabri how they are implemented locally and the results after the first three years. Data and system performance indicators have been developed to compare performance across sites.

Table 1. Summary of the regional farming systems being studied at each location in the northern farming systems initiative

System	Regional sites					
	Emerald	Billa Billa	Mungindi	Spring Ridge	Narrabri	Trangie x2 (Red & Grey)
Baseline – represents a typical zero tillage farming system	*	*	*	*	*	*
Higher nutrient supply – as for the 'baseline' system but with fertilisers for 100% phosphorus replacement and nitrogen targeted at 90% of the yield potential each season	*	*	*	*	*	*
Higher legume - 50% of the crops are sown to legumes	*	*	*	*	*	*
Higher crop diversity – a wider range of crops are introduced to manage nematodes, diseases and herbicide resistance		*	*	*	*	*
Higher crop intensity – a lower soil moisture threshold is used to increase the number of crops per decade	*	*		*	*	*
Lower crop intensity – crops are only planted when there is a near full profile of soil moisture to ensure individual crops are higher yielding and more profitable		*	*	*	*	*
Grass pasture rotations – pasture rotations are used to manage soil fertility. One treatment has no additional nitrogen fertiliser, while the other has 100 kg N/ha/year to boost grass production		Grass (+/-N)				
Higher soil fertility (higher nutrient supply plus organic matter) - as in the high nutrient system but with compost/manure added	*	*				
Integrated weed management (incl. tillage) – this system is included at Emerald where crops, sowing rates, row spacings and 'strategic tillage' are included to manage weeds and herbicide resistance	*					

Narrabri farming system research site

The Narrabri farming system research site is located on the University of Sydney research farm - "Llara" (-30.263321, 149.860037). "Llara" is representative of the dryland farming operations throughout north-west NSW. The soils are predominately chocolate vertosols and have a plant available water capacity of 190 mm to a depth of 120 cm. The site has a long history of high productivity and has been under a controlled traffic system for many years. The first season of the farming system project was winter 2015, where wheat was grown across all systems to ensure the site had a consistent starting base.

Traditionally, the dryland farming systems grown in the Narrabri region are winter cereal dominated, with summer crops such as sorghum or dryland cotton planted on an opportunity basis. In recent years there has been a push by growers to bring summer crops into a routine cropping rotation due to the greater crop gross margin returns and to utilise summer rainfall. Another benefit of growing summer crops is the increase of cropping diversity that may reduce the amount of soil borne disease (e.g. crown rot) that have caused great productivity loss in the area.

Figure 1. Narrabri farming systems site – 20 September 2017

Cropping sequence at the Narrabri farming systems site

Wheat was planted in the winter of 2015 across all systems to establish a consistent base allowing various crops to be planted in the 2016 cropping year. Early rain provided good establishment and early plant vigour, but a dry finish to the 2015 winter meant yield was quite low (2.1 t/ha) and grain size was small.

The 2016 winter saw chickpeas planted as the industry standard baseline and also as a high nutrient system. The industry standard was in line with local grain growers who planted above average hectares of chickpeas to take advantage of the higher chickpea grain price. Field peas and faba beans were planted in the greater diversity and higher legume systems respectively, while canola was planted in the high intensity system. The low intensity system was kept as winter fallow and initially planned for long fallow through to summer 2017/18, but high rainfall during the winter of 2016 filled the soil profile and thus the system was planted to cotton in November 2016 (Figure 2).

In autumn 2017 all the systems, except for the low intensity system which was following a summer cotton crop, had good soil moisture levels that triggered crop plantings during the optimum window for the specific crops (canola planted on 19th of April and wheat planted on 11th May). This saw the baseline, high nutrients, high crop intensity and high legume systems return to cereal plantings. The greater diversity system was planted to canola following the 2016 field peas. To prevent soil degradation, barley was planted as the cover crop in the low intensity system but sprayed out prior to booting. The 2017 winter crops received considerably less in-crop rainfall compared to the 2016 winter crops (184 mm verses 450 mm) and unfortunately a number of heavy frosts occurred during August/September which greatly impacted the 2017 canola yield.

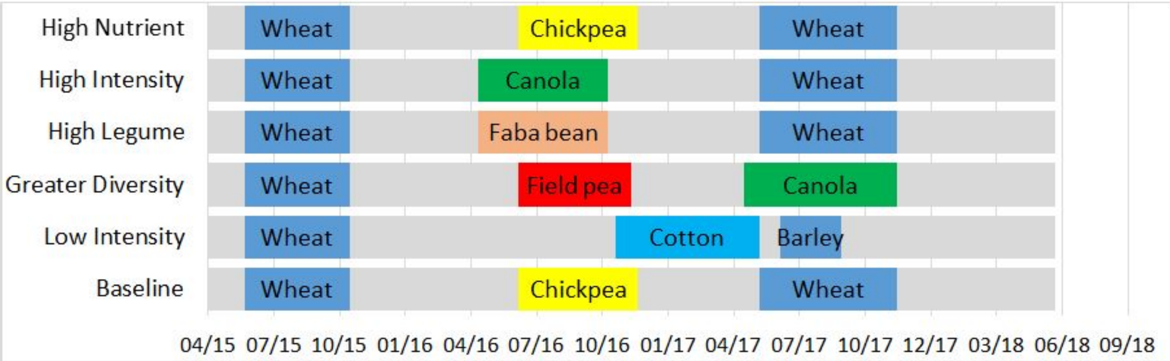


Figure 2. Cropping sequence and fallow length of the six farming systems at Narrabri

Grain / lint yield

The cumulative yield of the six systems (Figure 3) highlight the similar productivity of the baseline, high nutrients, high legume and high intensity systems (9.3, 9.1, 9.3, and 9 t/ha respectively). As stated before, the baseline and high nutrient system followed similar cropping sequences (Wh-Ch-Wh), while the high legume contained faba beans (Wh-Fb-Wh) and the high intensity had canola (Wh-Can-Wh) during the 2016 winter. These four systems produced significantly more total grain (or grain + lint) than both the greater diversity and low intensity systems (5.95 and 3.4 t/ha respectively). These lower yielding systems received unfavourable growing conditions during 2017. The low intensity system, which had cotton in the 2016/17 summer, received large yield penalties due to the extreme heat during the important boll development stage. While the 2017 canola crop (greater diversity system) received a number of frosts during late August/ early September (during the flowering/ pod fill stage) that devastated final yield.

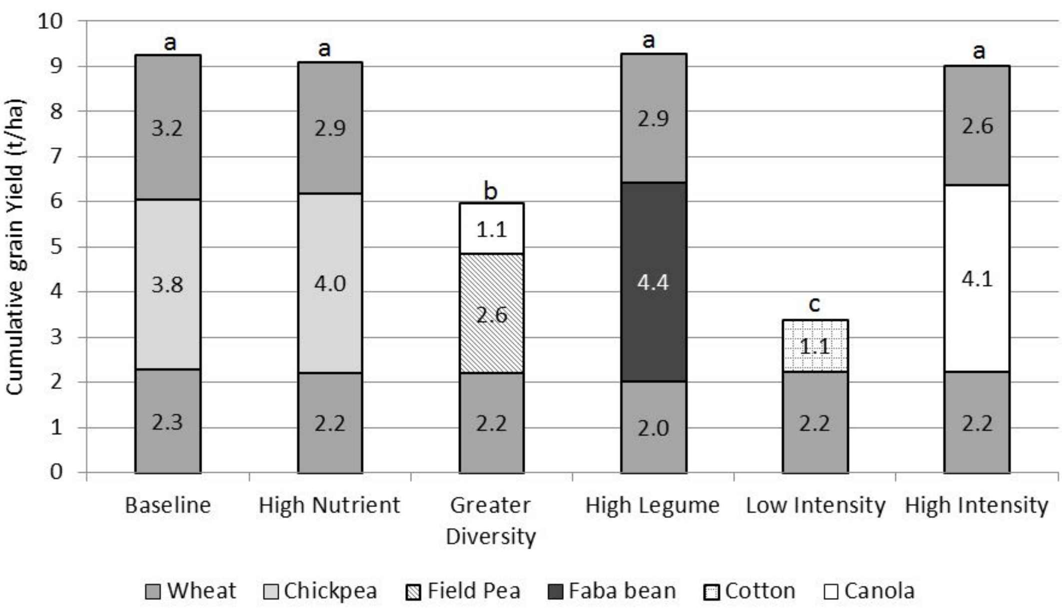


Figure 3. Cumulative grain yields of the six systems at the Narrabri farming systems trial. Labels a, b, c denotes significance groups, l.s.d.=1.2, P<0.001.

System economics

After the first three growing seasons of the farming systems trial at Narrabri, the high intensity system has the greatest cumulative gross margin with $2407/ha or $802/ha/yr (Figure 4). The baseline system had similar system gross margin with $2339/ha, while the high nutrient system was $133/ha less than the baseline system due to the extra cost of the higher applied fertiliser rate. The high legume system had the next highest gross margin with $2165/ha. The difference in gross margins of the top four systems is primarily driven by the grain value of the crops planted in 2016. Of the crops grown in 2016, chickpea (baseline and high nutrients) and canola (high intensity) had the highest grain value ($504/t and $503/t respectively), followed by faba bean (high legume - $382/t). It is noted that grain prices used for the farming system project's gross margin analysis are 10 year median grain prices (Brisbane port) less transport costs ($40/t) across all northern farming system sites. This was to ensure there is no confusion between biophysical characterisations of each site and changes in transportation/market costs between sites.

The low crop intensity system which grew two crops in the three seasons (one less than the other farming systems) had the second lowest gross margin at Narrabri with $1232/ha. While the greater diversity system resulted in the lowest gross margin of the six Narrabri farming systems ($858/ha).

These results highlight the impact of the harsh growing conditions during the summer of 2016/2017 and the winter of 2017. The cotton crop (low intensity system) had a gross margin of $843/ha, the second lowest returning crop for the 2016 planting season. While the greater diversity system had the two lowest retuning crops, field peas ($320/ha - 2016) and canola ($158/ha - 2017).

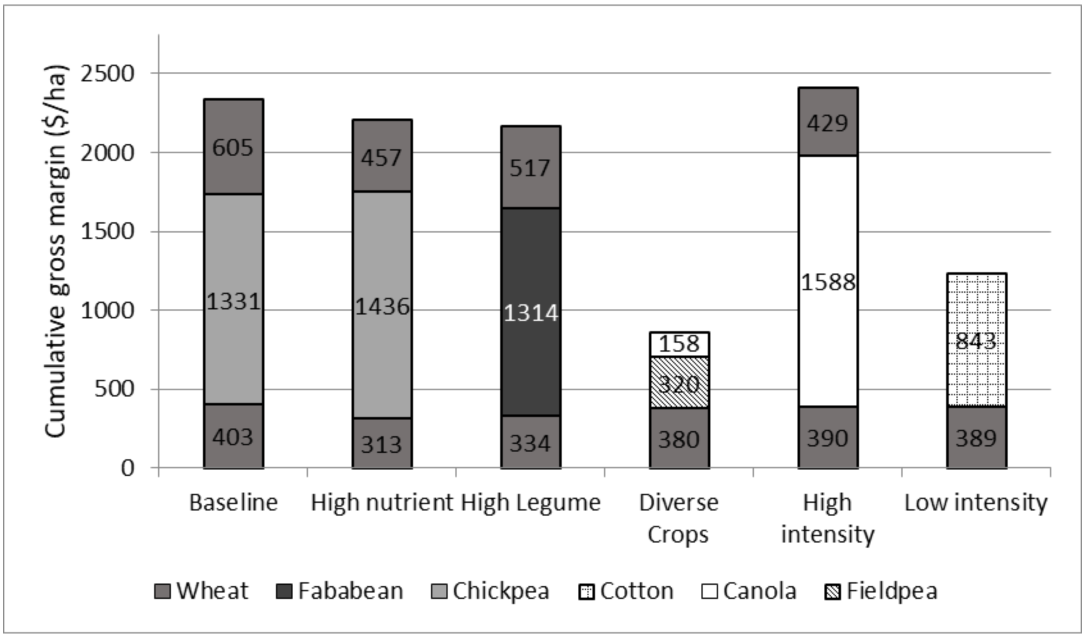


Figure 4. Cumulative gross margins of the six farming systems at Narrabri (includes crop and fallow costs). Grain values used for gross margin analysis are 10 year median prices at port, minus transport costs. Prices used at Narrabri include: wheat - $269/t, faba bean – 382/t, canola - $503/t, chickpea - $504/t, field pea - $350/t and cotton - $1090/t (includes lint and seed).

Water use efficiency

The low intensity system (with the two harvested crops from the three seasons) had the lowest fallow efficiency (the proportion of rainfall available to the next crop) and lowest crop water use efficiency (kg yield/mm crop water use) in 2016 (cotton – 2 kg /mm) (Figure 5). Conversely the high intensity system resulted in the highest fallow efficiency to date (61% 2015/16 summer fallow). Although there were five different crops planted in 2016, all systems resulted in similar crop water use efficiency in 2016, except the low intensity system (cotton). The impact of the 2017 frost damage on the greater diversity system (canola) is highlighted by the crop's water use efficiency of 4.5 kg/mm (which is the lowest efficiency rating for crops harvested in 2017), compared to the high intensity canola crop (2016) which had 7 kg/mm water use efficiency.

From the cropping sequences at Narrabri, we are able to compare the water use efficiency of wheat grown from two different seasons in the same system. The water use efficiency for both the baseline and the high legume systems were 4.5 and 5 kg/mm higher in 2017 compared to 2015, even though there was similar in crop rainfall for both the seasons (approx. 180 mm). A difference of the two seasons is that the 2017 crop was planted with an extra 35 mm of plant available water compared to the 2015 wheat crop and yield for both systems were 0.9 t/ha greater in 2017 compared to 2015.

Baseline, high nutrient, high legume and high intensity systems all had similar system water use efficiency (system gross margin per mm of rainfall). These four systems are had greater efficiency than the low intensity and greater diversity systems. The greater diversity system had the lowest system water use efficiency ($0.57 ha/mm) due to the poor gross margin of its 2016 field pea crop and the frost impacted 2017 canola crop. The long fallow periods in the low intensity system did reduce the system efficiency ($0.84 ha/mm), but it must be noted that the system had the highest plant available moisture (> 40 mm) than the other five systems at the completion of the 2017 cropping season (15/12/2017).

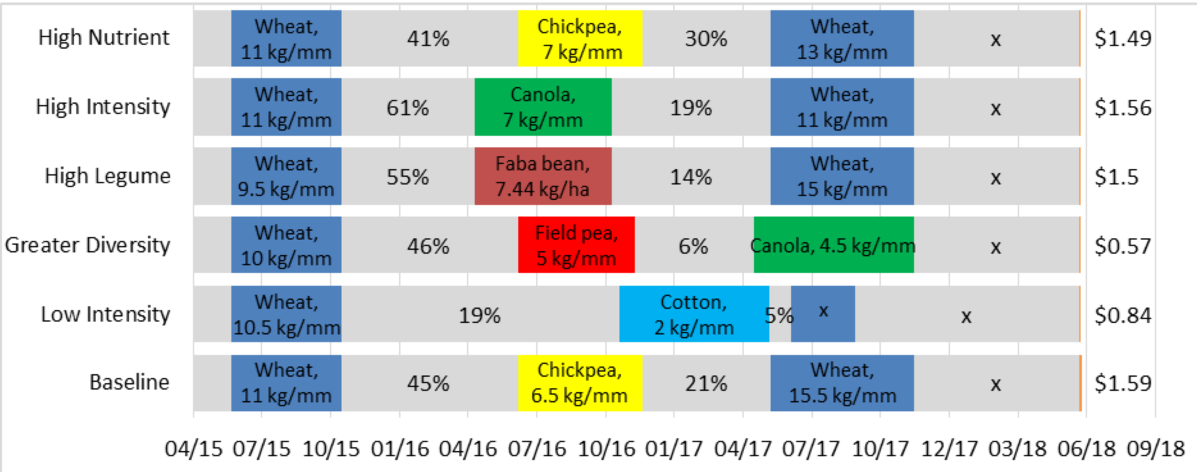


Figure 5. Crop water use efficiency, fallow efficiency and system gross margin per mm of rainfall for the six Narrabri farming systems up to the harvest of the last crop. Coloured bars represent crop choice and water use efficiency; grey bars contain the fallow efficiency or the proportion of rainfall available to the next crop.

Soil pathogens

Of the 18 soil pathogens tested pre and post every crop within the farming system project at Narrabri, *Pratylenchus thornei* results have shown a strong system related trend during the first three seasons. Crop choice during the 2016 season had the biggest impact on *P. thornei* numbers, with chickpeas (PBA HatTrick ⌽) grown in the baseline and high nutrient systems increasing *P. thornei* numbers by up to 5 times the pre-sown number. The other legumes planted in 2016 (field pea - PBA Oura⌽ (greater diversity) and faba bean – PBA Warda⌽ (high legumes)) also increased *P. thornei* numbers but not to the extent of the chickpeas. The cotton (Sicot 748B3F) and canola (44Y89) in the low and high intensity systems respectively decreased the number of *P. thornei* in the soil during the 2016 winter. Although *P. thornei* did increase to moderate levels in 2016 within the baseline and high nutrient systems, no yield impact was recorded as chickpea yield equalled 3.8 t/ha for the baseline and 4 t/ha for the high nutrient system.

While *P. thornei* numbers across all six systems did reduce during the 2016/17 summer fallow, *P. thornei* numbers in both the baseline and high nutrient systems increased slightly during the 2017 winter wheat crop (Longreach Lancer⌽). As a result both these systems had more than three times the *P. thornei* numbers than the other four farming systems at the end of 2017. Conversely the other four farming systems continued to reduce *P. thornei* numbers during 2017 and had approx. 1.2 nematodes/g soil (Figure 6) at the end of 2017. To date the higher nematode numbers in the baseline and high nutrient systems have not impacted yield as there is no difference in yield from the 2017 wheat planted in the baseline, high nutrients systems with the high legume and high intensity systems (all systems were planted to the same wheat variety in 2017 - Longreach Lancer⟅b). These results complement industry guidelines as Longreach Lancer⟅b is rated as moderately susceptible in terms of increasing *P. thornei* numbers (NSW DPI winter crop variety sowing guide 2018). However Lancer⟅b is tolerant-moderately tolerant to *P. thornei,* therefore moderate levels of *P. thornei* are not expected to cause any yield impact.

