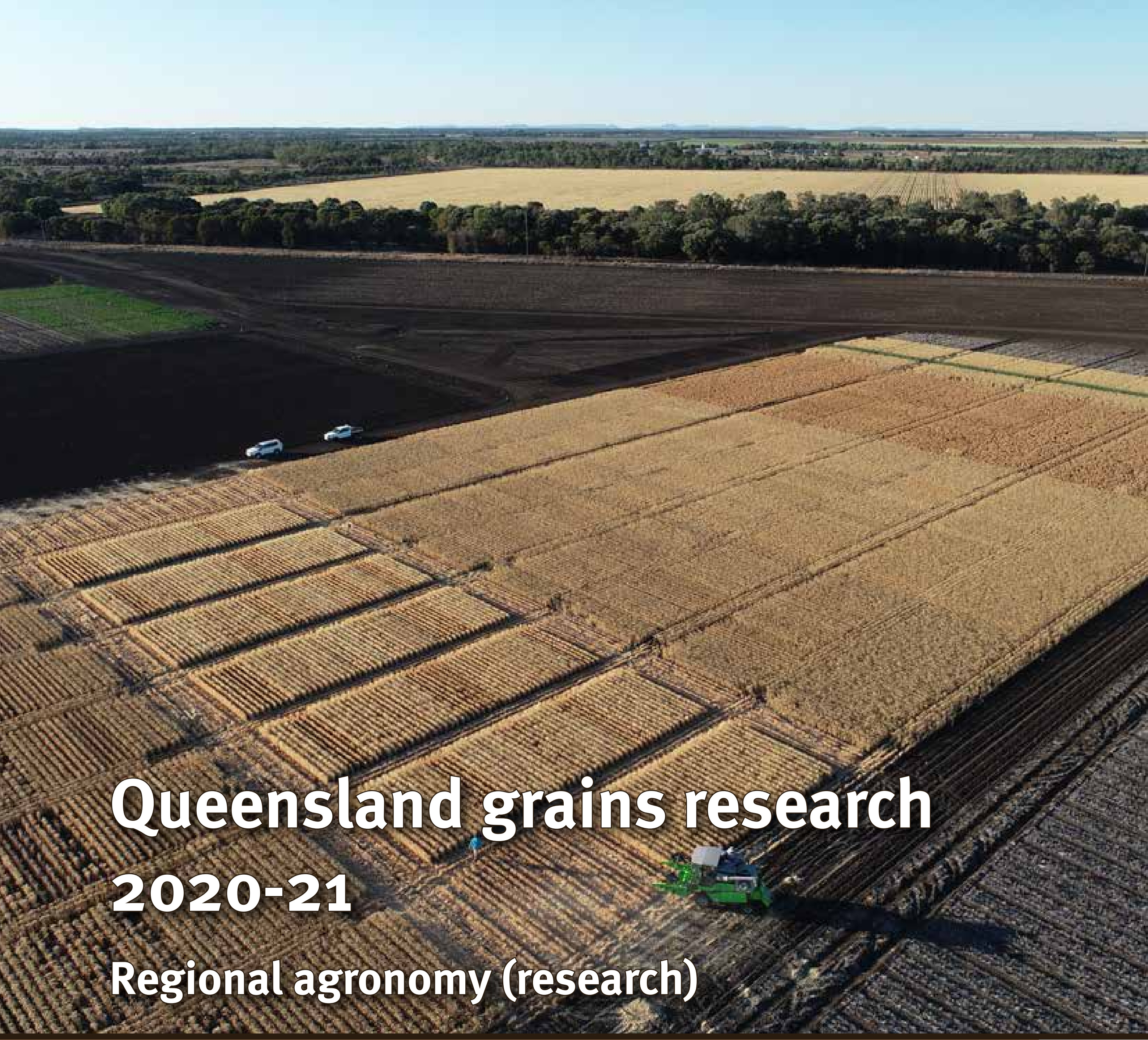

Queensland grains research

2020-21

Regional agronomy (research)

GRDC
GRAINS RESEARCH
& DEVELOPMENT
CORPORATION

Queensland
Government

This publication has been compiled by David Lawrence and Tonia Grundy on behalf of the Regional agronomy (research) team of Crop and Food Science, Department of Agriculture and Fisheries (DAF).

Plant Breeder's Rights

ⓟ denotes that a variety is protected by Plant Breeder's Rights (PBR) and unauthorised commercial propagation or any sale of propagating material of this variety is an infringement under the *Plant Breeder's Rights Act 1994*.

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Foreword

Welcome to the Department of Agriculture and Fisheries' (DAF) sixth edition of Queensland grains research that summarises the research, development and extension (RDE) conducted by DAF's Regional agronomy (research) team across the grain growing regions of Queensland.

The Regional agronomy (research) team is a key part of the Queensland Government's strategic investments to support more productive, profitable and sustainable farming systems. The team has up to 20 research agronomists, extension officers and technical support staff based in Goondiwindi, Emerald and Toowoomba. Every project reported here has co-investment from the Grains Research and Development Corporation (GRDC) in their pivotal role of investing in RDE to create enduring profitability for, and on behalf of, Australian grain growers.

This year's edition provides the usual results of annual trials, but also contains summaries of work to date across some longer-term initiatives, such as the Northern farming systems project that is now in its eighth year. Despite the constraints of a prolonged drought and the spread of COVID-19, the team have continued to 'get their hands dirty' conducting RDE within local farming systems and so ensure the results are both rigorous and relevant to grain growers and agronomists. *Queensland grains research* provides up-to-date local results and information that growers and agronomists can use to make the best decisions for the farms that they manage.

The Queensland grains industry faces a range of challenges as our soils age and our farming systems mature. For example, growers face declining soil fertility, extreme climate variability and the threat of herbicide-resistant weeds. However, agronomic advances from targeted RDE and on-farm innovation have delivered, and will continue to support, better practices that advance our agriculture. This edition reports the Regional agronomy (research) team's contribution to improved farming systems and practices with experimental work, data, analysis and insights across several RDE themes: Pulses, Nutrition, Soils, and Farming systems research. Articles report on both individual experiments and summaries across years, with valuable quantitative data on the responses and economic returns for those locations.

None of the RDE reported here would be possible without the collaborating RDE agencies across Queensland and New South Wales, co-investors including the Cotton Research and Development Corporation, and the growers, agronomists and agribusinesses that have provided support along the way. We thank them for this.

We trust that the RDE reported here will help the grains industry and the wider Queensland community use the improving seasons for the economic recovery that will be needed in the post COVID-19 era. Of course, we would also value any feedback on work contained in this publication.