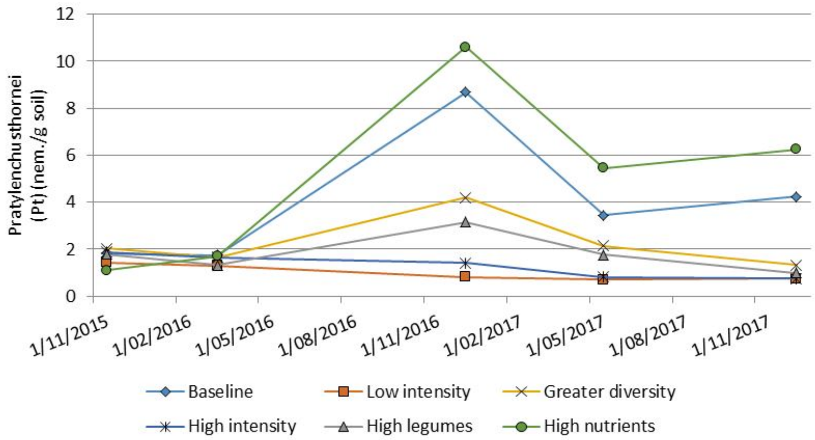


Figure 6. *Pratylenchus thornei* at the Narrabri farming system site

Conclusion

From the first three seasons at the Narrabri farming systems research site, the crop choice of the 2016 winter had the biggest impact on system gross margins and productivity, with the wheat-chickpea-wheat sequence and wheat-canola-wheat resulting in high grain yield and the highest gross margins. This result is due to the 2016 winter crops being significantly higher yielding than both the 2015 and 2017 winter seasons and the grain value of chickpea and canola in 2016 resulted in higher gross margins for the baseline and high intensity systems compared to the other four farming systems at Narrabri.

Although the sequence within the baseline and high nutrients systems have resulted in high grain production and system gross margins, the two-crop rotation does not reflect well for best management practice in the area. Of particular concern are long term implications on crop disease and nematode numbers (in particular *Pratylenchus thornei*). Future crop selections for the baseline and high nutrient systems will need to take into account the varieties' susceptibility to *Pratylenchus thornei.*

Acknowledgements

The research undertaken as part of this project (DAQ00190) is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We must also acknowledge the assistance provided by staff at the University of Sydney research farm – 'Llara'.

Contact details

Jon Baird
NSW Department of Primary Industries
21888 Kamilaroi Highway, Narrabri 2390
Ph: 02 67991520
Email: jon.baird@dpi.nsw.gov.au

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

Investigating the impact of rain-fed cotton on grain production in northern farming systems

Jon Baird[1], Gerard Lonergan[1], Lindsay Bell[2]

[1]NSW Department of Primary Industries, Narrabri, NSW
[2]CSIRO, Toowoomba, QLD

Key words

Northern farming systems, summer cropping, double cropping

GRDC code

DAQ00192

Take home messages

- Long fallow with good ground cover is paramount for preparing to establish a summer crop.
- November has the greatest probability of adequate planting conditions for summer crops in Northern grains regions.
- Chickpeas provided the best crop choice for double cropping in 2017 post the dryland cotton crop at Narrabri, due to high crop gross margins and its greater ability to extract soil moisture compared to wheat.
- Cultivating after dryland cotton crop did reduce cotton volunteers and ratoons by >100 plants/ha, but yield of the following chickpea crop was reduced by 42% in 2017.

Cotton's fit in a dry-land farming system

Rain fed cotton production is an integral part of dryland farming systems in the northern grain regions of NSW, and southern Queensland. New cultivars with greater lint yield potential, high commodity prices and improved moisture management with the uptake of minimum-till farming have resulted in greater areas of farming land purposely kept for growing dryland cotton. As a result, questions are being raised about the sustainability of growers committing to growing a long-season summer crop in an unpredictable rainfall climate, and its impact on their farming system.

Issues for growing cotton in a dryland farming system include: How to sequence back into grain crops? What crop to grow after the cotton crop? Does cultivation of the cotton ratoons impact yield potential, and if so for how long? If cultivation does not occur, what is the impact of ratoon and volunteer cotton control?

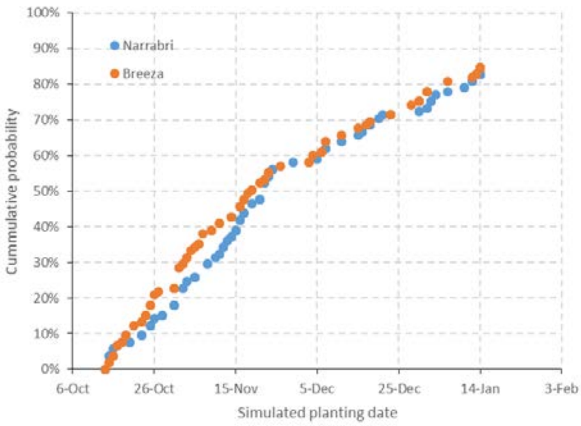
Issues such as planting moisture opportunity, gross margins, rainfall efficiency and the impact on crop sequencing are investigated by the GRDC-funded farming systems projects. In collaboration with the Queensland Department of Agriculture and Fisheries (DAF), CSIRO and the NSW Department of Primary Industries (NSW DPI), the farming systems program is focused on developing systems to better use available rainfall to increase productivity and profitability. We present results from 2 sources here that investigate the options for transitioning from a cotton crop back to a grain crop and the legacy impacts on subsequent crops in a dryland farming system.

Summer planting opportunities for dryland cotton

One of the major decisions growers have when sequencing a cotton crop is the probability of receiving ideal planting conditions. APSIM modelling was used to predict the probability for ideal planting conditions (i.e. 30 mm of rain over 3 days and plant available water > 100 mm) for two northern NSW sites (Spring Ridge and Narrabri) (1a) and south east Qld (Pampas)(1b). Simulations outputs were taken from simulations of crop sequences involving a summer crop following either a winter cereal or chickpea in the previous year (i.e. Wheat – chickpea - wheat - long fallow, or wheat - chickpea – long fallow). All simulations assumed no-till, full stubble retention, with optimum fallow weed management.

All three regions follow a similar trend, although Pampas achieves planting probabilities earlier than both Narrabri and Spring Ridge. The probability of planting summer crop at Narrabri is not as strong during the month of October compared to the other two sites. The models indicate that in approximately 25-30% of years there is a probability of meeting these sowing conditions in October, which is the optimum planting month for cotton in northern NSW (Cotton Seed Distributers, 2013). Importantly this shows that at both Breeza and Narrabri there is only a 65% probability of summer planting conditions occurring by the 15th December, meaning growers may miss out on ideal planting in 3 out of 10 years. On the eastern Darling Downs the simulations predict an extra 10% chance with 75% probability of planting before mid-December.

1(a) 1(b)



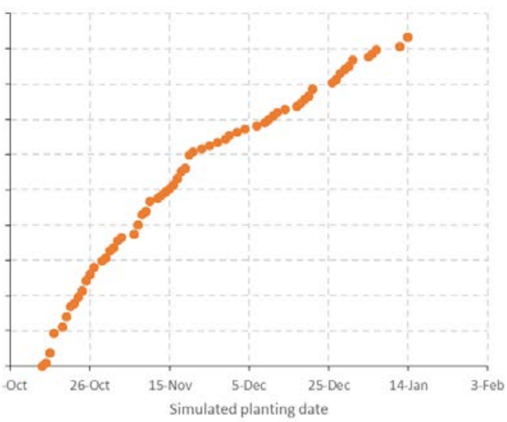


Figure 1. Summer planting opportunity for (a) northern NSW (Narrabri and Breeza) and (b) Pampas, Qld. Where conditions met >30 mm of rain over three days and >100 mm of PAW following a long-fallow after a winter cereal in the previous year (assuming no-till, full stubble retention and optimal fallow weed management).

Post-cotton crop management implications

A grain systems trial was established to evaluate selected farming system options post a cotton crop at the University of Sydney Narrabri research farm "Llara". The study initiated by the NSW DPI northern cropping systems team, investigated various farming management treatments after growing dryland cotton, in particular grain production, soil nutrition, weed control, pathogen levels and system gross margins.

In total six treatments were developed consisting of three crop choices (wheat, chickpeas and a cover crop - barley), and three post cotton cultivation practices (full cultivation, plant line ripping and no till).

The tillage treatments post the cotton crop included:

- No till: No cultivation with following crops sown directly into cotton stubble with a no till planter. Only herbicides were used to control cotton regrowth or volunteers.
- Plant line ripping: Ripping tynes cultivated along the plant line of the cotton crop to a depth of 30cm. No cultivation occurred between the plant lines

- Full cultivation: Offset discs were used twice to ensure full disturbance.

Following a rain fed cotton crop grown in the 2016/17 summer, tillage events occurred approximately 1 month after cotton harvest and subsequent crops were planted on the 26th June with approximately 40% of plant available water capacity (PAWC).

Grain crop yields

After the 2016/17 dryland cotton crop, there was low residual soil moisture in the profile (77 mm of plant available moisture to a depth of 120 cm). The implementation of the cultivation treatments further reduced the plant available water in both the full cultivation and plant line cultivation treatments (Table 1). Along with below average in-crop rainfall during the winter of 2017, these factors combined resulted in low grain yields for both wheat and chickpea. The no till systems resulted in greater grain yield for both crops. The wheat no till treatment yielded 0.28 t/ha higher than the wheat plant line cultivated treatment, while the chickpea no till yielded 0.275 t/ha higher than the chickpea plant line cultivated treatment. This equated to a yield difference of 38% for wheat, and 42% for chickpeas. Crop choice also impacted final grain yield with the wheat no till treatment yielding 34% higher than the chickpea no till treatment (0.97 t/ha and 0.64 t/ha respectively).

Table 1. Plant available water (PAW) after cultivation implementation and subsequent grain yield and crop biomass of wheat or chickpea crops following cotton at Narrabri, NSW (2017)

Site	Crop	Cultivation	Pre crop PAW (mm)	Yield (t/ha)	Crop biomass (t/ha)
Narrabri	Wheat	No till	78	0.97	2.5
Narrabri	Wheat	Plant line cultivation	67	0.70	2.4
Narrabri	Wheat	Full cultivation	56	0.67	2.3
Narrabri	Chickpea	No till	74	0.64	2.1
Narrabri	Chickpea	Plant line cultivation	64	0.37	1.5
Narrabri	Cover crop - barley	No till	79	NA	2.7

Economic returns of crops

An important aspect of the study based at Narrabri was to evaluate the economics of implementing the various management treatments. Due to the low yields, only two treatments were profitable after the 2017 winter harvest – no till chickpeas and no till planted wheat (Figure 2). Although both treatments did receive an extra herbicide than the cultivated treatments, the yield advantage resulted in higher gross margins. While crop choice did impact gross margin, as no till chickpeas resulted in a higher income than the no till wheat ($132/ha and $44/ha respectively). The results show that both cultivation and crop choice had an impact on the gross margin for the grain crop following cotton. For growers considering the value of planting a strategic cover crop after a dryland cotton crop, the farming system's 2017 cover crop (barley) resulted in a cost of $100/ha. The cost includes planting cost, seed purchase and herbicide applications and fallow maintenance up to December 2017.

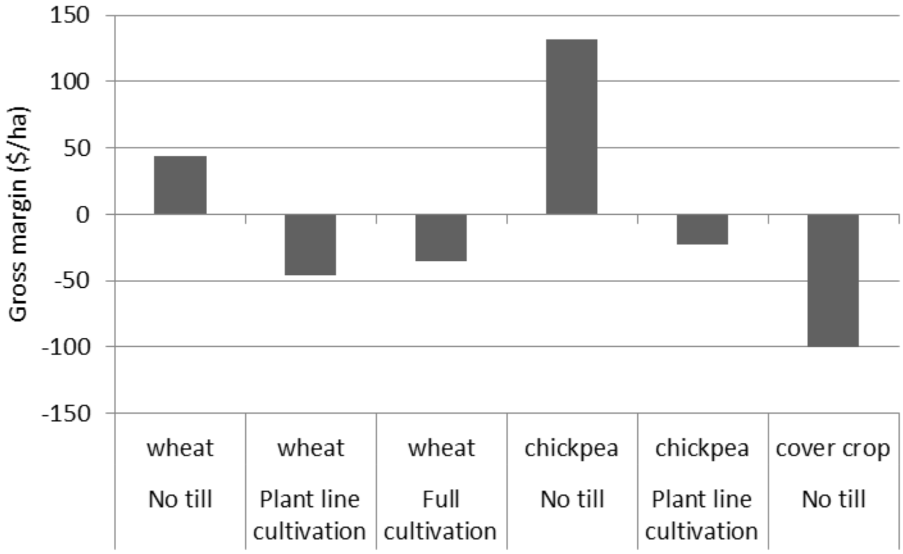


Figure 2. Crop gross margins post a dryland cotton crop from Narrabri, 2017. Grain values used for gross margin analysis are 10 year median prices at port, minus transport costs. Prices used at Narrabri include: wheat - $269/t and chickpea - $504/t

Crop water use efficiency (WUE)

After the 2016-17 rain fed cotton crop, there was 77 mm of plant available water (PAW) at the Narrabri farming systems site (equal to 42% of plant available water capacity (PAWC)). As expected, soil disturbance due to cultivation treatments led to a loss in soil water. The full cultivation reduced plant available water by 21 mm, while the plant line cultivation reduced plant available water by 12 mm. As a result the no till treatments had higher plant available water at planting. Subsequently, the no till chickpeas had the greatest crop water use for all the treatments planted in 2017 (189 mm, $p<0.05$). The impact of cultivation was highlighted by the three wheat treatments, with no till wheat using more moisture than plant line cultivated wheat, which in turn had higher crop water use than the fully cultivated wheat (178, 161 and 144 mm respectively).

While wheat had higher water use efficiency (kg grain/mm crop water use) than chickpea (4.6 and 3.4 respectively), a no till sowing operation resulted in higher water use efficiency than plant line cultivation for both crops (Table 2) ($p<0.001$).

Interestingly crop choice had an impact on the plant available water left in the profile after the 2017 winter crop harvest. There was an average of 57.8 mm plant available water for the wheat no-till and plant line cultivation treatments at harvest, while the chickpea averaged (for the same cultivation treatments) a lower amount of 42.5 mm. This result supports the theory that chickpeas can access more soil water than wheat. They were able to produce grain later in the season, while the wheat treatments were observed to have matured earlier due to moisture stress (Figure 3).

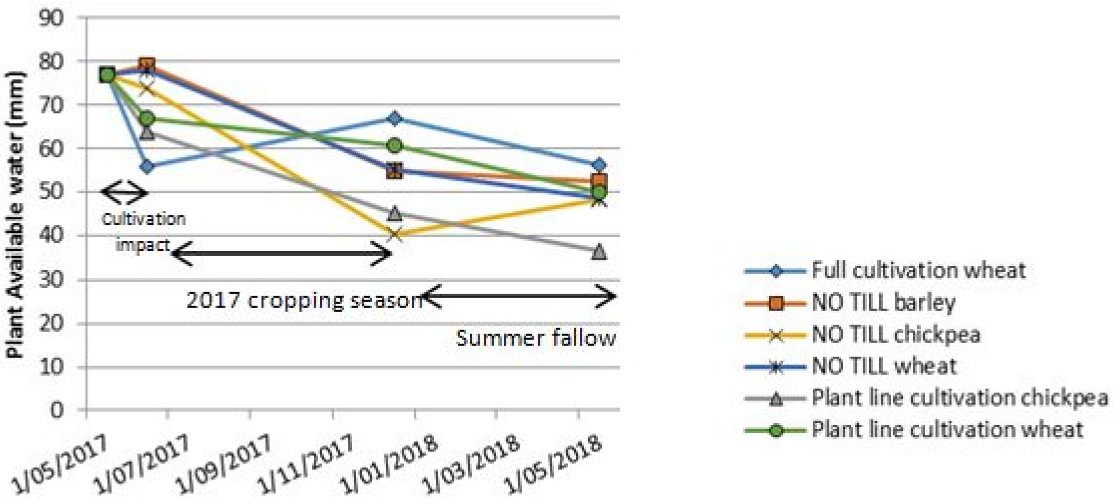


Figure 3. Plant available water, Narrabri 2017-18

Table 2. System water use efficiency, Narrabri 2017

Cultivation treatment	Crop	Crop water use (mm)	Water use efficiency (kg grain/mm/ha)
No till	Cover crop - barley	179	-
No till	Chickpea	189	3.4
No till	Wheat	178	5.5
Plant line cultivation	Chickpea	174	2.1
Plant line cultivation	Wheat	161	4.3
Full cultivation	Wheat	144	4.6
	l.s.d	31	2.4

Cotton regrowth and volunteer control

A major concern for growing rain fed cotton is the number of ratoon and volunteer cotton plants that occur after cotton harvest. Controlling ratoon and volunteers can be expensive and become hosts for pests and diseases. Weeds counts conducted 184 and 300 days after the harvest of the cotton crop show the longevity of the volunteers and ratoon plants. The application of the two cultivation treatments did reduce the number of cotton ratoons and volunteers, with the plant line cultivation having the greatest effect. While both the cultivation activities did incur an extra cost for the management systems, the higher number of ratoons and cotton volunteers resulted in extra herbicide applications for the no-till treatments.

It should be noted that there are no registered or consistently reliable herbicide options available for the control of cotton ratoon.

Table 3. Residual ratoon and volunteer cotton plant numbers (plants/ha) at Narrabri, at 184 and 300 days after cotton harvest

Cultivation	Crop	24/11/2017 184 (DAH)	19/03/2018 300 (DAH)
No till	Wheat	153	90
No till	Chickpea	103	11
No till	Cover crop	156	36
Plant line	Wheat	0	4
Plant line	Chickpea	3	1
Full cultivation	Wheat	26	33
	s.e	80	45

Crop yields following cotton compared to other crop sequences

Farming system trials at Narrabri and Pampas have provided opportunities to compare the yield of crops grown as a double crop after a summer crop, with the yield of crops grown after different previous crops in the cropping sequence. At both Narrabri and Pampas, cotton and sorghum crops were followed by a double crop of wheat. Here the yield of these wheat crops were compared with the yield of wheat crops grown after chickpeas followed by a summer fallow. As shown Table 4, a chickpea- fallow-wheat sequence clearly resulted in a higher yield at both the Pampas and Narrabri trial sites when compared to wheat yields following cotton or sorghum. The yield of the wheat crop following directly after cotton was 65% lower at Narrabri and 47% lower at Pampas compared to following chickpea. It must be noted that both Pampas and Narrabri received below average rainfall during the 2017 winter growing season, but the results show the large impact cotton has on the following crop's yield. At the Pampas site, it should also be noted the impact of a long season summer crop (cotton) compared to a shorter growing summer crop (sorghum). Wheat yield when double-cropped following sorghum yielded significantly higher than following cotton (1.75 and 1.06 t/ha respectively – Pampas 2017).

Table 4. Wheat yield at farming systems research sites Narrabri and Pampas in 2017 following cotton compared to other previous crop sequences.

Site	Previous crop	Crop	Pre-plant PAW (mm)	Wheat crop yield (t/ha)	Wheat crop biomass (t/ha)
Narrabri	Cotton	Wheat	78	0.97	2.5
Narrabri	Chickpea - fallow	Wheat	115	2.20	7.6
Pampas	Cotton	Wheat	146	1.06	3.38
Pampas	Chickpea - fallow	Wheat	188	2.01	6.73
Pampas	Sorghum	Wheat	181	1.75	5.58

The Pampas experiment also compared the impact of different summer crops (maize and cotton) on the pre-plant soil water and yield for subsequent summer crops (sorghum or mungbean) (Table 5).

When cotton was the previous crop compared to maize, starting plant available water for the next summer crop was approximately 20 mm lower and yields of sorghum were reduced by 0.4 t/ha and yields of mungbean were reduced by 0.3 t/ha.

Table 5. Comparison of soil water pre-plant and subsequent grain yields of sorghum or mungbean crops following either cotton or maize the previous summer, Pampas 2017.

Previous crop history	Pre-plant PAW (mm) 01/09/2017	Sorghum yield (t/ha)[A]	Mungbean yield (t/ha)[B]
Maize – fallow	145	4.44	1.04
Cotton – fallow	127	4.04	0.73

[A] *cv.* Taurus, sown 3 Nov 17, soil N 150-180 kg/ha, 65 000 plants/ha

[B] cv. Jade⦶, sown 8 Dec 17, 360 000 plants/ha

Conclusion

There are many challenges sequencing cotton in a dry land farming system. Firstly, growers need to evaluate the impact and risk of growing a long season summer crop in a variable climate with unreliable summer rainfall. Northern NSW and south-east Queensland do have high probability of adequate spring – summer planting conditions especially after a long fallow with good ground cover; however, the planting conditions may occur later than the ideal planting date for full lint yield potential.

The opportunity to plant a double crop after cotton in optimum conditions is limited; therefore, if growers do plant, the crop will benefit from capacity to tolerate moisture stress. At Narrabri, chickpeas stood out as the ideal second crop in a double cropping sequence, as they were able to extract a greater amount of soil moisture in a low moisture environment and also resulted in the greatest gross margin. Wheat and the cover crop (barley) did have greater biomass accumulation and did result in greater residual stubble cover, which may have a beneficial impact on future grain crops. While cultivating did have benefits such as reducing the cotton ratoons and volunteer numbers, the cost of the implementation on soil moisture caused significant yield reduction. If growers are able to defoliate their cotton within the regulated date, the ideal treatment is to leave the field in a no till situation. It is noted that there are no registered or reliable options for control of ratoon cotton with herbicides.

We have also found that the greater moisture extraction of cotton compared to other summer crop options can have legacy impacts that last > 12 months, resulting in lower grain yields compared to growing crops after other summer crop options. These negative impacts should be considered when evaluating the profitability of dryland cotton compared to other summer grain crop options (e.g. sorghum, maize).

References

Bell, L. et al (2015). “Improving northern farming systems performance”. GRDC Update paper

Keating, B. A. et al (2003). "An overview of APSIM, a model designed for farming systems simulation". Europ. J. Agronomy 18: 21.

Cotton Seed Distributers. “A guide to dryland cotton”. csd.net.au

Acknowledgements

The research undertaken as part of this project (DAQ00190 and CSA00050) is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We must also acknowledge the assistance provided by staff at the Pampas experimental site (Jack Mairs, Duncan Weir, John Lawrence) and co-operators and hosts at 'Anchorfield' and 'Llara' who assist us implement this experiment in a variety of ways (too many to mention).

Contact details

Jon Baird
NSW Department of Primary Industries
21888 Kamilaroi Highway, Narrabri 2390
Ph: 02 6799 1520
Email: jon.baird@dpi.nsw.gov.au

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

Water extraction, water-use and subsequent fallow water accumulation in summer crops

Lindsay Bell[1], Andrew Erbacher[2]

[1] CSIRO Agriculture and Food
[2]Department of Agriculture and Fisheries, Queensland

Key words

sorghum, maize, cotton, mungbean, water-use-efficiency, soil, yield, systems

GRDC code

CSA 00050, DAQ 00192

Take home messages

- Consider both soil water extraction as well as subsequent fallow accumulation when considering different summer crop options.
- Cotton and maize had higher water use than sorghum, but less efficient fallows.
- Mungbean water use and soil water extraction is often lower than summer cereal crops, but differences are often diminished after the subsequent fallow.
- Differences in soil water extraction under different sorghum configurations are small and seasonal, but impacts on subsequent fallow efficiency could be significant.

Introduction

The efficiency that soil water accumulates during fallows and crops ability to extract that water and convert into yield is a key driver of farming system productivity and profitability. While a large amount of work has been done on winter crops in farming systems, significantly less information is available on the relative water extraction of different summer crops and their impact on subsequent fallow water accumulation. Some previous work was conducted in the western farming systems projects and in Central Queensland that examined the impact of different sorghum crop configurations on water extraction and fallow accumulation. The current GRDC-funded farming systems projects have also gathered useful information on the soil water dynamics during and after different summer crop options in the farming system. This paper aims to provide an update on some of this information and improve understanding of how crop choice and management might influence residual soil water at the end of the crop and accumulation during a subsequent fallow.

Differences in crop water extraction between summer crops

Amongst the various summer crops grown across farming systems research sites, there are 3 cases where there are opportunities to draw comparisons of soil water dynamics during and after summer crops of different types.

Core farming systems site 2016/17

At the farming systems experiment at Pampas in 2016/17 a range of summer crops (maize, sorghum and cotton) were sown in the same season, with similar crop history and starting soil water (220 mm plant available water) (see Table 1). This allows a useful comparison of the extent of soil water extraction between these crops under the same conditions and the soil water accumulation during the subsequent fallow. Mungbean was also sown, but later in the same summer season.

In this season 136 mm of rain fell after soil sampling at the end of August and before sowing maize, sorghum and cotton on 5 October. Hence, the soil profile was full at sowing for each of these crops. Similarly, 265 mm of rain, replenished the soil profile to > 200 mm before Mungbean sowing on 10 Jan 17. Hence, all crops began with a full soil profile.

Soil sampling post-harvest in all these crops revealed only small differences in soil water – ranging from 130 mm in mungbean to 175 mm in sorghum. Effective crop water use over this period, after estimated soil evaporation was subtracted, was similar in maize and cotton, about 30 mm lower in sorghum and about 80 mm lower in mungbean. Despite relatively high crop water use, mungbean and maize yields (1.4 and 3.4 t/ha respectively) resulted in much lower returns per mm of crop water use ($ 0.70-0.80/mm) compared to cotton (4.1 bales/ha) and sorghum (6.8 t/ha) which produced higher returns per mm of crop water use ($ 1.80-2.00/mm).

A dry winter followed these crops with little soil water accumulating. Soil water status after sorghum and maize was maintained, while this declined after cotton and mungbean – presumably due to lower ground cover following these crops. Hence, at the start of the next summer cropping season, soil water was 20 mm lower after cotton than it was after maize, and this was significantly lower than after sorghum (35 mm). Over the whole annual sequence (from 30 Aug 16 to 20 Sept 17), including the crops water extraction and subsequent fallow accumulation, the relative change in soil water was 20 mm less for maize than cotton, 50 mm higher for sorghum than cotton and 65mm higher for mungbean than cotton.

Table 1. Comparison of soil water extraction, crop water use efficiencies and subsequent fallow soil water status between summer crop options sown at the core farming systems experiment, Pampas during the summer of 2016/17

		Sorghum	Maize	Cotton	Mungbean
Crop water availability and use					
Plant available water (PAW) pre-sowing (30 Aug 16)		**220**	**221**	**223**	**117**
Plant available water (PAW) post harvest (1 May 17)		**175†**	**148**	**141**	**130**
In crop Rainfall – 740 mm	Pre-sowing to sowing	136	136	136	265
	Sowing - maturity	287	337	347	280
	Maturity to post-harvest	317	267	257	9
Effective crop water use (30 Aug 16 – 1 May 17)[A]		**495**	**523**	**532**	**437**
Crop water use efficiency (WUE) (kg product/mm water use)		**13.7**	**6.1**	**1.7**	**2.8**
Crop WUE ($/mm water use)		**2.02**	**0.74**	**1.82**	**0.83**
Fallow water accumulation					
Fallow rainfall (1 May – 20 Sept 17)			78		
PAW at end of subsequent fallow (20 Sep 17)		**180†**	**146**	**127**	**92**
Net change in soil water (30 Aug 16 to 20 Sept 17)		**-40**	**-75**	**-96**	**-25**

† - Calculated from soil samples taken earlier; [A] – Total rainfall + soil water extraction – APSIM predicted soil evaporation (290 mm)
Price assumptions used in calculations were 10 year median port prices less $40/t cartage costs. These were $221/t for sorghum, $667/t for mungbean, $281/t for maize and $1090/t for cotton ($537/bale plus seed).

Core farming systems site 2017/18

In the subsequent summer cropping season, data from the core experimental site at Pampas allowed for comparisons of soil water extraction and crop water use between sorghum (solid plant 1 m row spacing, 60,000 plants/ha), high density sorghum (solid plant 0.5 m row spacing, 90, 000 plants/ha) and mungbean (see Table 2). The crops compared here had a common crop history (following maize in 2016), and soil nutrient status was also similar. This showed little difference in soil water extraction between these different crops, but effective crop water use was estimated to be 20 mm less in mungbean than sorghum in the same summer. Interestingly there was no difference in sorghum crop water extraction, or crop water use efficiency between the standard or high density configurations.

Table 2. Comparison of soil water extraction, crop water use efficiencies and subsequent fallow soil water status between summer crop options sown at the Core Farming Systems experiment, Pampas during the summer of 2017/18.

		Sorghum	Sorghum (high density)	Mungbean
Plant available water (PAW) (20 Sept 2017)		166	156	152
PAW post harvest (26 Mar 2018)		**58**	**40**	**42**
Change in soil water		**-108**	**-116**	**-110**
In crop Rainfall – 362 mm	Pre-sowing to sowing	125	125	169
	Sowing - maturity	140	140	96
	Maturity to post-harvest	97	97	97
Effective crop water use (20 Sep 17 – 26 Mar 18)[A]		**269**	**266**	**245**
Crop water use efficiency (WUE) (kg product/mm water use)		**18.9**	**18.5**	**4.2**
Crop WUE ($/mm water use)		**2.62**	**2.86**	**1.75**

[A] – Total rainfall + soil water extraction – APSIM predicted soil evaporation (200-220 mm)
Price assumptions used in calculations were 10 year median port prices less $40/t cartage costs. These were $221/t for sorghum and $667/t for mungbean.

Billa Billa farming systems site 2016/17

Two separate comparisons of summer crops are possible at the Billa Billa Farming systems site in summer 2016/17 (Table 3). The first, between spring sown sorghum crops with different starting soil waters (after a long-fallow after wheat, and after a short-fallow following mungbean). Both sorghum crops finished with similar post-harvest soil water status, despite nearly 100 mm difference in starting soil water. The sorghum crop with the higher availability of water yielded significantly more and ended with a much higher crop grain WUE than the crop starting with more marginal soil water. This translated into double the gross margin return per mm.

The second comparison can be made between sorghum and mungbean crops sown in January following a pulse crop the previous winter. Both crops started with a similar soil water status, but soil water was about 100 mm lower following the sorghum crop compared to the mungbean crop in July after harvest. This was largely driven by the difference in maturity timing between the crops, with the sorghum crop having access to an additional 115 mm of in-crop rain that fell after the mungbean crop was mature. So in the case of the mungbean crop, this 115mm would have added to finishing soil PAW levels. Despite these differences in post-harvest soil water at July 2017, differences in soil water were negated at the end of the subsequent fallow (in March 2018); with soil water similar at this time. Over the whole annual cycle, there was only a marginal difference in the change in soil water, with sorghum extracting more soil water than mungbean but higher subsequent fallow efficiency after sorghum made up for this difference.

Table 3. Comparison of soil water extraction, crop water use efficiencies and subsequent fallow soil water status between summer crop options sown at the Billa Billa farming systems experiment during the summer of 2016/17

		Date	Comparison 1		**Date**	Comparison 2	
			Sorghum (long-fallow)	Sorghum (short-fallow)		Sorghum	Mungbean
Plant available water (mm)	Pre-sowing	1 Sep 16	**237**	**142**	13 Oct 16	181	181
	Post-harvest	31 Jan 17	51	44	12 July 17	**78**	**188**
Change in soil water (mm)			**-186**	**-98**		**-103**	**+9**
Rainfall	Pre-sow to sowing		149	149		71	71
	Sowing - maturity		128	128		329	177
	Maturity – post-harvest		12	12		0	115
Total rainfall pre-sow to post-harvest			289	289		401	401
Estimated soil evaporation			195			274	
Effective Crop water use (mm)[A]			**326**	**238**		**432**	**320**
Crop water use efficiency (WUE) (kg product/mm water use)			**4.6**	**3.69**		**3.71**	**1.58**
Crop WUE ($/mm water use)			**1.45**	**0.77**		**0.74**	**0.39**
Post-fallow plant available water (20 Mar 18)			**223**[†]			**196**	**172**
Net change in soil water to 20 Sep 17			**-14**			**+15**	**-9**

[†] - calculated from soil samples taken earlier; [A] – Total rainfall + soil water extraction – APSIM predicted soil evaporation
Price assumptions used in calculations were 10 year median port prices less $40/t cartage costs. These were $221/t for sorghum and $667/t for mungbean.

Impact of sorghum configuration on crop water extraction and water accumulation

Little contemporary work has examined the effects that different sorghum crop configurations, such as solid planting, single skip or double skip, have on crop water use, crop water-use-efficiency and subsequent fallow accumulation. The information presented here is from research conducted previously by others.

In the study of Routley et al 2003 (Table 4), few differences in soil water change and crop water use were statistically significant due to high site variability. However, at 3 of the 4 experimental locations double-skip sorghum crops extracted 20-40 mm less soil water than solid plant. Single skip sorghum was intermediate in soil water extraction and crop water use, with around 10 mm less soil water extraction but these small differences are hard to assess experimentally. Interestingly in these data sets, the high rainfall year at Croppa Creek (> 400 mm in-crop rain) showed a significant yield penalty and lower crop WUE under the double skip configuration compared to single skip or solid plant. In contrast in the low rainfall season at Bungunya (165 mm in-crop rain), the single-skip and double-skip crops yielded similarly to solid plant crops but due to lower soil water extraction had higher crop WUE. Analysis over a wider range of environments and seasons has shown that double-skip or single-skip row sorghum crops only outperform solid-plant sorghum in dry growing seasons or when soil water at sowing is marginal (e.g. <60% full profile) (Whish et al. 2005).

Other locations have also shown marginal differences in total crop water use and soil water extraction between different sorghum row configurations. Results in 10 experiments Nebraska in the USA show no significant difference in total crop water use or extraction between solid, single-skip or double skip configurations (Abunyewa et al. 2011)

Table 4. Effect of sorghum configuration on soil water change, crop water use, yield and crop water-use efficiency over 4 seasons and locations

Site & year (in-crop rain)	Sorghum configuration	Change in soil water (mm)	Crop water use (mm)	Yield (t/ha)	WUE (kg/ha/mm)
Croppa Creek 2000/01	Solid (1 m)	+59	350	5.53	15.8
(409 mm)	Single skip	+71	338	5.60	16.7
	Double skip	+82	327	4.54	13.9
Billa Billa, 2000/01	Solid (1 m)	+13	311	2.91	9.4
(324 mm)	Single skip	+23	301	2.63	8.7
	Double skip	+19	305	2.85	9.4
Bungunya 2001	Solid (1 m)	-126	291	2.62	9.0
(165 mm)	Single skip	-112	277	2.74	9.9
	Double skip	-87	252	2.63	10.5
Billa Billa 2001/02	Solid (1 m)	+17	236	2.57	10.9
(253 mm)	Double skip	-2	255	2.81	11.0

Source: Routley, R., Broad, I., McLean, G., Whish, J., and Hammer, G. (2003). The effect of row configuration on yield reliability in grain sorghum: I. Yield, water use efficiency and soil water extraction. Proceedings of the Eleventh Australian Agronomy Conference, Geelong, Jan 2003.

The impact of the different row configurations on subsequent fallow water accumulation is also a critical factor to consider. It is expected that narrower rows with more even ground cover should improve soil water infiltration during a fallow after sorghum, while wide-row crops would be less efficient at accumulating water. However, there is little information on this currently. An experiment in Emerald conducted in 2006 (Table 5), showed that sorghum sown on narrow rows (0.5 m) had higher average ground cover at the end of the subsequent long fallow and had accumulated about 20 mm more soil water compared to sorghum on wide rows of 2.0 m. Other differences were not significant but intermediate row spacings accumulated soil water between these two extremes.

Further examination of the impact of narrow row (0.5 m) and higher density sorghum crops on subsequent fallow water accumulation is expected in the coming 12 months from farming systems experiments.

Table 5. Effects of sorghum row spacing on ground cover at the end of the subsequent fallow and fallow water accumulation.

Sorghum row spacing (m)	Average ground cover at end of fallow (%)	Fallow water accumulation (29 Mar 05-26 Apr 06)
0.5	22	101
1.0	19	88
1.5	14	86
2.0	14	78

Source: Routley R, Lynch B, Conway M (2006) the effect of sorghum row spacing on fallow cover distribution and soil water accumulation in Central Queensland. In Proceedings of the 13th ASA Conference, 10-14 September 2006, Perth, Western Australia.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We would like to thank the project teams and collaborators contributing to the management and implementation of the farming systems experiments across the northern region. Particular thanks and recognition must go to Richard Routley for reminding me of the past work on sorghum configuration effects on water extraction and fallow efficiency presented here.

References

Abunyewa A, Ferguson RB, Wortmann CS, Lyon DJ, Mason SC, Irmak S, Klein RN (2011) Grain sorghum water use with skip-row configuration in the Central Great Plains of the USA. *African Journal of Agricultural Research* 6 (23), 5328-5338.

Routley R, Lynch B, Conway M (2006) the effect of sorghum row spacing on fallow cover distribution and soil water accumulation in Central Queensland. In Proceedings of the 13th ASA Conference, 10-14 September 2006, Perth, Western Australia.

Routley, R., Broad, I., McLean, G., Whish, J., and Hammer, G. (2003). The effect of row configuration on yield reliability in grain sorghum: I. Yield, water use efficiency and soil water extraction. Proceedings of the Eleventh Australian Agronomy Conference, Geelong, Jan 2003.

Whish J, Butler G, Castor M, Cawthray S, Broad I, Carberry P, Hammer G, McLean G, Routley R, Yeates S (2005) Modelling effects of row configuration on sorghum yield reliability in north-eastern Australia. *Australian Journal of Agricultural Research* **56**, 11-23.