Dr Chris Downs
General Manager
Crop and Food Science
Department of Agriculture and Fisheries

Dr Peter Carberry
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Applied Research, Development and Extension
Grains Research and Development Corporation

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The DAF biometry team and Statistics for the Australian Grains Industry (SAGI—co-funded by GRDC) have provided statistical analysis of the data presented in these reports when identified in the acknowledgement section.

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Research facilities

The regional research trials reported here would not have been possible without the support of dedicated technical and operational officers at the Department of Agriculture and Fisheries' major research facilities across the grain region. Thanks to all those staff at the Hermitage Research Station (near Warwick), the Leslie Research Facility (Toowoomba), the Bjelke-Petersen Research Station at Kingaroy, and staff based at the Emerald Research Facility (formerly the Emerald agricultural college) for their operation of heavy plant and research machinery.

Pulse research

Regional agronomy's focus on nutrition management in mungbean has continued with the second season of trials harvested under the new Mungbean agronomy project (DAQ1805-003RTX). The emphasis was on assessing the potential to get a rate response to applied nitrogen (N) fertiliser from inoculated mungbean. The 2019/20 season began with a hot, dry spring followed by a slightly milder and more humid summer.

Key learnings were that mungbean does not respond to applied N under normal field conditions but can use significant amounts of mineralised N, with uptake greatest in the top 30 cm of the soil profile. This may have implications for farming systems nutrition management more broadly. One exception was a high yielding irrigated crop (2 t/ha) where yield did respond to the addition of N fertiliser but did not increase with higher N rates. High soil nitrate levels in the top 30 cm of the soil profile reduced N fixation by the plant to zero. The percentage of fixed N by the irrigated mungbean reached as high as 50% in the control (no N fertiliser) in SQ and 20% in CQ. Increasing N fertiliser rates simply decreased N fixation by the crop, regardless of inoculation.

The yield of dryland crops did not change regardless of the proportion of fixed N to mineralised N used by the crop. There is apparently little benefit in applying N to mungbean crops as they can switch between using fixed N and mineralised N without any yield penalty.

The 2019/20 season also saw the first structured examination of the physiology parameters of pigeonpea. Several new varieties, with both determinate and indeterminate maturities, were planted at the Emerald and Kingaroy research facilities. The Emerald time of sowing trial showed large differences in biomass across the varieties planted in early summer (December; 10.0 t/ha) and late summer (February; 3.5 t/ha). The flowering periods and grain yields changed significantly (up to 1.8 t/ha and 1.2 t/ha respectively) from these planting dates, with significant differences in the development of individual varieties when they were planted at different times.

The data suggests that pigeonpea is sensitive to day length and heat accumulation, and that these sensitivities vary for determinate or indeterminate varieties. There is a lot of diversity within the pigeonpea genotype. The resulting crop physiology and its expression under Queensland needs further research to identify the ideal type for grain production in our more arid regions.

Mungbean: response to different levels of soil nitrogen—Hopeland (spring)

Cameron Silburn and Jayne Gentry
Queensland Department of Agriculture and Fisheries

RESEARCH QUESTIONS: *How much nitrogen is required to maximise mungbean yield? | Can well-nodulated mungbean achieve the same yield as fertilised crops?*

Key findings

1. Mungbean did not respond to nitrogen fertiliser with a 1 t/ha yield and a starting soil nitrogen of ~90 kg N/ha.
2. Mungbean has limited ability to maintain its water balance in high evaporative conditions. Timely in-crop rainfall/irrigation may still not maximize yields under very hot conditions during flowering to pod fill.
3. Irrigation decreased canopy temperatures by up to 8 °C.
4. Charcoal rot levels increased, with the greatest rise occurring in the irrigated trial.

Background

Over the past two years the Mungbean Agronomy team has investigated the impact of applied nitrogen (N) fertiliser on yields of inoculated versus uninoculated mungbean. Grower consultation identified a gap in knowledge regarding the nutritional management of mungbean, specifically nitrogen. Industry bodies have indicated that most mungbean crops are inoculated. However, poor nodulation commonly results in N deficiency and significant yield reductions (up to 50%) where residual N levels are low. To counteract poor nodulation, a proportion of the industry have decided that it may be easier and more efficient to apply N to maximise yield.

As mungbean is a very short duration crop, some people consider that even with good nodulation, the fixation process is too slow to supply the required amount of N to maximise yield. Past research results have been inconsistent, with mungbean often not responding to N applied at planting. There is further anecdotal industry evidence that mungbean yield increases in response to higher nitrate levels in the profile when N is applied in the fallow.

In the 2018/19 season, a series of trials investigated how the timing and placement of nitrogen impacted on mungbean yields compared to well-nodulated mungbean. A constant rate of nitrogen was applied, both during the fallow and at planting, at different positions within the soil profile. This established treatments with varying amounts of available N at different positions within the soil profile. There were no statistically significant differences detected. As a result, the project adapted the research question and experimental design to further investigate this issue by investigating a range of rates of nitrogen.

What was done

A field experiment was conducted at Hopeland, near Chinchilla. The site was selected for its low soil mineral nitrogen at the time of preliminary sampling (50 kg N/ha, 0-90 cm, 19/07/2019), and the ability to flood irrigate. Both a spring and summer planted trial were conducted in the same field; this report outlines details of the spring planted trial. Deep phosphorus (P) was applied across the whole site on 2 September 2019 to rectify a potential P deficiency. The P was applied as MAP at a rate of 100 kg/ha, 20-25 cm depth and 50 cm spacing.

Nitrogen applications were surface spread on 24 September 2019 (Table 1). All treatments were replicated four times and repeated with and without irrigation to alter yield potential. A pre-sowing irrigation (flood) was applied across the site on 3 October 2019 to enable planting. Mungbean was then planted on 14 October 2019 with Jade-AU$^{(D)}$ at 50 cm row spacing with 40 L/ha of Flowphos 13Z. The 'double starter' treatment had 80 L/ha applied.

The paddock nitrogen status at planting (control plots only) was 58 kg N/ha for the irrigated trial and 89 kg N/ha for the dryland trial. All treatments, except treatment 1, were inoculated at planting through water injection.

Table 1. Treatments applied at Hopeland.

	Treatment	Inoculation	Irrigation
1	No applied N	- inoculation	+/- irrigation
2	No applied N	+ inoculation	+/- irrigation
3	No applied N, Double starter	+ inoculation	+/- irrigation
4	30 kg N/ha	+ inoculation	+/- irrigation
5	60 kg N/ha	+ inoculation	+/- irrigation
6	90 kg N/ha	+ inoculation	+/- irrigation
7	120 kg N/ha	+ inoculation	+/- irrigation
8	150 kg N/ha	+ inoculation	+/- irrigation

The irrigated trial received two subsequent irrigations, one at pre-flowering and a second at podding. The crops were harvested on 2 January 2020. AMF levels were low with nematodes detected.