Contact details

Lindsay Bell
CSIRO Agriculture and Food
203 Tor St, Toowoomba Qld, 4350
Ph: 0409 881 988
Email: Lindsay.Bell@csiro.au

Farming systems discussion

Notes

Impact of narrow row spacing on grain yield, seed quality and weed competitiveness in sorghum

Trevor Philp, Pacific Seeds

Key words

Sorghum, narrow row spacing, grain yield, seed quality, weed management, competition

Take home message

In a tough season sorghum grown in narrow rows didn't not reduce the yield or increase lodging, narrow row sorghum did reduce weed populations and has potential to increase fallow efficiency.

Introduction

Grain sorghum is currently grown in three main row widths in the north eastern Australian grain belt, 150cm, 100cm and 75cm. Broadly the higher the yield potential and the more reliable the environment the narrower the row spacing.

There has been a renewed interest in narrow rows in field crops due to two main factors

1. Weeds with resistance to one or more herbicide mode of action group.
2. Improving ground cover to drive improvement in the efficiency of subsequent fallows.

Little data is available for Australia on the effect of narrow row spacing in grain sorghum on yield, grain quality, suppression of weeds and improvement in fallow efficiency. There is also no data on narrow row sorghum planted with precision planters.

Summary

In the 2017-18 season nine grain sorghum trials were conducted to measure the effect of row spacing on yield grain quality and weed populations. Six trials compared 50cm, 75cm and 100cm rows, one trial compared 50cm and 100cm rows and two trials compared 50cm, 75cm and 150cm rows.

All configurations were sown at the same plant density using a single hybrid. Only eight trials were harvested, with the trial at Felton abandoned due to lodging. The Felton site was assessed for weed competition and was the only site that had significant weed populations to assess.

No grain quality data is available at this stage.

A significant difference in grain yield was measured at two of the eight sites, one at Tamworth and one at Goondiwindi, no significant difference between the row configurations was measured at any of the other sites.

Row width had a significant effect on weed population at the Felton Site, with weed population reducing with row width.

An across site analysis of the five sites comparing 100cm, 75 cm and 50 cm was conducted. No difference in grain yield was measured between row configurations.

The 2017-18 sorghum season was below average for yield, with grain size also reduced. Most spring planted crops suffered high levels of stress in the grain fill period, due to no rainfall in January.

Trial analysis description

The trait of yield (kg/ha) was analysed in two ways, firstly with row width included as a fixed effect (model 1: Best linear unbiased estimate BLUE) otherwise known as least square mean. This gives an estimate of the mean yield of the each of the treatments.

And secondly with row width included as a random effect (model 2: Best linear unbiased prediction BLUP). The BLUP value is used to estimate/predict the difference between row widths.

Only the BLUPS are reported.

Results

Table 1. Locations, row widths compared and sowing rate by site

Location	State	Row widths compared	Plant density/ha
Clifton	QLD	100, 75, 50 cm	85,000
Felton	QLD	100, 75, 50 cm	75,000
Brookstead	QLD	100, 75, 50 cm	85,000
Pampas	QLD	100, 75, 50 cm	85,000
Yelarbon	QLD	150, 75, 50 cm	65,000
Goondiwindi	QLD	150, 75, 50 cm	65,000
Yallaroi	NSW	100, 75, 50 cm	85,000
Tamworth	NSW	100, 75, 50 cm	75,000
Premer	NSW	100, 50 cm	85,000

Table 2. Individual trial results, grain yield by row width

Location	Row width	BLUP kg/ha	RANK	Rel mean %	se	Rep number	CV%	h2	P.value
Goondiwindi	50CM	3262	1	132.9	58	2	3.37	0.99	0.16
Goondiwindi	75CM	2214	2	90.2	58	2			
Goondiwindi	150CM	1886	3	76.9	58	2			
Premer	50CM	7462	1	100.0	70	3	NA	NA	NA
Premer	100CM	7462	1	100.0	70	3			
Pampas	50CM	3655	1	108.2	263	3	30.22	0.24	0.28
Pampas	75CM	3173	3	94.0	263	3			
Pampas	100CM	3303	2	97.8	260	3			
Brookstead	50CM	3075	1	103.2	186	3	20.01	0.22	0.32
Brookstead	75CM	3039	2	102.0	186	3			
Brookstead	100CM	2828	3	94.9	181	3			
Yelarbon	50CM	1947	2	94.8	177	3	15.52	0.89	0.19
Yelarbon	75CM	1626	3	79.2	177	3			
Yelarbon	150CM	2588	1	126.0	177	3			
Tamworth	50CM	6469	3	97.0	52	2	1.12	0.95	0.18
Tamworth	75CM	6770	2	101.5	42	3			
Tamworth	100CM	6771	1	101.5	42	3			
Yallaroi	50CM	4480	1	101.8	139	3	9.39	0.15	0.34
Yallaroi	75CM	4321	3	98.2	149	2			
Yallaroi	100CM	4396	2	99.9	144	2			
Clifton	50CM	2972	3	100.0	26	2	0.23	0.03	0.04
Clifton	75CM	2972	1	100.0	26	4			
Clifton	100CM	2972	2	100.0	26	3			

Table 3. Across site result, Clifton, Pampas, Brookstead, Yallaroi, Tamworth, and Premer

Treatment	est_blup	rank_blup	rel_blup	se_blup
100CM	4627	1	100	0
75CM	4627	1	100	0
50CM	4627	1	100	0

Table 4. Weed population by row spacing at harvest, Felton Site 2018

Row width	Subscript	Weed count blup	Rank blup	Rel %	se_blup		
100CM	a	49.8	1	175.6	3.2	CV%	19.861
75CM	b	23.5	2	82.8	3.2	h2	0.974
50CM	b	11.8	3	41.6	3.2	P.value	0.166

Discussion

Overall these trials demonstrated no consistent significant difference in yield by row width, although only one hybrid was tested at a single planting rate.

Two sites showed significant difference in row spacing, Goondiwindi showed a clear advantage in the 50cm rows against the commercial standard row spacing of 150cm. This advantage was created due to less lodging in the 50cm, the 50cm rows appeared to create more biomass early and ran into stress earlier than the 150cm rows. The earlier stress resulted in less yield potential, and reduced height, no rainfall occurred in the grain fill period which resulted in the higher yield potential treatment to lodge.

The Tamworth trial had a similar environment but stressed earlier and then was relieved by late rain, which favoured the 100cm rows over the 75 and 50cm rows.

In all sites row canopy closure occurred much earlier in the 50cm row configuration, providing better ground cover. Water use and water use rate wasn’t measured in these trials, but the 50cm rows may use soil water at a faster rate in the vegetative phase and potentially increase the chance of stress prior to flowering.

The combination of an appropriate hybrid and plant density and the 50cm row spacing has the potential to improve the sorghum crops competition against weeds, reducing weed seed set and improving yields. This system has potential to improve the fallow efficiency of the overall system, as well as lifting the sorghum yield and reliability in most seasons.

Further work to assess the impact on yield and quality is needed and work is needed to assess the effect on the fallow efficiency after the sorghum crop. Detailed economic analysis is needed to determine the cost benefit of purchasing a narrow row precision planter.

Contact details

Trevor Philp
Summer Grains Agronomist
Pacific Seeds
Email: trevor.philp@advantaseeds.com
Mb: 0427 568 517

Pushing a tropical crop into the arctic zone?
Sowing sorghum into cold soil temperatures - risks and rewards

Loretta Serafin[1], Mark Hellyer[1], Annie Warren[1], Andrew Bishop[1] and Michael Mumford[2]

[1]NSW Department of Primary Industries, Tamworth
[2] Department of Agriculture and Fisheries, Toowoomba

Key words

Sorghum, agronomy, sowing time, soil temperatures, flowering, grain yield

GRDC code

DAN00195 Tactical sorghum and maize agronomy for the northern region – NSW component

Take home messages

- Plant establishment was significantly impacted by the super early (early August) and early (late August) sowing times when soil temperatures were between 8.4 and 12.2°C.
- Plant populations from the early August (super early) sowing, particularly at the Mallawa and Gurley sites, were approximately half the population established from the standard sowing time (October) when soil temperatures were consistent with or greater than current recommendations of 16-18°C.
- Viable plant stands were established at sub optimal temperatures and produced higher yields than the standard sowing time at Mallawa and Breeza. Sowing sorghum into cool soils has the potential to shift the flowering window and reduce the risk of heat and moisture stress during flowering and grain fill and increase the likelihood of double cropping opportunities.
- However, this is dependent on being able to establish the crop in a timely manner. At the Breeza site for example, the time taken for emergence was significantly lengthened for the early August and late August sowing. As a result there was little impact on flowering date achieved by varying sowing time compared to the standard window in late September.
- There is a need to further understand the effect of cool and freezing temperatures on germination, emergence, canopy and growing point development before the practice of "super early" or "early" sowing could be extended commercially across the northern grains region.

Background

Grain sorghum is the most important summer cereal crop in NSW, providing important rotational, logistical and cash flow benefits for the northern grains region.

Many in the industry would agree that climatic variability in the past 10 years has seen an increasing trend of crop yield reduction, and sometimes failure, as a result of sorghum crops flowering and filling grain in periods of extreme heat and moisture stress.

NSW DPI and GRDC have partnered in research to evaluate options for sorghum sowing and agronomic management that challenge our current practices. This includes our accepted views on ideal sowing time and hybrid selection by comparing alternative practices which could be readily adopted by growers using current genetics and technology.

Seasonal overview

Three sites were sown in northern NSW in the 2017-18 season; Gurley (south east of Moree), Mallawa (west of Moree) and Breeza on the Liverpool Plains. At each of these sites three treatments were included:

1. Varying time of sowing, based on soil temperature at 8am EST; super early (~ 10°C), early (14°C) and a standard (16-18°C) in an attempt to bring flowering and grain fill forward.
2. Varying sowing depth; standard (3-4 cm) and deep (7-8 cm) seeding depth to chase warmer soil temperatures.
3. Comparing cold tolerance of 9 commercial hybrids: MR Buster, MR Apollo, Cracka, Tiger, HGS114, HGS102, Archer, Agitator, G33.

The 2017-18 season produced three distinct environments as outlined in Table 1.

I. Breeza which experienced cool spring temperatures; 21 days with temperatures <0°C for the early August sowing; and warm summer temperatures 35 days >36°C;

II. Gurley which had mild and wet late spring conditions (109 mm in Oct), warmer flowering and grain fill conditions compared to Breeza;

III. Mallawa which had cool conditions for August (12 days <0°C) and then extreme heat (60 days >36°C) and dry summer conditions for December – January.

Table 1. Summary of weather conditions for sorghum trials sown during the 2017-18 season. Soil temperature is at 8 AM across seven days after sowing.

Site	Time of sowing	Sowing date	Sowing depth	Average Soil T (°C) at sowing	Mean max T (°C)	Mean min. T (°C)	In- crop rain-fall (mm)	*No.* days ≤ 0 °C	*No.* days ≥ 36 °C
Gurley (NE NSW)	Super early	2nd Aug	Shallow	10.8	29.8	13.7	315	2	39
			Deep	11.4					
	Early	21st Aug	Shallow	12.0	30.5	14.5	293	2	39
			Deep	12.2					
	Standard	17th Oct	Shallow	20.0	33.0	17.5	206	0	39
			Deep	19.1					
Mallawa (NW NSW)	Super early	1st Aug	Shallow	8.4	31.5	13.2	222	12	60
			Deep	10.5					
	Early	24th Aug	Shallow	9.2	32.7	14.6	222	6	60
			Deep	10.8					
	Standard	18th Oct	Shallow	18.6	35.2	17.9	149.5	0	57
			Deep	15.6					
Breeza (LP)	Super early	10th Aug	Shallow	9.7	29.3	11.6	225	21	35
			Deep	10.2					
	Early	28th Aug	Shallow	10.8	30.2	12.8	225	12	35
			Deep	11.5					
	Standard	21st Sept	Shallow	15.8	31.4	14.7	220	0	35
			Deep	15.7					

Statistical methods

A split-split plot design was employed at each of the 3 sites. The data was analysed using the REML procedure in ASReml-R and the level of significance for least significant difference (LSD) testing was set at 5%.

Results

Plant establishment

The early August (super early) sowing times established only half the number of plants compared to the standard sowing time (Table 2) at Gurley and Mallawa. Establishment improved for the late August (early) sowing but was still less than the standard.

In addition to the lower plant populations established, the time taken for these plants to emerge was substantially longer. For example there were no plants present until 3 weeks post sowing at Breeza for the two early sowings and plants were still emerging up to 6 weeks post sowing.

There was no difference in the establishment of hybrids except at the Mallawa site where Agitator had significantly lower establishment (data not shown).

Table 2. Established plant populations at sorghum trials sites - averaged across treatments

Site/ Established population (plants/m^2)	Super Early (early August)	Early (late August)	Standard (Mid Oct[1], Late Sept[2])	LSD value
Mallawa[1]	1.9	2.5	4.1	0.9
Gurley[1]	1.6	2.8	4.4	0.6
Breeza[2]	3.2	3.3	5.0	0.5

Days to flowering

There was a large reduction in the time taken to reach 50% flowering at the Mallawa site when moving from the super early (120-136 days) and early (105 -116 days) sowing times (Figure 1, i). The spread of flowering times between hybrids also became smaller with the later planting, from 16 down to 11 days.

Similarly, at Gurley the days to 50% flowering was reduced between each of the sowing times, super early (116 – 132 days), early (101-116 days) and standard (66-69 days) planting dates, as was the spread between hybrids (Figure 3,ii).

This equates to flowering in late November – mid December for the super early panting times and mid-December for the early sowing time at Gurley and Mallawa. The standard sowing time flowered between Christmas and New Year and so no dates were recorded. There was a significant TOS by hybrid interaction effect at both sites. Sowing depth had no significant impact on flowering date at either site.

At Breeza, there was very little impact of sowing time on days to 50% flowering with all three flowering similarly around early to mid-December. This is likely due to emergence being spread over an extended period at this site for the super early and early sowing times.

There was a significant hybrid effect with MR Buster and Agitator flowering much earlier than the other hybrids with MR Apollo being the slowest to reach flowering. This was a similar trend at the other two sites.

At the Breeza site only, the shallow sowing depth was quicker to reach 50% flowering than the deep sowing.

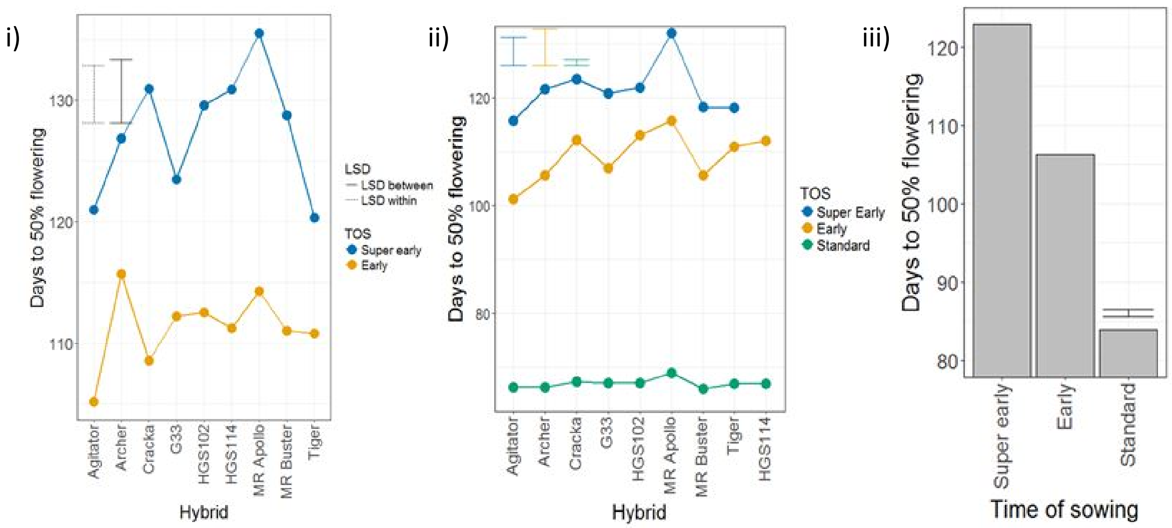


Figure 1. Days to 50% flowering at i) Mallawa, ii) Gurley iii) Breeza

Grain yield

Grain yields ranged from a low of 1.3 t/ha on average at Mallawa to 3.2 t/ha at Gurley and 3.4 t/ha at Breeza averaged across treatments at 0% moisture content.

At Mallawa the early August (super early) and late August (early) sowing time produced higher yields than the standard sowing time despite having highly reduced plant establishment (Figure 2). There was no difference in grain yield associated with varying the sowing depth (data not shown).

At Gurley, the standard October sowing performed generally better than the early August (super early) and late August (early) treatments. MR Apollo showed no significant response to time of sowing which was similar to the Mallawa site (Figure 2). MR Buster, Agitator and Archer showed the same relationship with the standard sowing time out yielding the super early and early sowing times. G33 and HGS102 showed similar yield performance for the super early and early sowing times.

For HGS102 there was a significant interaction between hybrid and seeding depth, with the shallow seeding depth increasing yield whilst other hybrids had no significant response to seedling depth.

At Breeza, yields were generally higher from the early August (super early) and late August (early) sowing times compared to the September sowing even though established plant populations were only two thirds of the plant stands achieved with the standard sowing time in September (Figure 2).

There was also a significant TOS by seedling depth interaction effect with the early TOS having a significantly higher yield than the standard TOS for the shallow but not the deep seedling depth. Archer, Cracka and MR Buster performed relatively well in terms of yield across all three times of sowing at Breeza. G33 and HGS114 performed well in the super early and early sowing times but were disappointing for the standard sowing time. Agitator did not perform well across the three sowing times at this site in 2017/18.

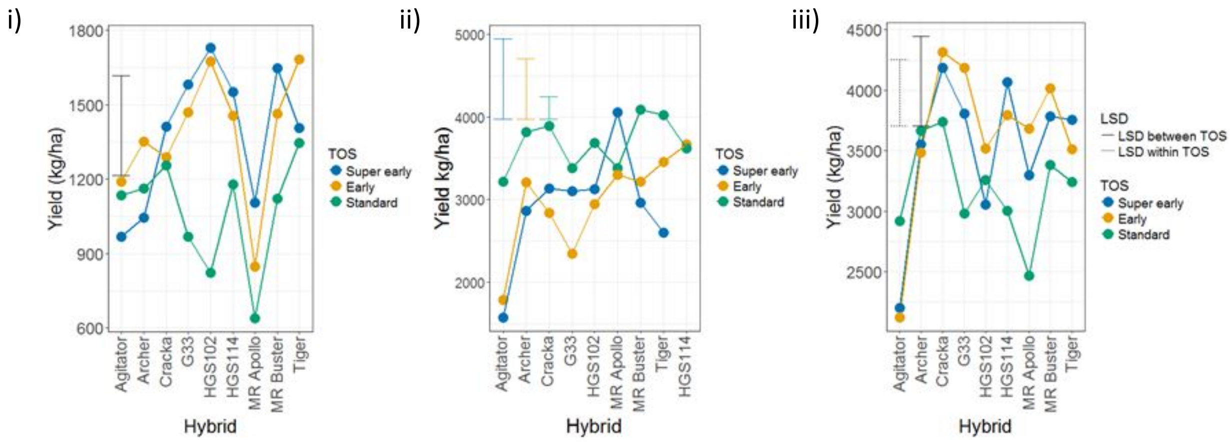


Figure 2. Grain yield at 0% moisture at i) Mallawa, ii) Gurley iii) Breeza

Conclusions

Growers currently have access to a range of tools to vary the time to flowering and the conditions experienced by their sorghum crops during grain fill. These tools are, however accompanied by an increased level of risk.

In this single year of research across three sites, benefits were minor from varying sowing depth to seek warmer soils for early sowing conditions. While differences in soil temperatures between the two depths shallow and deep were detected this did not equate to improvements in plant establishment or grain yield at two of the three sites.

Sowing in early and late August at all three sites, showed that sorghum can be established at sub optimum temperatures and handle some cold (<0°C) conditions. However, this early sowing time came at a significant establishment cost. Further, evaluation of the impacts of severe frosting on plant growth and survival are needed.

At Mallawa and Gurley, establishment was less than half that which occurred in the standard sowing time. Therefore a lot of seed never contributed to grain yields but an input cost had been incurred. The impact of drying soil conditions at these two sites needs to be considered also.

In contrast, at Breeza where soil moisture was controlled through irrigation, establishment losses from the early and late August sowing were still significant but not as great as the other two sites, when compared to the standard sowing time.

At all three sites viable plant stands were established. At Mallawa and Breeza, the two early sowing times resulted in superior yields compared to the standard sowing time. At Gurley it was the opposite, most likely due to the timing of in-crop rainfall.

Flowering data has shown that it is possible to move the flowering and grain fill window to earlier in the season, provided that the time taken for crop establishment is not excessively prolonged by cool early growing conditions such as occurred at Breeza. At Breeza there was little difference in days to flowering between all three sowing times even though sowing time varied from 10th august to 21st September.

It was not possible to detect many differences between hybrids with respect to cold tolerance in this year's field trials, due to confounding background genetics, seed production and quality attributes. A pot trial has been conducted to try and further separate some of these confounding factors.

As expected, these results should be considered preliminary as they are the results of three experimental sites in one season. It is hoped that this research can be continued into the future to further validate these preliminary findings.

Acknowledgements

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

In particular thanks to our trial co-operators; Mark & Wendy Manchee, Gurley; Jason & Geoff Hunt, Mallawa and Scott Goodworth NSW DPI Breeza for their assistance with the sites.

Thanks to Delphi Ramsden, Alice Bowler and Simon Tydd for technical assistance.

Contact details

Loretta Serafin
NSW Department of Primary Industries
4 Marsden Park Road, Calala, NSW
Ph: 0427 311 819 or 02 6763 1100
Email: Loretta.serafin@dpi.nsw.gov.au

The efficacy of chaff lining and chaff tramlining in controlling problem weeds

Annie Ruttledge[1], Michael Widderick[1], Michael Walsh[2], John Broster[3], Kerry Bell[1], Annie Rayner[2], Adam Jalaludin[1], Onella Cooray[1], Linda Heuke[2], Shona Robilliard[2] and Alison Chambers[3]

[1] Department of Agriculture and Fisheries, PO Box 2282, Toowoomba, Queensland 4350, Australia
[2] University of Sydney, 12656 Newell Highway, Narrabri, New South Wales 2390, Australia
[3] Charles Sturt University, Locked Bag 588, Wagga Wagga, New South Wales 2678, Australia

Key words

Chaff lining, chaff tramlining, harvest weed seed control, annual ryegrass, brome grass, wild oats, wild radish, turnip weed, common sowthistle

GRDC code

US00084 (Innovative Crop Weed Control for Northern Region Cropping Systems)

Call to action/take home messages

- Use chaff lining or chaff tramlining concentrates weed seeds into a narrow area.
- A heavy layer of chaff will lead to better suppression of weed emergence.
- Small seeded broadleaf weeds (e.g. common sowthistle) are more easily suppressed than grass weeds with larger seeds (e.g. annual ryegrass).
- Thick tramlines and chaff lines reduce but do not prevent weed emergence, so other measures may be needed to control weeds in tramlines/chaff lines (e.g. spraying the tramlines with a shielded sprayer).

Background

Herbicide resistance is a major concern for northern region crop production due to the increasing frequency of resistance in key weeds. Of particular concern is the increasing incidence of glyphosate resistance, with 9 weed species now confirmed as glyphosate resistant in the northern region (Heap, 2018). Regardless of the ever-increasing frequency of herbicide-resistance, herbicides will likely remain the most effective form of weed control in cropping systems. However, for herbicides to remain effective, non-herbicide weed management alternatives are needed to delay the spread and onset of further herbicide resistance (Walsh et al., 2013). One such alternative is harvest weed seed control (HWSC).

In this paper we report on research evaluating the effectiveness of chaff tramlining and chaff lining as harvest weed seed control tactics for northern region weeds.

Chaff lining and chaff tramlining are forms of harvest weed seed control (HWSC) that have potential for widespread adoption in northern Australia owing to their relative low cost and ease-of-implementation. Chaff tramlining is the practice of concentrating the weed seed bearing chaff material on dedicated tramlines in controlled traffic farming (CTF) systems. Chaff lining is a similar concept, where the chaff material is concentrated in a narrow row between stubble rows directly behind the harvester. The chaff environment is likely to be suboptimal for seed persistence and seedling establishment, therefore, this practice has the potential to be as effective as other forms of harvest weed seed control in depleting weed seed banks.

Aim

To evaluate the influence of different amounts and types of chaff on weed seedling emergence.

Method

Pot experiments were conducted at Narrabri and Toowoomba. There were some variations on the method used at each location (i.e. type and dimensions of experimental unit e.g. pot versus trays), but the basic method involved 4 replicates of each experimental unit (pot or tray filled with potting mix and sown with either 100 or 200 weed seeds on the surface), with 8-9 rates of chaff (either wheat or barley). A pre-weighed layer of chaff was added to the surface of each pot at the equivalent rates of 0, 3, 6, 12, 18, 24, 30, and 42 t/ha. Once the chaff was evenly spread across the soil surface, the pots were watered thoroughly and kept moist for 28 days, over which time weed emergence was recorded. Differences between chaff types and rates were assessed using the total germination over a 28 day period.

The chaff rates used in the pot experiments were designed to mimic the rates of chaff that may occur in a field situation. To calculate the rates of chaff that might be expected in a field situation, the following formula was used:

Y = 0.3 x Z x (harvester width/tramline width)

Where Y = chaff yield and Z = grain yield of wheat

Note: assuming chaff yield is 30% of grain yield

This formula is based on previous experimentation in wheat (data not shown), where chaff yield was determined to represent approximately 30% of the grain weight. For example, using a wheat yield of 3.5 t/ha, a 12m harvester width and a 30cm chaff line width, the amount of chaff concentrated into a chaff line would be 42 t/ha.

Statistical analysis

The treatments used in the Narrabri pot experiment were 8 rates of wheat chaff laid out in a randomised complete block design with four replicates to explore emergence of annual ryegrass. The Toowoomba-based pot experiment was a factorial combination of eight rates by two chaff types (wheat and barley) by two weed species (annual ryegrass and common sowthistle), also laid out in a randomised complete block design with latinisation of the treatment.

The emergence data from both the Toowoomba and Narrabri pot experiments were transformed using angular (or arcsine) transformation and predictions back-transformed. The data were analysed using ANOVA or REML procedure in Genstat 19th Edition (VSN International, 2017). In the analysis of the Toowoomba-based pot experiment the rate and chaff type treatments were partitioned for each weed species. The level of significance was set at 5% for all testing. The protected least significant test (LSD) was used for pair-wise comparisons of significant treatment effects.

Results and discussion

Annual ryegrass

In both the Narrabri (Figure 1) and Toowoomba (Figure 2) pot experiments; there was a consistent reduction in annual ryegrass emergence with increasing amounts of wheat chaff. More detailed results including the LSDs used to compare treatments are presented in the Appendix. Relative to the zero chaff treatment, emergence of annual ryegrass was reduced by the presence of wheat chaff at rates equal to and over 18 t/ha and 24 t/ha in the Narrabri and Toowoomba experiment, respectively.

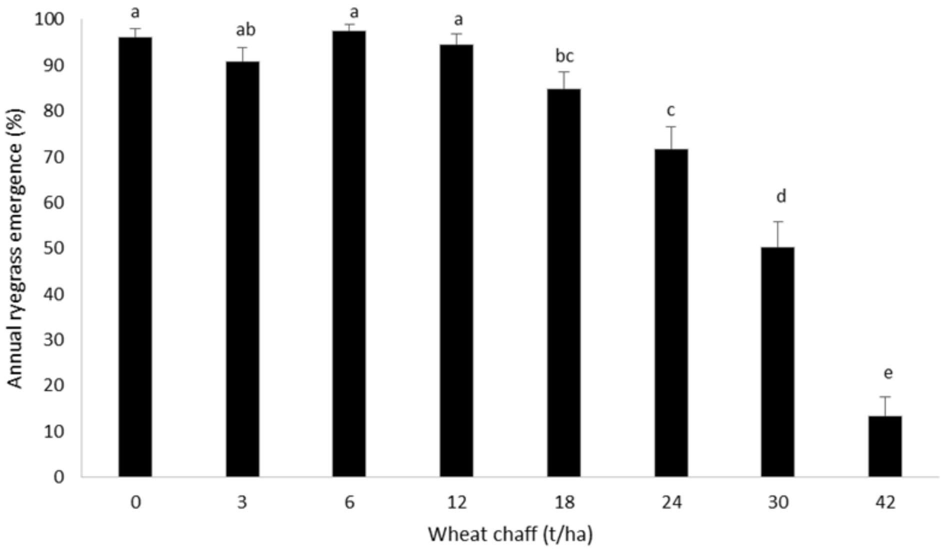


Figure 1. Emergence of annual ryegrass through wheat chaff at 8 different rates (t/ha) in a pot experiment conducted at Narrabri, NSW

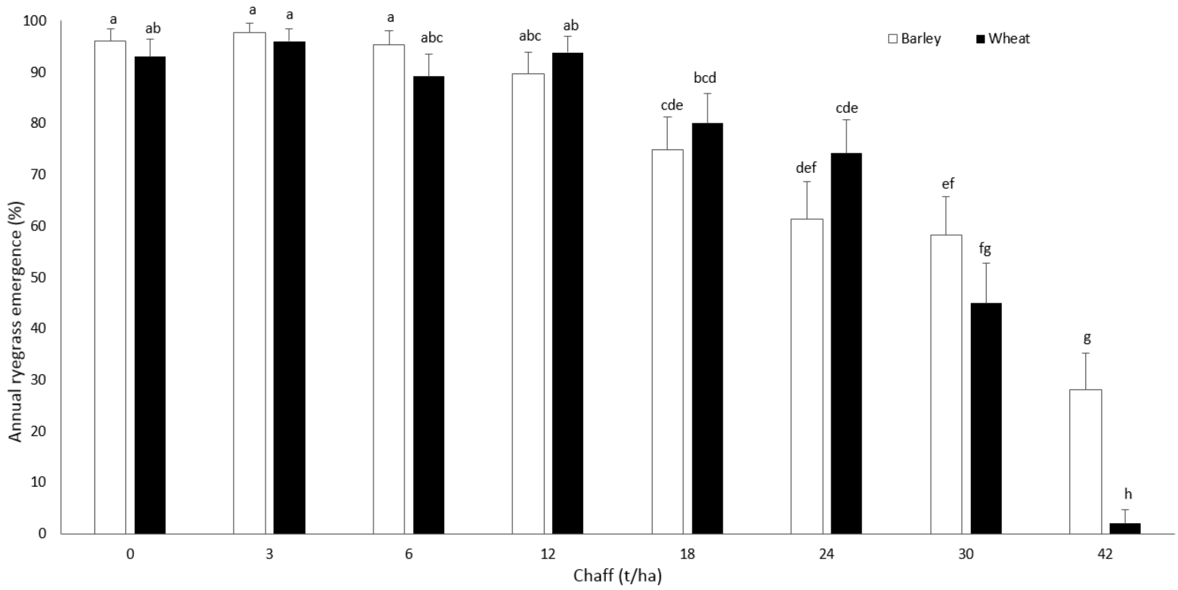


Figure 2. Emergence of annual ryegrass through barley and wheat chaff at 8 different rates (t/ha) in a pot experiment conducted at Toowoomba, QLD

There was an interaction between chaff amount (weight) and chaff type (barley vs wheat) on annual ryegrass emergence. There was no significant difference between chaff types at rates = 0, 3, 6, 12, 18, 24 and 30 t/ha. At 42 t/ha of barley chaff there was greater annual ryegrass emergence than at the same amount of wheat chaff (Figure 2).

At the greatest chaff rate (42 t/ha), annual ryegrass emergence from wheat chaff was 14% in the Narrabri experiment and 2% in the Toowoomba experiment. In the case of barley chaff, emergence was much greater (28%) at the 42 t/ha chaff rate. The Toowoomba pot experiment is currently being repeated to confirm the results of the first experiment and an additional greater chaff amount (60 t/ha) treatment is being used.

Common sowthistle

Emergence of common sowthistle declined sharply with increasing amounts of chaff at rates equal to and exceeding 12 t/ha (Figure 3). More detailed results including the LSD used to compare treatments are presented in the Appendix. There were significant main effects of chaff type and chaff rate, but no significant interaction (for this reason, data are combined for both chaff types). Overall, there was higher sowthistle emergence from beneath barley chaff (49.0%) compared with wheat chaff (40.6%). There was no difference between the chaff rates at 0, 3 and 6 t/ha, but emergence was reduced at all higher chaff amounts. Common sowthistle emergence was almost completely suppressed (0.02% emergence) at the heaviest chaff amount (42 t/ha).

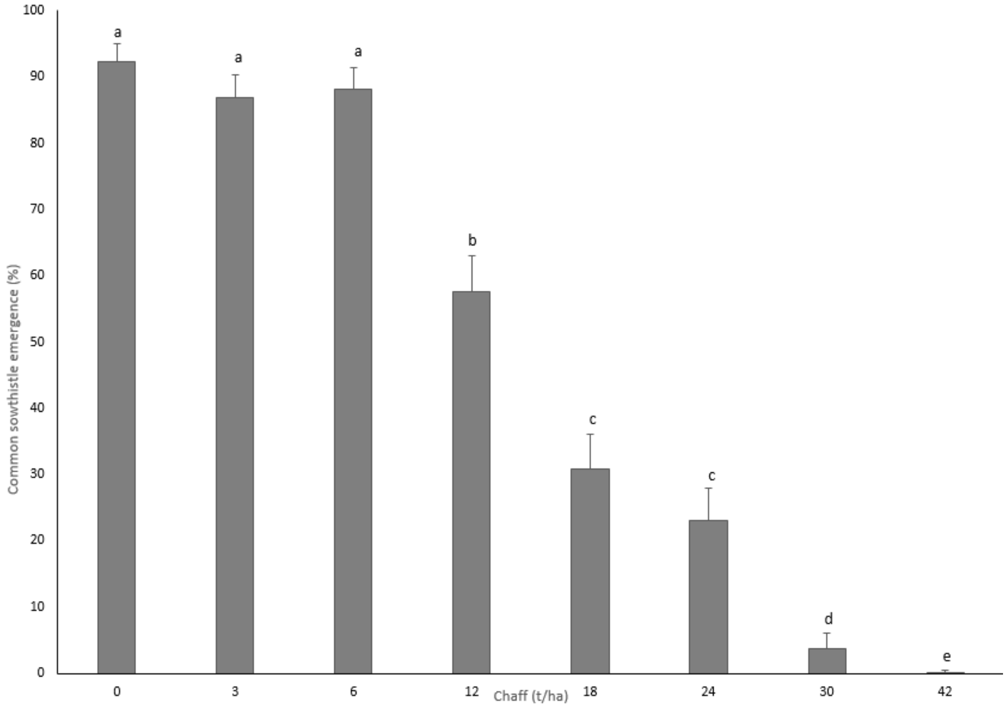


Figure 3. Emergence of common sowthistle through barley and wheat chaff (combined data) at 8 different rates (t/ha) in a pot experiment conducted at Toowoomba

The difference in emergence responses of the two weed types is likely due to the larger seed size of annual ryegrass, providing the seedlings with greater energy reserves to grow through deeper layers of chaff to reach light. An alternative suggestion is that, relative to grasses, the broad leaf structure of sowthistle seedlings renders them less capable of penetrating through chaff layers. These two reasons could work in combination to render common sowthistle more susceptible to smothering by chaff layers, relative to annual ryegrass.

Conclusions

The results of these pot studies indicate that emergence of common sowthistle will be better suppressed than annual ryegrass under similar amounts of chaff.

Relative to barley chaff, wheat chaff had a greater suppressive effect on the emergence of annual ryegrass seedlings. This could be due to structural or chemical (allelopathic) differences between the chaff types and will be the subject of further research over the next 6-12 months.

In a chaff tramlining system chaff material is deposited on both tramlines, and therefore each tramline will have only half the amount of material than is concentrated in a single chaff line. For this reason, chaff lining may be more effective than tramlining in achieving weed suppression, owing to the greater concentration of chaff in one line versus 2 lines.

In summary, using tramlining or chaff lining can considerably reduce weed emergence given sufficiently high chaff loads. Because chaff tramlining/chaff lining will concentrate the weed seeds into narrow strips, the bulk of the seed bank is distributed over a small area favouring the use of more efficient and targeted chemical/mechanical approaches.