Results

The mungbean crop experienced very hot and dry conditions; a large proportion of days were over 35 °C from flowering to harvest, combined with no significant in-crop rainfall (Figure 1). This resulted in the dryland trial only yielding approximately 300 kg/ha. The irrigated crop however yielded approximately 800 kg/ha, almost 500 kg/ha more from the two irrigations at pre-flowering and mid-pod fill.

All treatments nodulated well, even the non-inoculated treatment. Considerable care was taken to avoid contamination with inoculant in the uninoculated treatment. However, it appears that residual rhizobium in the paddock and soil movement between plots caused nodulation.

It is interesting to note the cooling effect of the irrigations on the mungbean (Figure 2). When irrigations were applied, the canopy temperature rapidly dropped compared to the dryland trial and remained lower for 10 days.

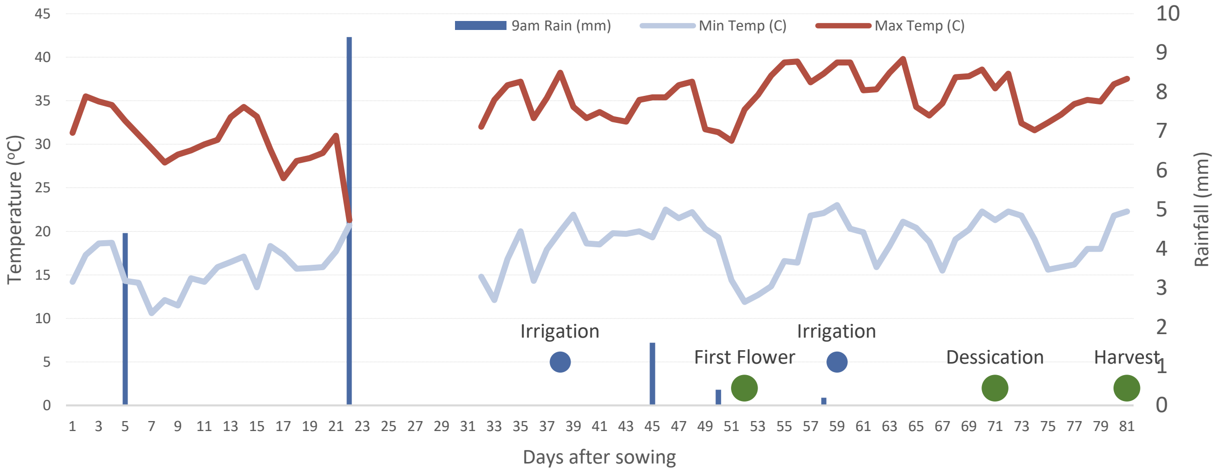

Figure 1. Crop weather. Maximum and minimum daily air temperatures, daily rainfall total, irrigation applications and crop phenology throughout mungbean growth period. Gap in temperatures due to weather station failure.

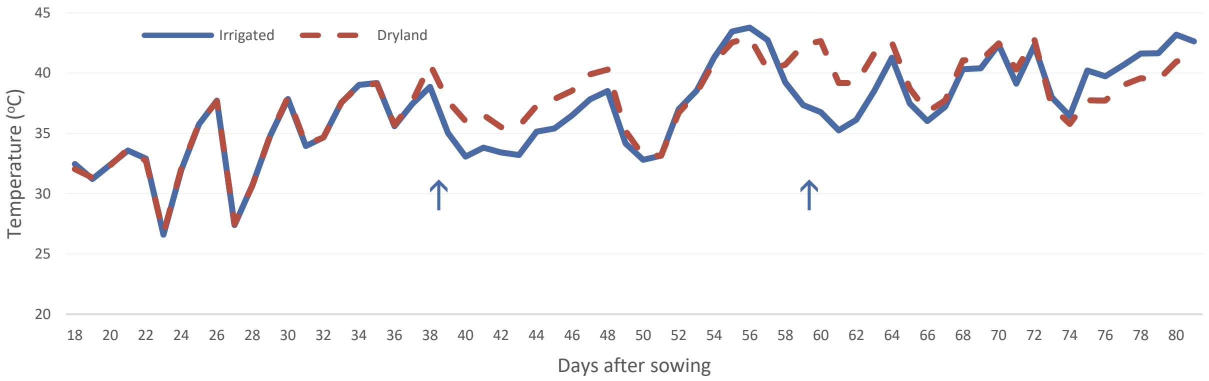

Figure 2. Maximum canopy temperatures. First irrigation at 38 days after sowing, second irrigation at 59 days after sowing (indicated by arrows).

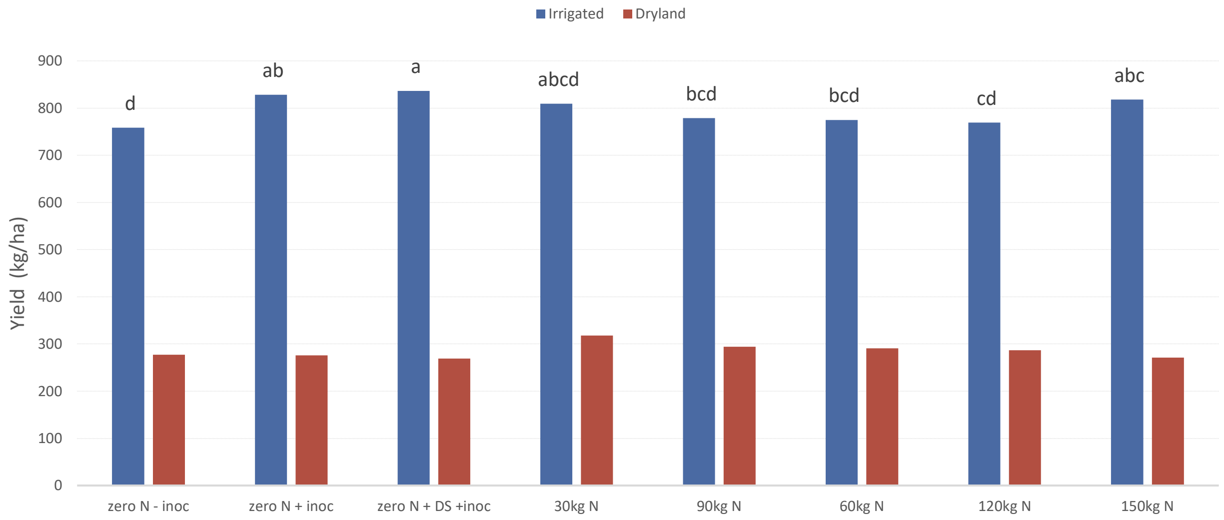

Figure 3. Machine harvested yield.
The letters on each bar are presented to show significant differences at P(0.05).

This cooling effect could be attributed to several factors, including cooling of the soil surface due to the water, rapid biomass response to irrigation resulting in canopy closure and increased evapotranspiration. Hence, this yield response to irrigation may be due to both increased plant available water (PAW) and a cooler, more humid microclimate during critical times of crop development. Critical times include flowering and pod fill; mungbean yield potential significantly declines when temperatures reach more than 33 °C.

There were no significant yield differences between treatments in the dryland crop (Figure 3). This crop was unlikely to record any significant responses to nitrogen, due to severe moisture stress and high temperatures during critical periods of flowering and podding, limiting yield and hence reducing N requirement.

Currently, it is believed that a one tonne mungbean crop requires 60 to 70 kg N/ha. The dryland crop would only have required approximately 20 kg N/ha, so the soil N available at planting (89 kg N/ha) was more than adequate, even before any contribution of fixed N due to nodulation.

The irrigated crop did record significant yield differences. Like the dryland trial, all treatments nodulated. The highest yielding treatments were the zero N + double starter, zero N + inoculant, 30 kg N/ha and 150 kg N/ha. Again, the lack of response to nitrogen is not surprising given the low crop requirements due to an average yield of 800 kg/ha (~55 kg N/ha).

Although inoculant was not applied and all efforts were made to ensure this treatment did not nodulate, its nodulation was most likely due to residual rhizobia in the soil or irrigation

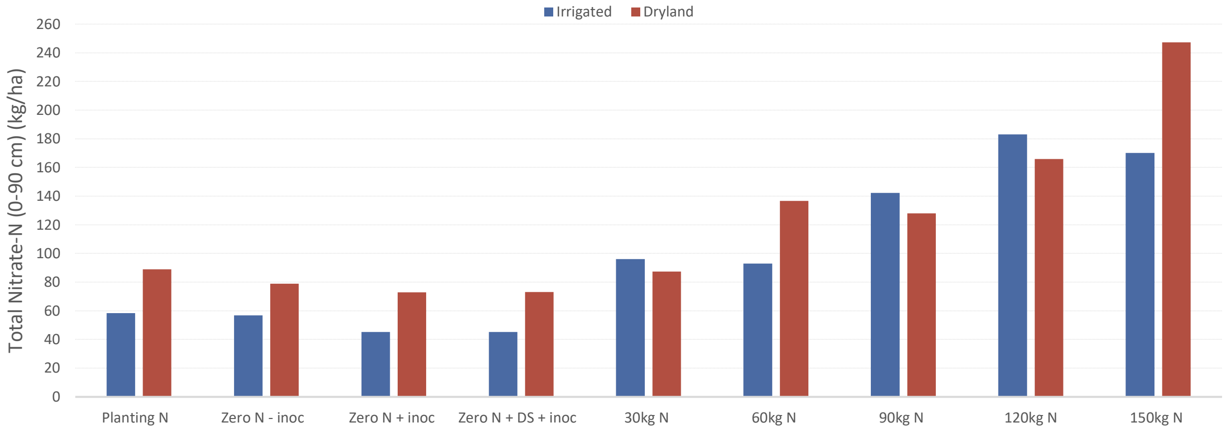

Figure 4. Total soil N status at harvest to 90 cm for dryland and irrigated crops.

water. As a result, the nodules would have been formed later than the other treatments, hence providing fixed N slower and in lesser quantities.

The nitrogen status was also measured after harvest. The harvest soil N results show very little change in N levels in all the zero N treatments (Figure 4).

Biomass samples collected at flowering and maturity didn't show any clear trends towards the application of N (data not shown). The irrigated crop had approximately double the biomass compared to the dryland crop at maturity. Irrigation was clearly able to increase the crop's yield potential, however irrigation alone couldn't maximise yield as the irrigated crop only yielded 800 kg/ha. It appears that the very high temperatures during flowering and pod fill dramatically reduced the yield potential of this crop.

Charcoal rot (*Macrophomina phaseolina*) increased during this mungbean crop (Figure 5). A 'low risk' rating at planting rose at harvest to a 'medium risk' rating for the dryland crop and a 'high risk' rating for the irrigated crop.

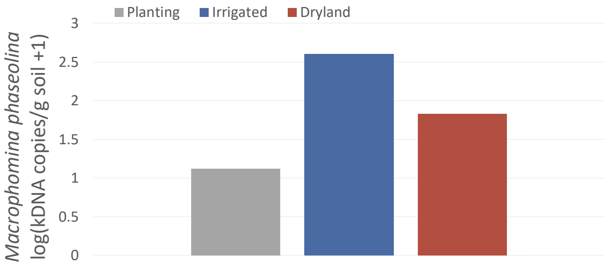

Figure 5. Charcoal rot - log DNA/g soil *Macrophomina phaseolina* at planting (grey) and harvest.

Population density levels (from PREDICTA® B manual): below detection <0.3; low 0.3-<1.61; medium 1.61-2; high >2.

Flood irrigation of spring mungbean 38 days after sowing at Hopeland.

Implications for growers

Mungbean crops of less than 1 t/ha are unlikely to respond to nitrogen fertiliser if ~90 kg N/ha is available (and accessible) in the soil at planting. Yields below this are common as rain and heat often limit yield potential. Hence there is sufficient available N to support this yield, whether it is mineral N or fixed N. Consider the starting available N and yield potential of the crop to determine whether to apply N fertiliser.

Mungbean have high water requirements when weather conditions promote high evaporative demand (low humidity and high temperatures), and need in-crop rainfall/irrigation to maximise yield. However, in-crop water may still not maximize yields under very hot conditions during flowering through to pod fill. Plant mungbean on a full soil profile of water and try to time flowering and podding to avoid hot conditions if possible. Often this means planting mungbeans later in summer. Mungbean increases levels of charcoal rot so do not follow with crops (e.g. sorghum) that are susceptible to this disease.

Acknowledgements

The research undertaken as part of this project is made possible by the contributions of growers through both trial host farmers and the support of the Gains Research Development Corporation, Department of Agriculture and Fisheries and New South Wales Department of Primary Industries (DAQ1806-003RTX).