Acknowledgements

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

References

Heap, I. The International Survey of Herbicide Resistant Weeds. Online. Internet. Sunday, June 17, 2018. Available www.weedscience.com

VSN International (2017). *Genstat for Windows 19th Edition*. VSN International, Hemel Hempstead, UK. Web page: Genstat.co.uk

Walsh MJ, Newman P, Powles SB (2013) Targeting weed seeds in-crop: A new weed control paradigm for global agriculture. *Weed Technol.* 27:431-436

Contact details

Annie Ruttledge
Department of Agriculture and Fisheries
Leslie Research Facility, 13 Holberton Street, Toowoomba QLD 4350
Ph: 07 4529 1247
Email: annemieke.ruttledge@daf.qld.gov.au

Site-specific physical weed control

Michael Walsh and Guy Coleman, University of Sydney

Key words

physical weed control, site-specific weed management, energy requirements

GRDC code

US00084

Take home messages

- Developments in sensing technology will soon allow the direct targeting of weeds within cropping systems
- Site-specific weed control creates the opportunity to use alternate physical weed control technologies
- Energy required to effectively control weeds is an effective approach to identifying suitable physical weed control techniques

Background

The reliance on herbicidal weed control has resulted in the widespread evolution of herbicide-resistant weed populations (Boutsalis et al., 2012; Broster et al., 2013; Owen et al., 2014). Changing regulations and expensive herbicidal development costs combined with the perennial threat of herbicide resistance, ensures future effective weed control is reliant on the inclusion of alternate weed control technologies in weed management programs. Physical weed control techniques were in use well before herbicides were introduced and the development of new options has continued throughout the era of herbicides. However, most of these new technologies have not been adopted, primarily due to cost, speed of operation and fit with new farming systems. The introduction of weed detection and actuation technologies creates the opportunity to target individual weeds i.e. site-specific weed management. This greatly increases the potential cost-effectiveness of many directional physical weed control techniques in conservation cropping systems.

Comparison of physical weed control technologies

There is a diverse array of effective physical weed control options with a proven ability to control weeds. The majority of these have not been commercialized and evidence of their efficacy relates to research findings, making cost-effectiveness comparisons difficult. While inputs and control methods differ significantly between physical control options, all systems share an energy requirement value for activation and use. Therefore, the energy required for effective weed control can be a reasonably accurate approach to comparing the efficiency and efficacy of physical control systems on an energy consumed per weed or hectare basis.

The direct energy requirements for the control of two-leaf weed seedlings were estimated from published reports on the weed control efficacy of a comprehensive range of physical weed control techniques (Table 1). To determine the energy requirement per unit area, a weed density of 5.0 plants m^{-2} was chosen to represent a typical weed density in Australian grain fields, based on results from a recent survey of Australian grain growers (Llewellyn et al., 2016).

Broadcast weed control

Broadcast weed control is defined as the indiscriminate use of a control method on a whole paddock basis when controlling weeds within crops or in fallow situations.

Chemical weed control

Herbicides are the most commonly used form of weed control in global cropping systems primarily due to their high efficacy and reliability. Herbicides are highly cost effective and have a relatively low energy cost of approximately 220 MJ ha^{-1}, covering manufacture and application. Importantly, herbicides remain the only broadcast weed control option that provides highly selective in-crop weed control and, therefore have been critical to the adoption of highly productive conservation cropping systems. No other currently available form of weed control offers similar weed control efficacy with equivalent crop safety.

Physical weed control

Historically, tillage was relied on for weed control as well as seedbed preparation and continues to be used extensively in global cropping systems despite the extensive reliance on herbicides. As a group, soil disturbance-based options are the most energy efficient form of physical weed control (Table 1) with no additional energy inputs beside the draft force requirements. Tillage acts to control weeds by uprooting plants, severing roots and shoots and/or burial of plants. Consequently, the efficacy and impact of this approach is reliant on rainfall and soil moisture. Effective control can only be achieved when disturbed weeds are exposed to a drying environment after the tillage operation. Although tillage can be a highly effective weed control option the soil disturbance involved is not compatible with conservation cropping systems and, therefore this approach needs to be used sparingly.

There are a group of thermal weed control technologies (flaming, hot water foaming and steaming etc.) using chemical or electrical energy that may be used for broadcast weed control (Table 1). In comparison to tillage and herbicide-based options these approaches are considerably more energy expensive. With 100 to 1000-fold higher energy requirements it is not surprising that these technologies have not been widely adopted for use in large-scale cropping systems, although in more intensive operations flaming is used to some extent.

Table 1. Total energy requirement estimates for physical weed control options currently available for broadcast application. Estimates are based on the control of two-leaf weeds present at 5 plants m^{-2}.

Weed control method	Energy consumption ($MJ\ ha^{-1}$)
Plastic mulching	3
Flex tine harrow	4
Sweep cultivator	11
Rotary hoe	13
Organic mulching	16
Rod weeding	18
Spring tooth harrow	22
Basket weeder	29
Roller harrow	29
Disc mower	31
Tandem disk harrow	36
Flail mower	57
Offset disk harrow	64
UV	1701
Flaming	3002
Infrared	3002
Hot water	5519
Hot foam	8339
Steam	8734
Freezing	9020
Hot air	16902
Microwaves	42001

Site-specific weed control

The opportunity for substantial cost savings and the introduction of novel tactics are driving the future of weed control towards site-specific weed management. This approach is made possible by the accurate identification of weeds in cropping systems using machine vision typically incorporating artificial intelligence. Once identified, these weeds can be controlled through the strategic application of weed control treatments. This precision approach to weed control creates the potential for substantial cost savings (up to 90%) and the reduction in environmental and off-target impacts (Keller et al., 2014). More importantly for weed control sustainability, site-specific weed management creates the opportunity to use alternate physical weed control options that currently are not suited for whole paddock use.

Accurate weed detection allows physical weed control treatments to be applied specifically to the targeted weed. As weed identification processes develop to include weed species, size and growth stage, there exists the potential for some approaches (such as electrical weeding, microwaving and lasers) to be applied at a prescribed lethal dose. This dramatically reduces the amount of energy required for effective weed control (Table 2). For example, microwaving, as the most energy expensive weed control treatment as a broadcast treatment (42,001 MJ ha^{-1}), requires substantially less energy when applied directly to the weed targets (3.4MJ ha^{-1}). Thus, even though the same number of weeds are being controlled (5 plants m^{-2}) the specific targeting of these weeds results in a 99% reduction in energy requirements.

The accurate identification of weeds allows the use of alternate weed control technologies that are not practically suited for use as whole paddock treatments. For example, lasers are typically a narrow beam of light that is focussed on a point target. In a site-specific weed management approach with highly accurate weed identification and actuation, lasers can be focussed precisely on the growing points of targeted weeds, concentrating thermal damage. By reducing the treated area of the weed, off-target losses are further reduced allowing additional energy savings.

Table 2. Total energy requirement estimates for physical weed control options when used for site-specific weed control treatment. Estimates are based on the control of two-leaf weeds present at 5 plants m^{-2}.

Weed control method	Energy consumption ($MJ\ ha^{-1}$)
Concentrated solar radiation	0.0
Precise cutting	0.01
Pulling	0.01
Electrocution: spark discharge	0.1
Nd:YAG IR laser pyrolysis*	0.7
Hoeing	1.3
Water jet cutting	1.4
Stamping	2.1
Nd:YAG IR laser pyrolysis*	2.5
Microwaves	3.4
Abrasive grit	10
Thulium laser pyrolysis*	12
CO_2 laser cutting*	40
Targeted flaming	46
Electrocution: continuous contact	47
Nd:YAG laser pyrolysis*	70
CO_2 laser pyrolysis*	78
Nd:YAG UV laser cutting*	115
Hot foam	117
Dioide laser pyrolysis*	119
Nd:YAG IR laser cutting*	190
Targeted hot water	503

* Different laser weeding systems

Conclusions

By using energy requirements as a level playing field for comparison, the various efficiencies of each control method became more apparent. Furthermore, this approach enabled a better understanding of site-specific opportunities for physical weed control. Targeting treatments on individual plants results in significant energy savings and makes previously impractical options on a broadcast basis, available for use on a site-specific basis. The opportunities here are immense for the future management of problem weeds.

Acknowledgements

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

References

Boutsalis P, Gill GS, Preston C (2012) Incidence of herbicide resistance in rigid ryegrass *(lolium rigidum)* across South Eastern Australia. Weed Technol. 26:391-398

Broster JC, Koetz EA, Wu H (2013) Herbicide resistance levels in annual ryegrass (*Lolium rigidum* Gaud.) and wild oat (*Avena* spp.) in southwestern New South Wales. Plant Prot. Quart. 28:126-132

Keller M, Gutjahr C, Möhring J, Weis M, Sökefeld M, Gerhards R (2014) Estimating economic thresholds for site-specific weed control using manual weed counts and sensor technology: An example based on three winter wheat trials. Pest Management Science 70:200-211

Llewellyn R, Ronning D, Clarke M, Mayfield A, Walker S, Ouzman J (2016) Impact of weeds in Australian grain production: the cost of weeds to Australian grain growers and the adoption of weed management and tillage practices. CSIRO, Australia.

Owen MJ, Martinez NJ, Powles SB (2014) Multiple herbicide-resistant *Lolium rigidum* (annual ryegrass) now dominates across the Western Australian grain belt. Weed Res. 54:314-324

Contact details

Michael Walsh
University of Sydney
12656 Newell Highway
Narrabri 2390
Ph: 02 6799 2201
Mb: 0448 847 272
Email: m.j.walsh@sydney.edu.au

Helicoverpa armigera resistance management in pulses, and recent research findings on Rutherglen bug

Melina Miles, Adam Quade, Trevor Volp, DAF Queensland

Key words

Helicoverpa armigera, resistance, chickpeas, mungbeans, soybeans, Rutherglen bug, canola

GRDC code

DAQ00196, UM00048 (NIRM)

Call to action/take home messages

1. The *H. armigera* resistance management strategy is designed to prolong the useful life of the newer chemistry currently available to pulse growers. Familiarise yourself with the strategy and the full range of options available for *Helicoverpa* control in chickpeas, mungbeans and soybeans. Consider what products you will use if a second spray is required in these crops.
2. Rutherglen bug adults are present in canola crops much earlier than was previously thought. Females are depositing eggs in the soil and leaf litter from early spring through to harvest. At this point, there is no obvious option for preventing the build-up of large populations of nymphs in canola stubble, but recent work is helping to understand how these populations develop.

The *Helicoverpa armigera* resistance management strategy (RMS)

This material has been extracted from the "Science behind the strategy" document available at https://ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies/

General rationale for the design of the strategy

Chickpeas and mungbeans are currently, and for the foreseeable future, the most valuable grains crops influenced by the RMS. Therefore, the resistance management strategy (RMS) is primarily focused on insecticide Modes of Action (MoA) rotation in these systems and is built around product windows for Altacor® and Steward® because:

1. Altacor® (chlorantraniliprole) is at risk from over-reliance in pulses, but resistance frequencies are currently low.
2. Steward® (indoxacarb) is at risk due to genetic predisposition (high level genetic dominance and metabolic mechanism) and pre-existing levels of resistance in NSW and QLD (with elevated levels in CQ during 2016-17). In addition, the use of indoxacarb in pulses may increase as generic products come on to the market.

There are two regions within the RMS, each with their own resistance management strategy designed to make the most effective products available when they are of greatest benefit, whilst minimising the risk of overuse:

1. Northern Grains Region: Belyando, Callide, Central Highlands & Dawson (Table 1)
2. Central Grains Region: Balonne, Bourke, Burnett, Darling Downs, Gwydir, Lachlan, Macintyre, Macquarie & Namoi (Table 2)

- The RMS provides windows-based recommendations common to these regions because *H. armigera* moths are highly mobile and have the capacity to move between these regions.

- No RMS is currently proposed for the Southern and Western grain regions (Victoria, South Australia and Western Australia) for winter crops. Biological indicators suggest that that the risk of *H. armigera* occurring in winter crops, at densities where control failures may occur, is presently considered low. *Helicoverpa* control in summer crops in these regions should use the Central Grains region RMS.

Use of broad-spectrum insecticides

The early use of synthetic pyrethroids (SPs) in winter pulses (August – early September) is adopted where the assumption is made that early infestations of *Helicoverpa* will be predominantly *H. punctigera* which are susceptible to SPs. Similarly, the use of carbamates to delay the application of Group 28 or Group 6 products, carries risks. If adopting this strategy, be aware of the following risks:

- Recent monitoring with pheromone traps has shown *H. armigera* to be present in all parts of the Northern Grains region from early August (www.thebeatsheet.com.au).
- Reduced efficacy of SPs and carbamates against *H. armigera* can be masked when treating very low population densities (< 3/sqm).
- If *H. armigera* are present, even at low levels in a population treated with SPs or carbamates, the treatment will select for further resistance. Whilst initial applications may be effective, later treatments may be significantly less effective.

Table 1. Grains resistance management strategy for *Helicoverpa armigera* across Australia. Best practice product windows and use restrictions to manage insecticide resistance in *H.armigera.* **Northern Region: Belyando, Central Highlands, Dawson and Callide.**

Increasing ↑ SELECTIVITY ↓ Decreasing

Insecticide	June				July				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr				May			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Bacillus thuringiensis																																																
Helicoverpa viruses																																																
Paraffinic oil (Note 1)																																																
Chlorantraniliprole (Note 2, 3)																																																
Indoxacarb (Note 4)																																																
Spinetoram (Note 2, 4, 5)																																																
Emamectin benzoate (Note 2, 4, 5)																																																
Carbamates (Note 2, 4 6)																																																
Pyrethroids (Note 2, 4, 7)																																																

No restrictions	**DO NOT USE during this period**	**No more than one application per crop per season**	**No more than two applications per crop per season**

ADDITIONAL INFORMATION

Notes:

1. Some nC27 paraffinic spray oils can be used to suppress Helicoverpa populations and are best used as part of an IPM program.
2. Observe withholding periods (WHP). Products in this group have WHP 14 days or longer.
3. Maximum one spray of chlorantraniliprole alone or in mixtures per crop per season.
4. Refer to label for warning of insecticide risk to bee populations.
5. Maximum two consecutive sprays alone or in mixtures per crop per season.
6. MODERATE RESISTANCE IS PRESENT IN *H.ARMIGERA* POPULATIONS – FIELD FAILURES LIKELY.
7. HIGH RESISTANCE IS PRESENT IN *H.ARMIGERA* POPULATIONS – FIELD FAILURES EXPECTED!

Table 2. Grains resistance management strategy for *Helicoverpa armigera* across Australia. Best practice product windows and use restrictions to manage insecticide resistance in *H.armigera.* **Southern QLD, Central & Northern NSW Regions: Balonne, Bourke, Burnett, Darling Downs, Gwydir, Lachlan, Macintyre, Macquarie & Namoi.**

Increasing ↑ SELECTIVITY ↓ Decreasing

Insecticide	June				July				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr				May			
	1	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Bacillus thuringiensis																																																
Helicoverpa viruses																																																
Paraffinic oil (Note 1)																																																
Chlorantraniliprole (Note 2, 3)																																																
Indoxacarb (Note 4)																																																
Spinetoram (Note 2, 4, 5)																																																
Emamectin benzoate (Note 2, 4, 5)																																																
Carbamates (Note 2, 4 6)																																																
Pyrethroids (Note 2, 4, 7)																																																

No restrictions	**DO NOT USE during this period**	**No more than one application per crop per season**	**No more than two applications per crop per season**

ADDITIONAL INFORMATION

Notes:

1. Some nC27 paraffinic spray oils can be used to suppress Helicoverpa populations and are best used as part of an IPM program.
2. Observe withholding periods (WHP). Products in this group have WHP 14 days or longer.
3. Maximum one spray of chlorantraniliprole alone or in mixtures per crop per season.
4. Refer to label for warning of insecticide risk to bee populations.
5. Maximum two consecutive sprays alone or in mixtures per crop per season.
6. MODERATE RESISTANCE IS PRESENT IN *H.ARMIGERA* POPULATIONS – FIELD FAILURES LIKELY.
7. HIGH RESISTANCE IS PRESENT IN *H.ARMIGERA* POPULATIONS – FIELD FAILURES EXPECTED!

Table 3. Explanatory notes for product windows in all regions

Insecticide	Number of insecticide windows	Duration of insecticide windows	Maximum number of applications/crop/season
Chlorantraniliprole (Altacor®)	2	10 weeks	1
• 10 week windows restrict selection to a maximum of 2 consecutive generations of *H. armigera* (includes 2-3 weeks residual beyond the end of each window i.e. 12-13 weeks total exposure). • Start date of first window correlates well with historical data relating to average daily temperatures that result in early pod-set. • Exposure of 2 consecutive generations is off-set by long non-use periods (8 weeks in southern/central region and 18 weeks in northern region). • Use is not recommended in spring mung beans as there is less likelihood of both *H. armigera* and bean pod borer being present.			
Indoxacarb (e.g. Steward®)	Northern - 3 Central - 2	6 weeks	1
• 6 week windows restrict selection to a single generation of *H. armigera*. • Each window is followed by a non-use period of a minimum of 6 weeks. • Indoxacarb is an important early season rotation option for chickpeas and faba beans, and provides a robust selective alternative to Altacor® when Helicoverpa pressure is high.			
Bacillus thuringiensis	1	Season long	No restrictions
Helicoverpa viruses			No restrictions
Spinetoram (e.g. Success Neo®)*			2
• Low resistance risk and not widely used.			
Emamectin benzoate (e.g. Affirm®)*	1	Season long	2
• Very low resistance frequency and not used widely. • However, emamectin benzoate is a good option for rotation to spread resistance risk away from Altacor®. • BUT industry needs to become more confident with using this product for it to be of value in resistance management.			
Carbamates	1	Season long	1
Synthetic pyrethroids			
• *H. armigera* resistance is present at moderate to high levels, but one strategic application per season in regions where *H. punctigera* predominates in early spring may be effective. • Carbamates are a rotation tool for indoxacarb and Altacor® either early season in chickpeas or late season in mungbean.			

*Resistance monitoring for selective products is a key component of the RMS and changes in resistance frequencies will result in the introduction of product windows for those insecticides not currently windowed.

The number of uses in the RMS is more restrictive than stated on the Altacor® label, why?

To avoid repeated use of either Steward® or Altacor® within the use window, the number of allowable applications is 1 per crop. Whilst this is currently inconsistent with the Altacor label (2 applications per crop), we expect that there will be changes to the label to ensure consistency in these recommendations.

Does the RMS impact on recommendations for insecticide use in cotton and other crops?

The RMS is not intended to compromise the ability of the cotton industry to use any products registered for *Helicoverpa* in Bollgard® cotton. This is because selection for insecticide resistance is considered low due to the high likelihood that survivors of conventional sprays used in Bollgard cotton would be killed by Bt toxins expressed in plants. For further information go to: http://www.cottoninfo.com.au/publications/cotton-pest-management-guide.

Similarly, the RMS does not attempt to align the use of the Group 28s in mungbeans and chickpeas with use in other grain crops or horticulture. To do so would add a level of complexity that would make the RMS impractical.

Shouldn't other modes of action (MoA) be windowed to prevent the potential development of resistance to these products?

There is little evidence to suggest that other products should be windowed now to slow the development of future resistance. Both Affirm® (emamectin benzoate) and Success Neo® (spinetoram) show no sign of reduced susceptibility in testing (L. Bird, CRDC data). This result is consistent with the relatively limited use these products in the grains industry to date. If a shift in susceptibility is detected in future testing, it is the intention that the product/s will be windowed to limit selection pressure.