Trial details

Location: Hopeland
Crop: Mungbean
Soil type: Grey Vertosol
Nutrients present in initial soil test:

	0-10 cm	10-30 cm
Phosphorus Colwell (mg/kg)	25	12
Phosphorus BSES (mg/kg)	33.5	14.1
Potassium Colwell (mg/kg)	189	86
Organic carbon (%)	0.89	0.73

In-crop rainfall: 15 mm
Fertiliser: 100 kg MAP/ha, 20-25 cm depth and 50 cm spacing prior to plant

N treatments as described above

Mungbean: response to different levels of soil nitrogen—Hopeland (summer)

Cameron Silburn and Jayne Gentry
Queensland Department of Agriculture and Fisheries

RESEARCH QUESTIONS: *How much nitrogen is required to maximise mungbean yield? | Can well-nodulated mungbean achieve the same yield as fertilised crops? | How does differing the concentrations of soil nitrogen impact nitrogen fixation?*

Key findings

1. Mungbean responded to nitrogen fertiliser with a yield of +2 t/ha when planted on a low starting soil nitrogen profile (~ 50 kg N/ha).
2. One irrigation at pod-fill increased yields by up to 850 kg/ha.
3. Applying irrigation during high temperatures reduced canopy temperature, which is believed to also improve pod filling and reduce flower abortion.
4. Mungbean can increase levels of charcoal rot.

Background

Over the past two years the Mungbean Agronomy team have investigated the impact of applied nitrogen (N) fertiliser on yields of inoculated versus uninoculated mungbean. Grower consultation identified a gap in knowledge regarding the nutritional management of mungbean, specifically nitrogen. Industry bodies have indicated that most mungbean crops are inoculated. However, poor nodulation commonly results in N deficiency and significant yield reductions (up to 50%) where residual N levels are low. To counteract poor nodulation, a proportion of the industry have decided that it may be easier and more efficient to apply N to maximise yield.

As mungbean are a very short duration crop, some people consider that even with good nodulation, the fixation process is too slow to supply the required amount of N to maximise yield. Past research results have been inconsistent, with mungbean often not responding to N applied at planting. Anecdotal evidence from industry is that mungbean yields increase in response to higher nitrate levels in the profile when N is applied in the fallow.

In the 2018/19 season, a series of trials investigated the impacts of timing and placement of applied nitrogen on mungbean yields compared to well-nodulated mungbean. A constant rate of nitrogen was applied, both during the fallow and at planting, at different positions within the soil profile. This established treatments with varying amounts of available N at different positions within the soil profile. There were no statistically significant differences detected. As a result, the project adapted the research question and experimental design to further investigate this issue by investigating a range of rates of nitrogen. The research was conducted in spring and repeated in summer. This report is for the summer crop; the spring crop is reported separately in this publication.

What was done

A field experiment was conducted at Hopeland, near Chinchilla. The site was selected for its low soil mineral nitrogen at the time of preliminary sampling (50 kg N/ha, 0-90 cm, 19/07/2019), and the ability to flood irrigate. Both a spring and summer planted trial were planted in the same field, this report outlines details of the summer planted trial. Deep phosphorus (P) was applied across the whole site on 2 September 2019 to rectify a potential P deficiency. The P was applied as MAP at a rate of 100 kg/ha, 20-25 cm depth and 50 cm spacing.

A cover crop of Panorama millet was planted on 11 October 2019 to draw down the nitrogen status of the soil. The cover crop was desiccated on 23 December 2019 and slashed on 8 January 2020. Nitrogen was applied the same day by banding the fertiliser 10 cm offset from the plant row (Table 1). All treatments were replicated four times and repeated with and without irrigation to alter yield potential. The soil N status at planting was 52 kg N/ha for the irrigated trial and 91 kg N/ha for the dryland site (control plots only), even though these were side by side in the same paddock. When comparing the summer and spring crop planting N, the cover crop was effective at maintaining the low N status of the summer trial, effectively buffering against mineralisation increasing available N from October to January.

Jade-AU$^{\Phi}$ mungbean was planted on 29 January 2020 with 50 cm row spacings with 40 L/ha of Flowphos 13Z. All treatments (except Treatment 1) had inoculant applied at planting through water injection. Micro-plots were planted with non-nodulating soybeans in each plot, as reference plants for the natural abundance method (^{15}N isotope) to measure the proportion of N in the plants that was fixed from the atmosphere (%Ndfa) by the mungbean plants under each treatment.

Table 1. Treatments applied at Hopeland.

	Treatment	Inoculation	Irrigation
1	No applied N	- inoculation	+/- irrigation
2	No applied N	+ inoculation	+/- irrigation
3	No applied N	+ inoculation	+/- irrigation
4	30 kg N/ha	+ inoculation	+/- irrigation
5	60 kg N/ha	+ inoculation	+/- irrigation
6	90 kg N/ha	+ inoculation	+/- irrigation
7	120 kg N/ha	+ inoculation	+/- irrigation
8	150 kg N/ha	+ inoculation	+/- irrigation

The trial received 200 mm rainfall within the first month of planting; as a result the irrigated trial only received one subsequent irrigation at podding. The crop was harvested on 24 April 2020. AMF levels were low, and no nematodes were detected.

Results

The summer mungbean crop experienced almost ideal conditions, with most days below 33 °C from flowering to desiccation (Figure 1). These conditions combined with the first month's rainfall, resulted in the dryland crop averaging 1.25 t/ha and 2.1 t/ha for the irrigated crop (Figure 2). Follow-up irrigation trial treatments were scheduled for pre-flowering and early pod-fill to maximise yield. However, due to the early rainfall only one irrigation (at pod fill) was applied (Figure 1).

The combination of low starting N (52 kg N/ha), high rainfall and mild temperatures resulted in a response to applied N. Both the irrigated and dryland trials show an upwards trend as nitrogen rates increased. The irrigated trial recorded statistically significant yield increases when N was applied compared to the zero N treatments. The 150 kg N/ha was significantly higher than zero N + incoc treatment by ~250 kg/ha, but was not significantly different to the other N rates except for 60 kg N/a. Both trials had the same starting water and experienced the same conditions; the only difference was one timely irrigation that resulted in an 850 kg/ha yield benefit (Figure 2).

Although no significant results were recorded, there was an upwards trend of increasing biomass as N rates increased (data not shown).

A major focus of this research was the impact varying amounts of mineral soil nitrogen have on nitrogen fixation. There was a significant difference between treatments (Figure 3). Both the uninoculated and inoculated 0 kg N/ha treatments fixed similar amounts of N. This was not surprising as both treatments nodulated, most likely due to background rhizobia in the

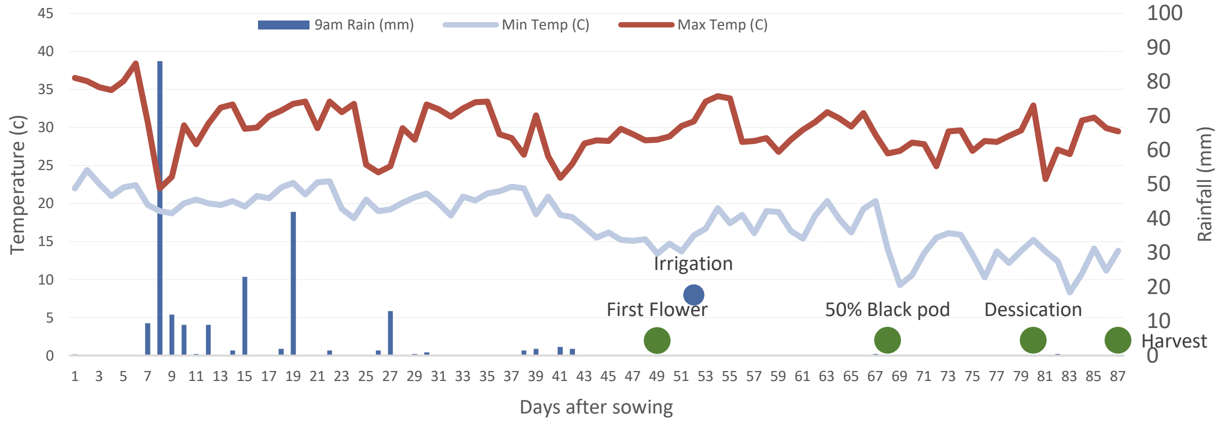

Figure 1. Maximum and minimum daily air temperatures, daily rainfall total, irrigation applications and crop phenology throughout mungbean growth period.

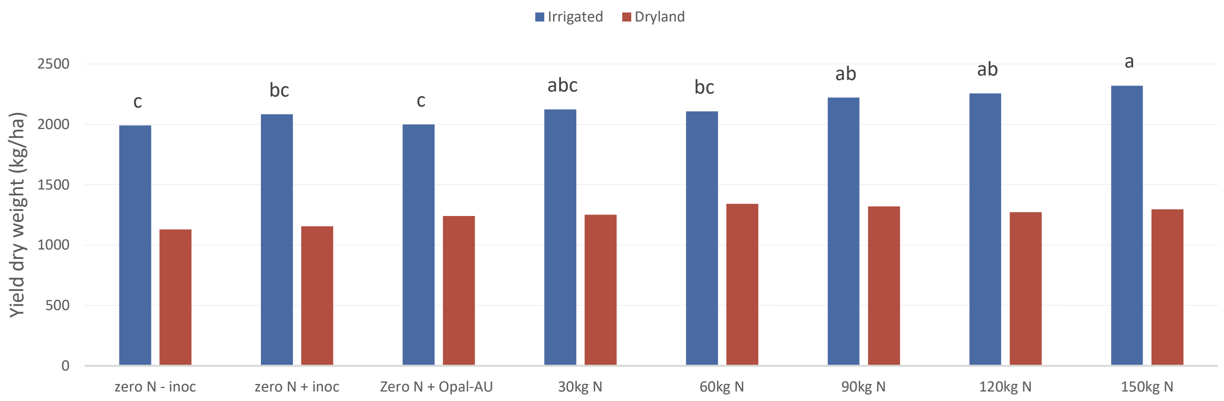

Figure 2. Mungbean yield.

The letters on each bar are presented to show significant differences at P(0.05).

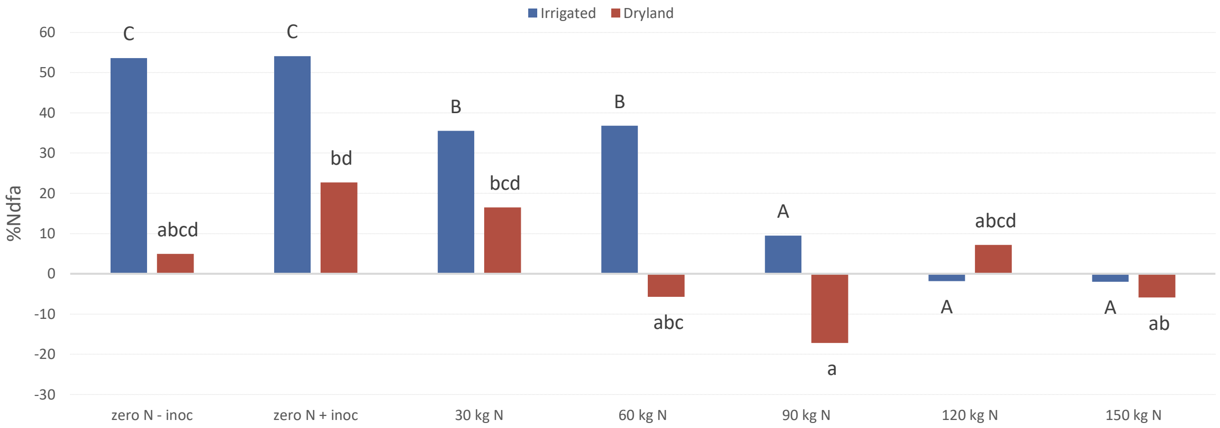

Figure 3. Nitrogen derived from the atmosphere percentage.

Within each experiment, means with same letters are not significantly different at P(0.05), using a protected lsd test.

paddock. The N fixation (%Ndfa) decreased as the N rate increased, with the higher N rates not fixing any N at all. Fixation was greatest in the higher yielding irrigated crop, which also had the lower mineral N at planting. These data confirm that N fixation of mungbean decreases as soil mineral N increases. With very little difference in yield across these treatments, it appears that mungbean can switch from utilising fixed N to nitrate N with no yield penalty.

Irrigation reduced canopy temperature in the trial. After the irrigation was applied at 52 days after sowing (early pod fill, Figure 1), the temperature in the mungbean dropped (Figure 4) and remained below 34 °C until desiccation (79 days after sowing). The maximum difference between canopy temperatures was 12 °C approximately 5 days after irrigation. This cooling effect could be attributed to several factors, including cooling of the soil surface due

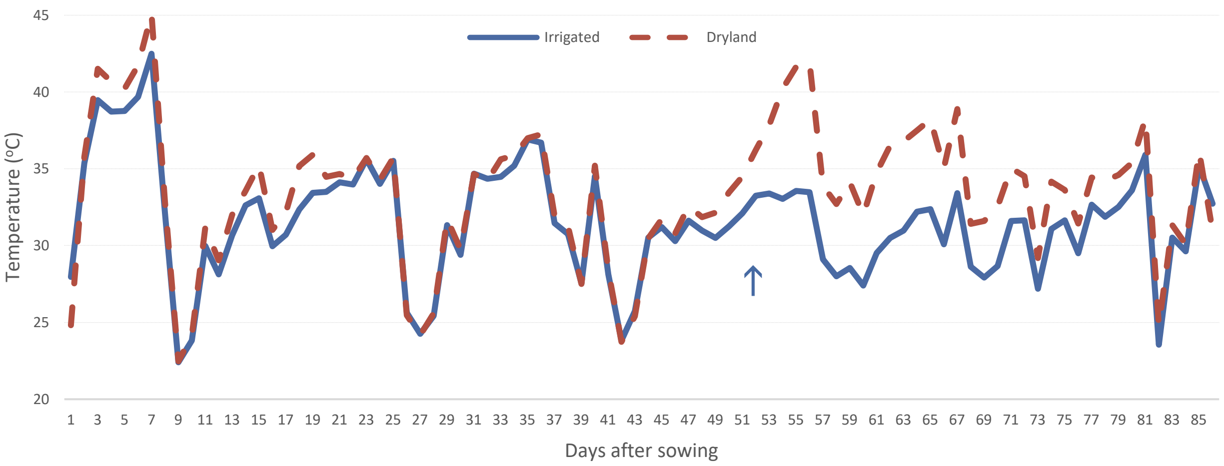

Figure 4. Maximum canopy temperatures. One irrigation was applied at early pod fill 52 days after sowing (indicated by arrow).