The SPs and carbamates are not windowed because there is already well established, relatively stable moderate-high levels of resistance to these MoAs, and limiting their use will not change this situation.

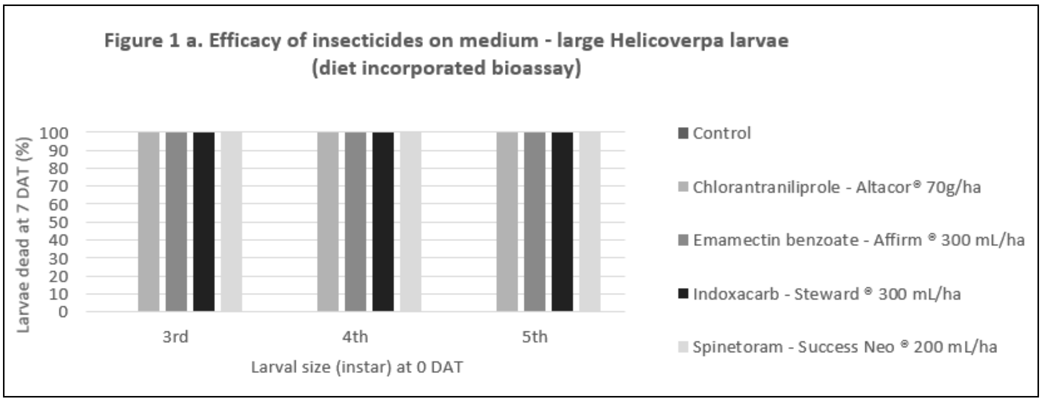
By restricting the use of just the 'at risk' products, keeping the RMS as simple as possible, and allowing maximum choice of registered products we anticipate that the grains industry will be more inclined to use the RMS.

What is the relative efficacy of the 'softer' options for Helicoverpa control in mungbeans and chickpeas?

In 2017, QDAF entomology undertook a number of trials to compare the knockdown/contact efficacy, and residual efficacy (persistence in the crop) of Altacor®, Steward®, Affirm® and Success Neo®. The purpose of these trials was to provide agronomists and growers with information on how well each of the products worked, and to provide confidence to use another option, rather than relying solely on the Group 28 products.

The results show that these products are equally effective on 3rd, 4th or 5th instar larvae that receive a lethal dose of the product – as would be achieved with good spray coverage (Figure 1a). However, there is considerable benefit in products persisting in the crop to control larvae that may hatch after the spray, or emerge from flowers, buds or pods where they may have been protected from an earlier application. The long residual efficacy Altacor ® has been a major factor in its popularity. The data in Figure 1b shows the relative efficacy of these products from 0 – 20 days after treatment in the field (at 5 day intervals).

For more information on the relative performance of these products in terms of feeding potential and recognising larvae affected by the different insecticides, see recent articles on the Beatsheet blog (www.thebeatsheet.com.au).



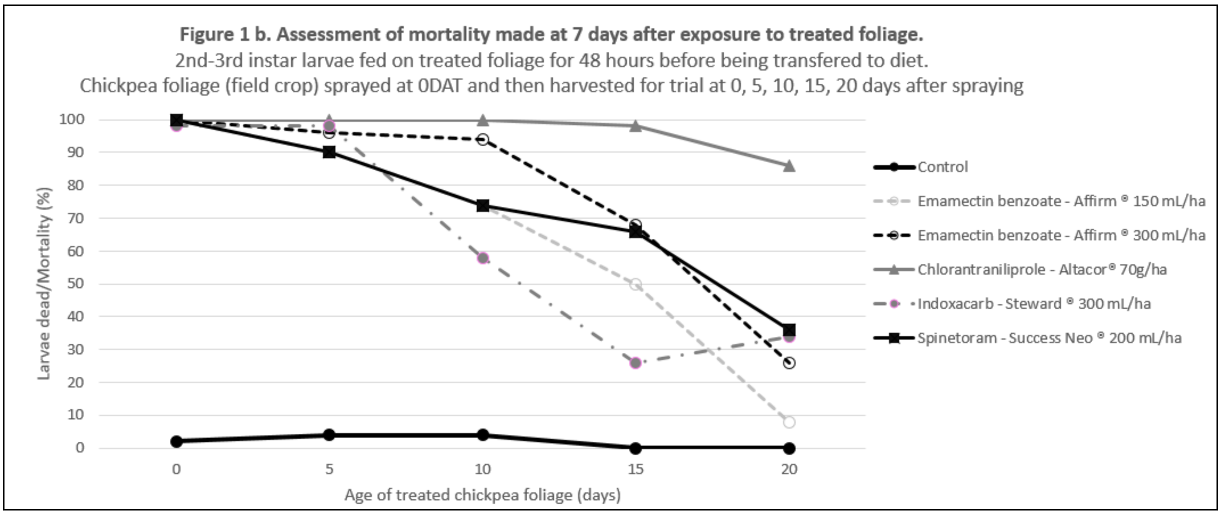


Figure 1. Relative efficacy (a) direct contact and (b) residual, of softer options for Helicoverpa control in chickpea and mungbean crops.

Rutherglen bug build up in canola – population dynamics during the 2017 season

In recent seasons, higher densities of Rutherglen bug (RGB) have been experienced. One of the challenges of this higher RGB pressure has been the movement of large numbers of nymphs from canola stubble into neighbouring summer crops. Through sheer weight of numbers, RGB nymphs can kill sorghum, cotton, soybean, corn and sunflower plants in the rows closest to canola. The movement of nymphs can occur over a period of weeks, and even regular spraying of the affected crops may not prevent significant crop loss.

Understanding how these enormous populations of nymphs develop is key to working out how they might be prevented, or managed, so that they don't affect neighbouring summer crops. Rather than focusing on controlling the nymphs, we were interested in whether there may be an opportunity to control the adults before they reproduce. During the spring of 2017, QDAF entomology monitored a number of canola crops, from the Darling Downs to the Liverpool Plains. We assessed the density of adults in the canola, dissected females to determine if they were reproductive (laying eggs), and assessed the crops for nymphs. We also attempted to determine the timing of egg laying by assessing the density of eggs – however, we were unable to do this effectively. Other than determining that eggs are deposited in the soil and on the leaf litter on the soil surface (not in the crop canopy), we could not reliably assess egg density.

Whilst this is only one season of data, it is presented here to highlight the following key findings.

RGB adults were present in the canola crops much earlier than we expected (Figure 2). Even at the most southerly site (Curlewis, NSW), RGB adults were present in canola from early August. At most sites, numbers increased through September and October.

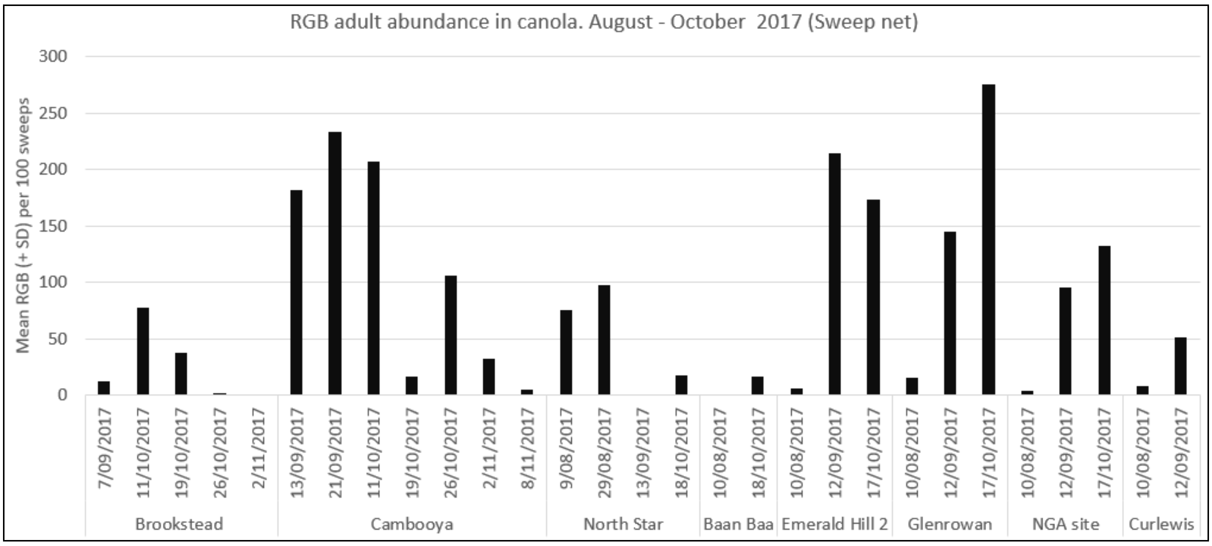


Figure 2. RGB adults were present in canola from late winter (August – September). (SD = standard deviation)

Female RGB were reproductive (had mature eggs in their ovaries ready to lay) from September onwards, and the percentage of the population that was reproductive increased from September through November (Figure 3).

Although the majority of female RGB were reproductive, and laying eggs, we did not see nymphs start to emerge until much later than expected based on the day degrees accumulated during this period (Figure 4).

It is possible that the development of eggs is slowed by the relatively cool temperatures experienced on the soil surface under the leaf litter and crop canopy. When the crop is harvested or windrowed, the temperature of the soil quickly rises, potentially resulting in synchronous hatching of eggs that have been laid over a period of 2-3 months.

More data is needed over additional sites and seasons to confirm our theory, and closer monitoring of soil temperature and RGB egg development is also needed to understand exactly what is happening.

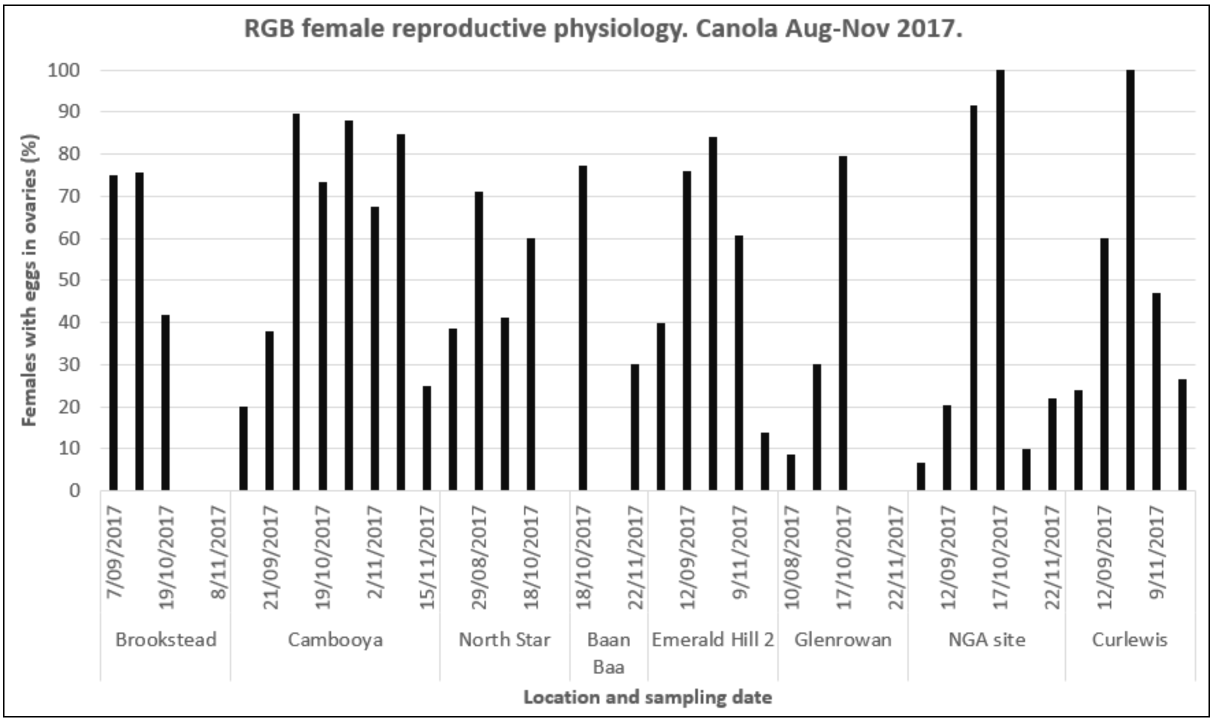


Figure 3. A high proportion of the female RGB sampled were laying eggs from September through November.

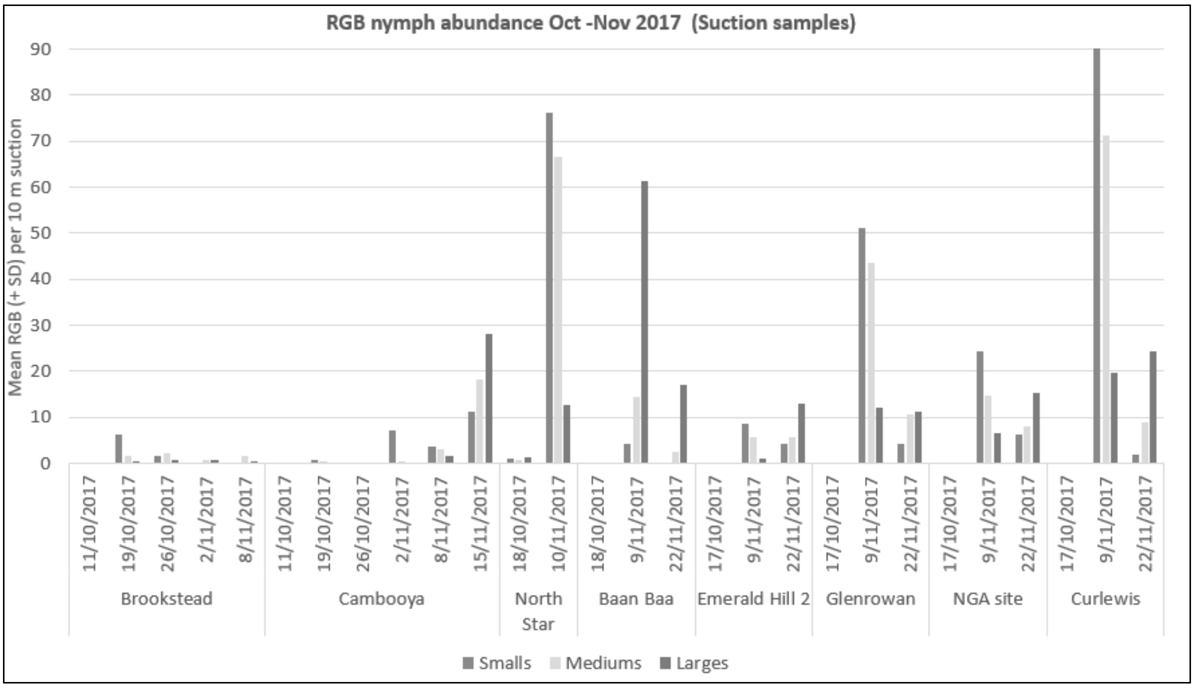


Figure 4. Nymphs did not start to emerge until much later than expected based on the day degrees accumulated during this period, despite the majority of female RGB being reproductive and laying eggs.

The take home message from this RGB work is that there doesn't seem to be an easy fix to prevent the build-up of RGB nymphs in canola stubble. The long period of egg laying by the females, and the potential challenges with controlling nymphs on the ground under the crop canopy, means that there is no obvious opportunity to prevent the population build up.

Acknowledgements

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

Information on the *H. armigera* RMS is extracted from material prepared by NIRM to support the implementation of the RMS. The authors acknowledge the contribution of NIRM members to the development of this material.

We are grateful to the growers who allow us access to their farms and crops, and to the agronomists who assist us in locating potential field sites. We also thank the many growers and agronomists who share with us their experiences and insights into the issues they face and the practicalities of the management options we propose.

Reference

NIRM (2018) Science behind the Resistance Management Strategy for *Helicoverpa armigera* in Australian grains. https://ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies/

Contact details

Melina Miles
Queensland Department of Agriculture and Fisheries
203 Tor St, Toowoomba. QLD 4350
Ph: 0407 113 306
Email: melina.miles@daf.qld.gov.au

® Registered trademark

Deep phosphorus (and potassium) experiments in Southern Queensland – multi-year results and returns

David Lester[1], Mike Bell[2], James Hagan[1]

[1] Queensland Department of Agriculture and Fisheries, Toowoomba
[2] University of Queensland, Gatton

Key words

Deep-placement, Phosphorous, Potassium, Fertiliser, Macro Nutrients, Phosphate, Yield, Test strips

GRDC code

UQ00063

Call to action/take home messages

- Understand what nutrients you need to manage – get your soils tested and separate the depth increments
- Yield gains of 8-18% have been achieved in the 3 years following the application of 20 kg/ha Phosphorous (P) at depth, increasing grower profitability
- Evaluate responses using test strips, look at the economic cost-benefit analysis for your farm
- Use an ammonium phosphate, not triple super
- Online calculators allow more scenario analysis

Introduction

The Darling Downs and Western Downs have now hosted four deep placed phosphorus (P) and a single deep placed potassium (K) experiment since 2013. The sites are located in the Wondalli, Condamine and Jimbour West districts. Most research experiments have had four crops sown and three of those harvested. The wet winter of 2016 meant two pulse crop sites didn't make harvest.

Subsoil P (i.e. below 0.1m) appears limiting across most of the region on soils formed from either alluvial deposition or in-situ, based on historic data from land management manuals and soil surveys. While Low K is mostly confined to just soils formed in-situ on the upland slopes and plains of the eastern production regions. While the soil surveys are extensive in their coverage, they are not universal and field testing is recommended to determine soil P and K nutrient levels. Soil testing with separation into surface and subsurface layers provides an assessment of availability of P and K for the soil on your farm. Soil P and K testing does not require a high intensity analysis campaign like that for nitrogen (N), which is much more dynamic and consequently requires a higher sampling frequency.

Results from the deep placement P field program has been operational for some time, what have been the multi-year grain yield responses from the deep-placed experiments? Is there an economically viable response to placing these immobile nutrients deeper in the soil?

Experimental outline

Deep P experiments have all been established with 6 treatments (Table 1a). The Jimbour West site is displayed as it has an additional basal K application (50 kg/ha), but at other sites where the exchangeable K was above 0.2 cmol/kg in the 0.1-0.3 m depth, potassium was not applied. Soil test values for the P trial area at Jimbour West are shown as an example of the soil test values where responses are expected (Table 2). The soil is a Grey Vertosol (Cecilvale), with stratified P and K distributions, meaning the availability of these nutrients is higher in the surface 0-0.1 m layer than the soils below that.

A second trial was established at the Jimbour West site only (Table 1b) to look at the interaction between deep P and deep K.