to the water, rapid biomass response to irrigation resulting in canopy closure and increased evapotranspiration. Hence, this yield response to irrigation may be due to both increased plant available water (PAW) and a cooler, more humid microclimate during critical times of crop development (flowering and pod fill). Mungbean yield potential begins to significantly decline when temperatures are higher than 33 °C during flowering and pod fill.

Charcoal rot (*Macrophomina phaseolina*) increased during this mungbean crop (Figure 5). A 'low risk' rating at planting rose at harvest to a 'medium risk' rating for the dryland crop and a 'high risk' rating for the irrigated crop.

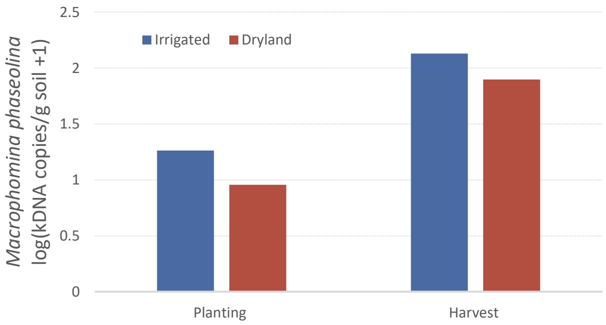

Figure 5. Charcoal rot - log DNA/g soil *Macrophomina phaseolina* at planting and harvest.
Population density levels (from PREDICTA® B manual): below detection <0.3; low 0.3-<1.61; medium 1.61-2; high >2.

Implications for growers

High yielding mungbean (+2 t/ha) can respond to nitrogen fertiliser if less than 50 kg N/ha is available (and accessible) in the soil at planting. However, in normal field conditions when yield potential is below 2 t/ha and available soil N levels are higher, then there is enough N to maximise yield. As N fixation decreases with increasing levels of soil N, it is possible that a mungbean crop will not fix any free N but will instead only utilise soil nitrates. This will reduce the amount of N available for the following crop. Consider measuring starting available nitrates and the yield potential of the crop to determine whether to apply N fertiliser. Inoculation is still recommended to ensure adequate N is available under all N profiles.

Mungbean have high water requirements when evaporative conditions are high (low humidity, high temperatures) and need in-crop rainfall/irrigation to maximise yield. However, in-crop water may still not maximize yields under very hot conditions during flowering through to pod fill. Plant mungbean on a full soil profile of water and try to time flowering and podding to avoid hot conditions if possible. Often this means planting mungbeans later in summer. Mungbean increases levels of charcoal rot so do not follow with crops (e.g. sorghum) that are susceptible to this disease.

Acknowledgements

The research undertaken as part of this project is made possible by the contributions of growers through both trial host farmers and the support of the Gains Research Development Corporation, Department of Agriculture and Fisheries and New South Wales Department of Primary Industries (DAQ1806-003RTX).

Trial details

Location: Hopeland

Crop: Mungbean

Soil type: Grey Vertosol

Nutrients present in initial soil test:

	0-10 cm	10-30 cm
Phosphorus Colwell (mg/kg)	25	12
Phosphorus BSES (mg/kg)	33.5	14.1
Potassium Colwell (mg/kg)	189	86
Organic carbon (%)	0.89	0.73

In-crop rainfall: 200 mm

Fertiliser: 100 kg MAP/ha, 20-25 cm depth and 50 cm spacing prior to plant

N treatments as described above

Hopeland summer mungbean crop

Mungbean response to applied nitrogen—Emerald

Douglas Sands and Peter Agius
Queensland Department of Agriculture and Fisheries

Research question: *Does applying nitrogen to mungbeans give a grain yield advantage over inoculation?*

Key findings

1. Mungbeans didn't respond to nitrogen fertiliser within a yield range of 1–1.4 t/ha.
2. Mineralisation rates four times that of published figures may potentially be masking any nitrogen responses.
3. A maximum of 30% of the total N taken up by mungbeans was fixed from the atmosphere in the control plots and this rate was reduced to zero as the supply of nitrates in the soil increased.
4. Nitrate levels at harvest were most depleted at a depth of 10-30 cm across all treatments.

Background

Feedback from growers has indicated that mungbean grain yields may respond to applied nitrogen (N). Anecdotal evidence suggests that fields that have high nitrate levels at planting have often produced the best mungbean yields. Trial work to date has been unable to replicate this response with applied N at planting, although there has been limited work done to date. It has also been suggested by industry that the length of time between application and planting is important with the most successful crops coming from fields that had the N applied the previous summer.

It is unclear whether the length of time of the fallow after the application of N improves N uptake by being better distributed in the profile, or by stimulating other microbial processes within the soil which in turns helps the availability of N and other nutrients.

This experiment was designed to indicate whether this anecdotal evidence can be replicated in a small plot field experiment. The other question was how inoculation and applied N interacted to supply N to the crop. While most growers are inoculating their seed at planting, evidence of rhizobia nodules is not always obvious. This may be a symptom of the surface soil drying out too quickly in summer conditions and the nodules not having a chance to establish, or the plant is simply obtaining its N from another source.

What was done

A trial site was established at the Emerald Research Facility that had a wheat cover crop planted for the winter of 2019. This wheat crop was planted without any additional fertiliser and taken through to harvest to reduce the amount of N in the profile for the mungbean trial.

After the wheat harvest, the site was set up for 32 plots (4 m x 24 m) in a randomised block design. The following eight treatments were replicated four times. Treatments applied were:

1. No N applied (0N)
2. No N applied and no inoculation at planting (0N-IN)*
3. No N applied plus double starter rate at planting (0N+2ST)
4. 30 kg N/ha applied (30N)
5. 60 kg N/ha applied (60N)
6. 90 kg N/ha applied (90N)
7. 120 kg N/ha applied (120N)
8. 150 kg N/ha applied (150N)

All treatments except Treatment 2 (0N-IN)* had inoculant applied at planting through water injection. All N treatments (4 to 8) were applied after the wheat harvest on 25 November 2019. The N was applied as urea dissolved in water solution and sprayed onto the soil surface between standing stubble rows as the soil profile was too dry and hard to use banding applications. The site was irrigated on 26 November with 100 mm (the day after the N applications) and irrigated again starting on 16 December with another 100 mm application by travelling boom irrigator.