A "Farmer Reference" (labelled "FR") treatment was included as an untreated control, providing baseline data on yield and nutrient uptake. Deep-placed fertiliser was applied perpendicularly to the crop sowing direction, at a depth of roughly 20 cm in bands 50 cm apart. Deep P plots were split so that growers could apply a starter P application to half of the treated area at sowing. The starter P treatments equate to grower practice for product and rate. There were 6 replicates in each site to better handle field variability across reasonably large trial areas. Urea was applied to balance the nitrogen input through a tine positioned between the bands of deep P and K. Full details of the agronomic management for the sites are contained in the Queensland Grains Research - 2017 regional agronomy trial book (yet to be released).

Table 1. Experimental treatments for deep placed a) P and b) K experiments

a) All sites deep-placed P treatment nutrient application rates (kg P/ha)

Trt no	1	2	3	4	5	6
P rate (as Mono Ammonium Phosphate)	FR	0	10	20	30	60
K rate (as Potassium Chloride) (Jimbour West only)	-	50	50	50	50	50
S rate (as Ammonium Sulfate)	-	10	10	10	10	10
N rate (as Urea, MAP and Ammonium Sulfate)	-	60	60	60	60	60
Zn rate (as Zinc chelate)	-	0.5	0.5	0.5	0.5	0.5

b) Jimbour West deep-placed K treatment nutrient application rates

Trt no	1	2	3	4	5	6	7
K rate (as Potassium Chloride)	FR	0	100	0	25	50	100
P rate (as Mono Ammonium Phosphate)	-	0	0	20	20	20	20
S rate (as Ammonium Sulfate)	-	10	10	10	10	10	10
N rate (as Urea, MAP and Ammonium Sulfate)	-	60	60	60	60	60	60
Zn rate (as Zinc chelate)	-	0.5	0.5	0.5	0.5	0.5	0.5

Table 2. Soil test results Jimbour West site

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	Col P	BSES P
(m)	(CaCl2)	(H2O)	(1:5)	(cmol/kg)					(mg/kg)	(mg/kg)
0.0-0.1	6.5	7.4	0.08	11.0	7.5	0.97	0.47	20	37	97
0.1-0.3	7.3	8.3	0.12	14.2	11.1	2.35	0.20	28	8	12
0.3-0.6	8.1	9.1	0.27	14.1	14.5	4.50	0.22	33	4	7
0.6-0.9	8.2	9.2	0.27							
0.9-1.2	7.8	9.1	0.61							

Above ground biomass was measured at maturity from selected treatments in both experiments. Grain yield was measured using a plot harvester and grain yield corrected to receival standard moisture content.

Results

The summary of statistical analyses at the four sites (Table 3) shows the starter P response was significant for half the crops harvested (mostly winter crops), deep P was significant for 10 of the 12 crops harvested and there was no interaction between starter and deep P treatments at any site.

We will not explore the starter response in any detail in this paper. Our recommendation is application of P as a starter with the seed at sowing continues, as significant reduction in grain yield often results when starter P is omitted. The role of starter P in cereals to establish early vigour and set yield potential has been well documented, so the focus of our work has been on the response to deep P, and whether this response is reduced or eliminated by the use of starter P application.

Table 3. Statistical significance of treatments for Jimbour West, Wondalli, Condamine South and North sites.

Site	Crop	Starter	Deep	Starter x Deep
Wondalli	Sorghum 13-14	n.s.	$p<0.001$	n.s.
	Wheat 15	$p<0.001$	$p<0.001$	n.s.
	Wheat 17	$p<0.001$	$p<0.01$	n.s.
Condamine South	Chickpea 14	n.s.	$p<0.05$	n.s.
	Wheat 15	n.s.	$p<0.001$	n.s.
	Wheat 17	$p<0.01$	$p<0.001$	n.s.
Condamine North	Sorghum 15-16	n.s.	n.s.	n.s.
	Mungbean 16-17	n.s.	n.s.	n.s.
Jimbour West	Barley 2014	$p < 0.05$	$p < 0.001$	n.s.
	Mungbean 14-15	$p < 0.05$	$p < 0.01$	n.s.
	Sorghum 15-16	n.s.	$p < 0.05$	n.s.
	Chickpea 17	$p < 0.05$	$p < 0.001$	n.s.
Summary		**6 of 12**	**10 of 12**	**0 of 12**

Individual site responses for deep P have been outlined at previous Grains Research Updates and are detailed in the latest Queensland Grains Research - 2017 regional agronomy trial book. In this paper, we are focussing on the cumulative impact of deep treatments on grain yield and economic returns.

Change in cumulative yield

At all sites, deep-placing P has increased cumulative grain yield compared to the untreated farmer reference control (Table 4). Increases have been largest at the Wondalli and Jimbour West sites, with increases approaching 20% from 20-30 kg P/ha at depth. The 10% response at Jimbour West to the zero P treatment is not able to be put down to a single factor, but the combination of deeper tillage to resolve any remnant compaction and the basal application of N and K are likely to be the major influences. This will be looked at again later in the paper. Responses at the Condamine sites are more muted, with the Condamine North site in particular experiencing a mixed run of seasons in which variable crop establishment has made detecting treatment responses more challenging.

Table 4. Cumulative difference in grain yield versus farmer reference at four deep-placed P experiments on the Darling and Western Downs, Qld.

Deep P rate (kg/ha)	Wondalli* (3 crops)	Condamine South * (3 crops)	Condamine North * (2 crops)	Jimbour West + (4 crops)
0	-88 (-1.1%)	400 (5.3%)	125 (2.1%)	914 (10.4%)
10	460 (5.5%)	880 (11.7%)	-37 (-0.6%)	1227 (14.0%)
20	1225 (14.7%)	826 (10.9%)	534 (8.1%)	1648 (18.8%)
30	1482 (17.8)	736 (9.8%)	429 (6.5%)	1658 (18.9%)
60	1769 (21.3%)	703 (9.3%)	524 (8.0%)	2065 (23.5%)
*Treatments include additional N, S and Zn to support P response research + Treatments include additional N, K, S and Zn to support P response research				

Cereal crops (wheat, sorghum) have a relatively straightforward mechanism to grain yield, with biomass related directly to grain yield via harvest index. To explore the relationship between P uptake and grain yield for the cereal crops, the relationship outlined in figure 1 shows that for each kg of P taken up an additional 277 kg/ha yield was grown. By increasing the amount of P the crop can access through deep placement, biomass production has increased and more grain has resulted.

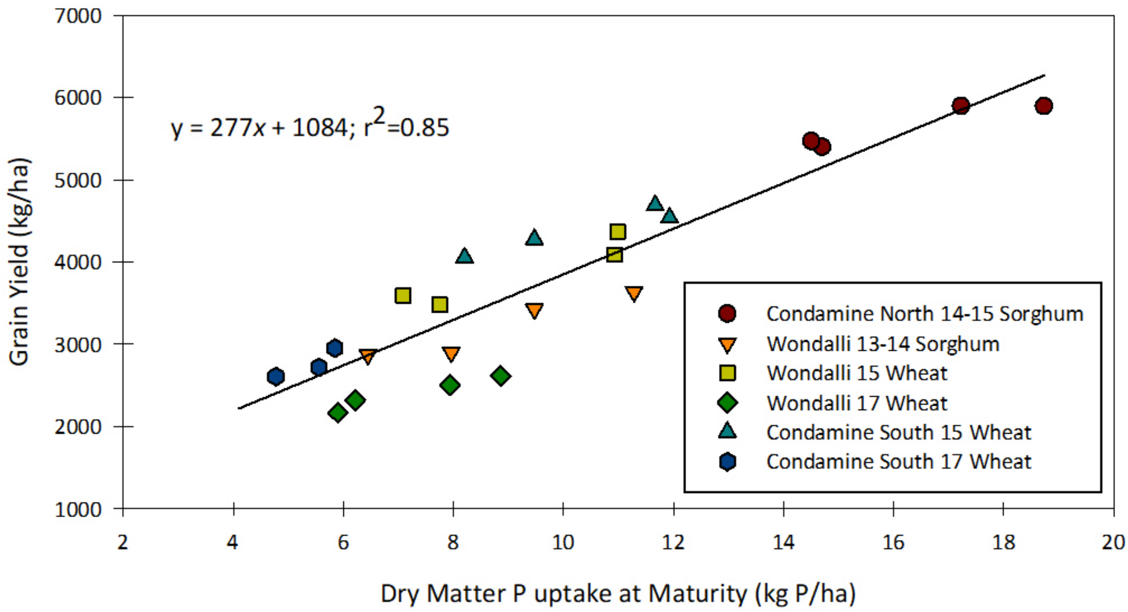


Figure 1. Maturity dry matter P uptake (kg P/ha) vs grain yield (kg/ha) in cereal crops grown at Western Downs deep-P sites.

When the relationship in Figure 1 is examined more broadly for grain crops, the linear relationship shown often flattens out at higher P uptake – not because the crop has enough P, but because the crop is not able to get enough N to meet the higher yield potentials. It is important to remember that removing a yield constraint like low subsoil P will have implications for nitrogen management, with potentially higher yields requiring a greater nitrogen supply.

Interaction with P and K

The 10% response to the zero P treatment (i.e. tillage and background N, K, S and Zn) at Jimbour West requires some further explanation, so the individual crop yields will be outlined to explore the responses to tillage, basal nutrients, P, K and their additive interaction. Refer again to Table 1b, which has the nutrient applications listed.

Barley yield in 2014 (Figure 2a) was increased across a number of treatments, with effectively two things happening to increase grain yield. First, the combination of deep tillage and extra nitrogen boosted yield by 438 kg/ha, not deep P or K. Looking at treatments 2 to 5 which are combinations of tillage and basal nutrient (treatment 2, 0K 0P), potassium only (treatment 3, 100 K 0P), phosphorus only (treatment 4, 0K 20P) and low K rate with P (treatment 5, 25 K 20P) they all have grain yields that are not significantly different. Once the K rate is 50 kg K/ha or higher (the 100 rate) with P application then grain yield is boosted to over 4800 kg/ha. The combination of deep tillage (to reduce compaction), and nutrients (N and P and K and S and Zn) are all working together.

Mungbean in 2014-15 (Figure 2b) showed statistically significant responses but is difficult to interpret as the effects were inconsistent across the treatments. While the comparison between the 0K- 0P and 100K-0P is valid with yield being increased, the lack of response to the same 100K with 20P treatment casts some doubt on the result.

The late-sown sorghum in 2015-16 (Figure 2c) performed relatively poorly for the available moisture, with yields not significantly affected by any treatment despite the trend for increasing yield with increasing K rate in the presence of deep P.

Chickpea grain yield in 2017 (Figure 2d) had several factors additively increasing yield, similar to the barley in 2014 (Figure 2a). Yield in the 0K-0P was higher by 226 kg/ha (11%) than the FR, so the combination of previous deep tillage and basal N, S and/or Zn nutrient was still boosting yield. Adding 100 kg K/ha without P then increased yield by another 317 kg/ha (15%). Phosphorus application without K had no yield effect, as the 0K/20P and 25K/20P treatments had same yield. Applying higher rates of K with P did increase the grain yield in the 50K/20P and 100K/20P treatments. Highest yields measured where 2780 kg/ha, which were 720 kg/ha (35%) more than the untreated farmer reference baseline.

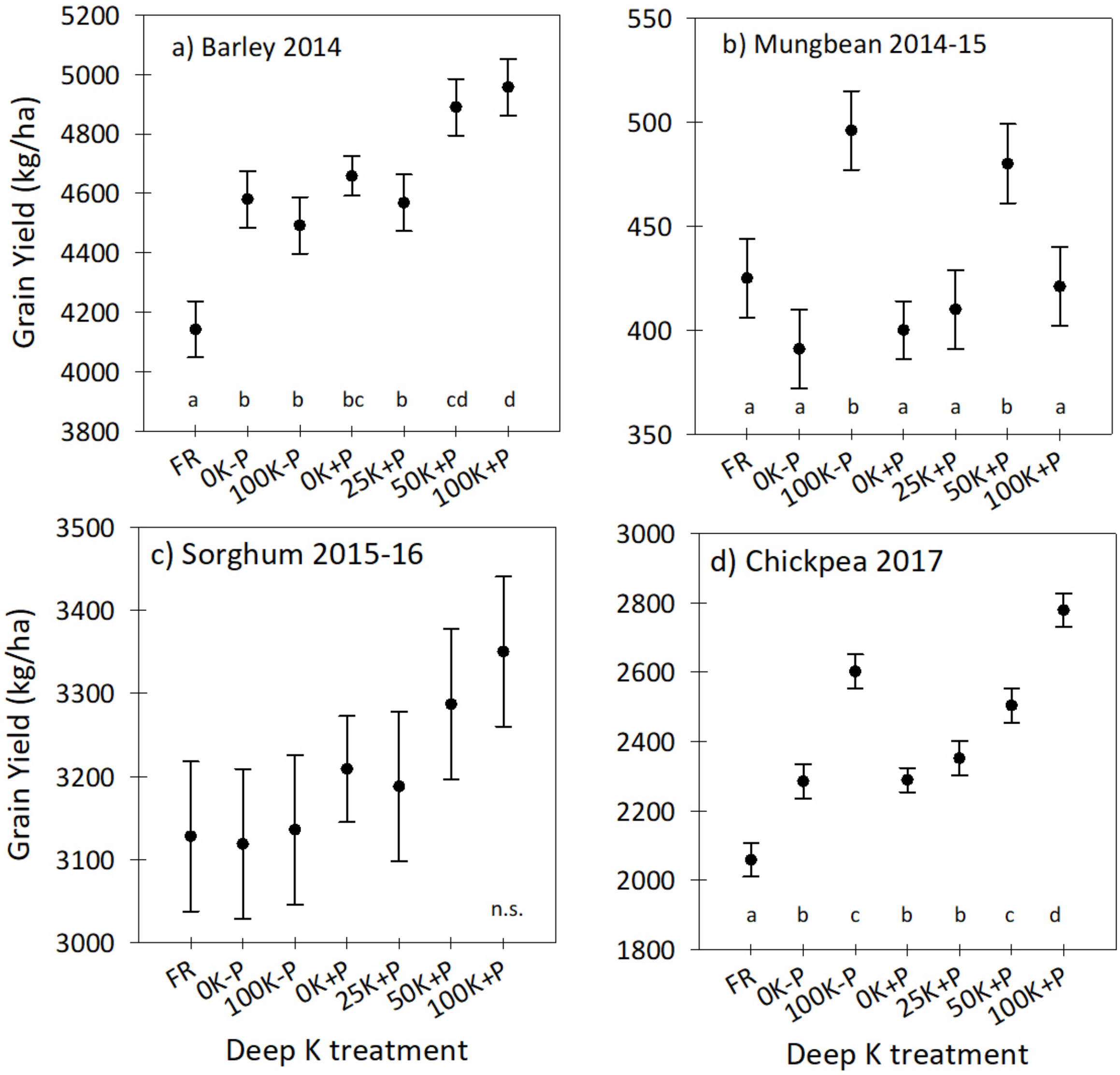


Figure 2. Grain yield (kg/ha) from deep-placed K and P treatments at Jimbour West for a) barley in 2014, b) mungbean in 2014-15, c) sorghum in 2015-16 and d) chickpea in 2017. Error bar are standard error for each mean. Letters indicated lsd at 5%. Note different yield scale each year.

Change in cumulative gross margin

The additional grain yield from these trials has been translated into a gross margin change, accounting for cost of application, basal nutrient and fertiliser P (Table 5) – again using the untreated farmer reference as the baseline. After 3 crops, each of the deep-P treatments at Wondalli and Condamine South have provided a positive return that has easily exceeded treatment costs. The $200/ha return for zero P at Condamine South and $440/ha at Jimbour West suggests there has been a response to one or more of the background treatments of deep-tillage and/or basal nutrient application, with the P treatments providing between $100 and $200/ha in additional benefit. At the

Wondalli site 20, 30 and 60 kg/ha of P have all currently generated greater than $300/ha in additional profit over three crops, however there appears to be no response to the deep tillage or basal nutrients. After 2 crops, both 20 and 30 kg/ha of P have generated positive returns at the Condamine North site, but although the 60P treatment has also generated yield benefits (Table 4), these have not yet been enough to overcome the additional fertilizer input cost, which was ~$120/ha more than in the 30P treatment.

The final economics of the different treatments will be dependent on response duration (and also crop price), with higher rates having higher upfront costs, but also expected to have a greater duration of benefit in the field. The period over which the responses can be maintained is currently under investigation, with sites due to finish field experimental operations in December 2019.

Table 5. Cumulative difference in gross margin versus farmer reference at four deep-placed P experiments on the Darling and Western Downs, Qld.

Deep P rate (kg/ha)	Wondalli (3 crops)	Condamine South (3 crops)	Condamine North (2 crops)	Jimbour West (4 crops)
0	-$11	$202	$46	$441
10	$57	$367	-$39	$510
20	$305	$277	$81	$665
30	$301	$340	$78	$593
60	$326	$172	-$90	$673

Assuming Urea $400/t MAP $800/t, Ammonium Sulphate $350/t MOP $500/t, Trace Zn $2000/t, application cost of $30/ha, wheat $300/t, chickpea $800/t, barley $270/t, and mungbean $1200/t.

This research has been conducted under controlled experimental conditions. Before commencing a large-scale nutrient application program, growers are urged to appropriately soil test their fields to establish the levels of available nutrients in both the surface and subsurface layers, and thus quantify any potential constraints to yield. They are then encouraged to evaluate the responses on their soils using an appropriate program of strip-trials and on-farm exploration. Growers should note a couple of key points –

- The size of the response can differ in response to seasonal conditions, and particularly the extent to which crops can access the relatively nutrient-rich topsoil. Growers need to be prepared to monitor strip performance across multiple crop seasons.
- If going to the trouble of setting up a trial, make sure at least some strips contain a high rate of P addition (e.g. 40-60 kg P/ha) to explore any upside of higher application rates. Crops have typically responded positively to increasing P rate, so knowing the potential 'upside' of improving crop P access is an important factor in deciding whether to change practices. This also is a future monitoring site to determine when re-application may be needed.
- Finally, make sure adequate N is available to allow grain crops to respond to additional P. If you continue to apply the N rate that met the old (pre-deep P) yield target, you will quite quickly find that deep P responses 'disappear' as grain yields become limited by N. An indicator of this happening is when an apparently unresponsive field suddenly becomes responsive again when a legume like chickpeas is grown.

The deep-P calculator (http://armonline.com.au/deepp) may allow you to estimate the economics of P applications in your individual conditions.

Acknowledgements

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

Contact details

David Lester
Department of Agriculture and Fisheries
PO Box 2282, Toowoomba Qld 4350
Ph: 07 4529 1386
Email: david.lester@daf.qld.gov.au

Grower experience with deep P

Tom Woods, Billa Billa

Contact details

Tom Woods
Mb: 0428 718 884
Email: wtwoods@bigpond.com

Notes

Discussion session on deep P