All treatments were repeated to enable two trials side-by-side with a total of 64 plots; one dryland and another higher productivity trial with irrigation to increase the pressure on nutrient uptake.

The site then received 217 mm of rainfall from the start of January through to planting. Average plant available water (PAW) at planting was 120 mm to a depth of 120 cm.

The whole site was planted on 14 February with Jade-AU$^{\Phi}$ at a seeding rate of 30 seeds/m^2. Non-nodulating soybeans were hand planted into each plot on 17 February (~1/m^2) and used as the contrast species for 15N testing and calculation of N fixation at peak biomass. In this case 15N was measured in plant samples taken from every plot in the trial at physiological maturity and compared to the non-nodulating soybeans.

The irrigated trial was given one application of 50 mm by travelling boom on 24 March. In-crop rainfall on 6 March reduced the time for a second irrigation prior to flowering.

Results

There were no responses for grain yield or dry matter across any of the treatments in the dryland or irrigated trial (Tables 1 and 2). The addition of one irrigation did lift the average yields of the crop by ~400 kg/ha, which should have given more opportunity to find a yield response between treatments. This was not the case as the data from both machine harvested yields and hand harvested yields show a similar pattern of non-significance in both trials. The general lack of crop height in both trials is the major reason for the machine harvest not being able to capture the full grain yield of the crop.

Table 1. Key results for dryland N response trial.

Treatment	Population (plants/m^2)	Days to flower	TDM @ flowering (kg/ha)	TDM @ peak biomass (kg/ha)	TDM @ maturity (kg/ha)	Plant height (cm)	Days to Maturity	Grain yield (kg/ha)	Hand cut grain yield (kg/ha)	Harvest Index (hand cuts)
0N	24	39	2441	3223	3006	39	60	573	983	0.33
0N+2ST	26	40	2458	2700	2735	43	60	577	895	0.32
0N-IN	27	39	2748	3481	3088	42	59	660	1041	0.34
30N	25	39	2500	3484	2732	43	60	681	1046	0.32
60N	26	39	2638	3001	3058	42	60	607	936	0.31
90N	26	39	2589	3280	3143	42	60	711	1034	0.33
120N	27	39	2663	3340	3264	41	60	670	1164	0.36
150N	26	40	2462	3330	3092	41	60	612	922	0.30
Trial mean	26	39	2562	3230	3015	42	60	637	1003	0.33
SE mean	1.2	0.2	196	363	245	1.6	0.4	60	100.0	0.018
LSD0.05	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s

Table 2. Key results for irrigated N response trial.

Treatment	Population (plants/m^2)	Days to flower	TDM @ flowering (kg/ha)	TDM @ peak biomass (kg/ha)	TDM @ maturity (kg/ha)	Plant height (cm)	Days to Maturity	Grain yield (kg/ha)	Hand-cut grain yield (kg/ha)	Harvest Index (hand cuts)
0N	25	39	2395	2538	3732	48	59	1069	1295	0.35
0N-IN	29	40	2161	4190	3920	48	60	1012	1199	0.30
0N+2ST	27	40	2203	3872	4323	52	60	941	1418	0.33
30N	27	39	2568	4782	4035	49	59	1130	1398	0.34
60N	27	40	2335	3320	4197	48	60	1045	1538	0.37
90N	27	40	2403	3630	4378	48	60	1019	1408	0.32
120N	25	40	2597	3537	4241	45	61	934	1349	0.32
150N	27	39	2452	4371	3779	46	60	1013	1229	0.32
Trial mean	27	39	2389	3780	4076	48	60	1021	1354	0.33
SE mean	1.2	0.4	205.7	489.3	288.2	2.7	0.6	195	153	0.02
LSD0.05	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s	n.s

The low crop height and the generally poor yields from these two trials is surprising, and it is worth examining some of the main physiology components of this crop to understand why.

Physiology

Average days to flowering (Tables 1 and 2) was close to optimum at 39 days, however average days to maturity was quite short (60 days).

Harvest index (HI) in both trials averaged 0.33 (Tables 1 and 2), which is close to optimum based on previous trial work. This would indicate that the grain yields were in-line with biomass accumulation, it appears the crops did not build sufficient vegetative biomass to support a bigger grain yield. The difference in grain yield between the irrigated trial and the dryland trial with the same HI supports the conclusion that soil water availability has been one of the main restrictions in yield; soil water data supplies some evidence of this (Figure 1).

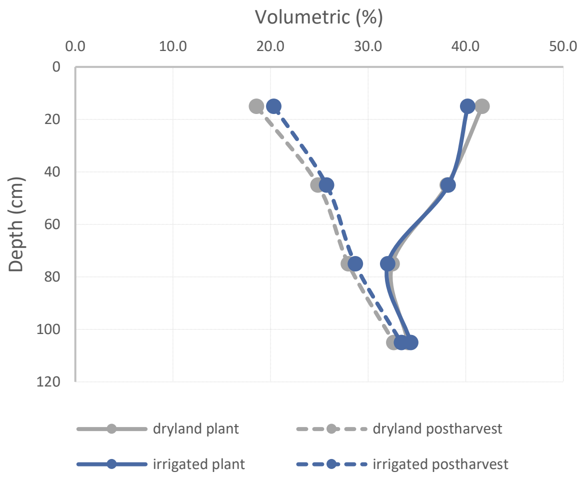

Figure 1. Changes in plant available water from planting to harvest.

Despite two 100 mm irrigations applied pre-plant and 211 mm of rainfall in January 2020, the soil profile was still not full, with a dryer soil layer in the 60–80 cm zone (Figure 1). The surface and subsurface soil water profile (0-60 cm) was well utilised by the plant. The fact that the irrigated trial had similar soil moisture levels at harvest as the dry land trial means soil water certainly restricted the dryland trial.

Weather conditions at the time of this trial (Figure 2) were mild as demonstrated by the maximum and minimum temperatures.

After the last major rainfall event, maximum temperatures stayed between 30–35 °C and minimum temperatures were mostly under 20 °C (Figure 2). Early in-crop rainfall was also considered to be beneficial for good early biomass production.

Overall, environmental conditions should have been conducive to better than average yields and soil water conditions were good in the top 60 cm of the profile. However, the dryer layer of soil between 60 and 100 cm may have contributed to the crop's poor performance. The addition of irrigation has created more grain yield, so it is logical that the soil moisture profile was still a key variable in the overall crop result.

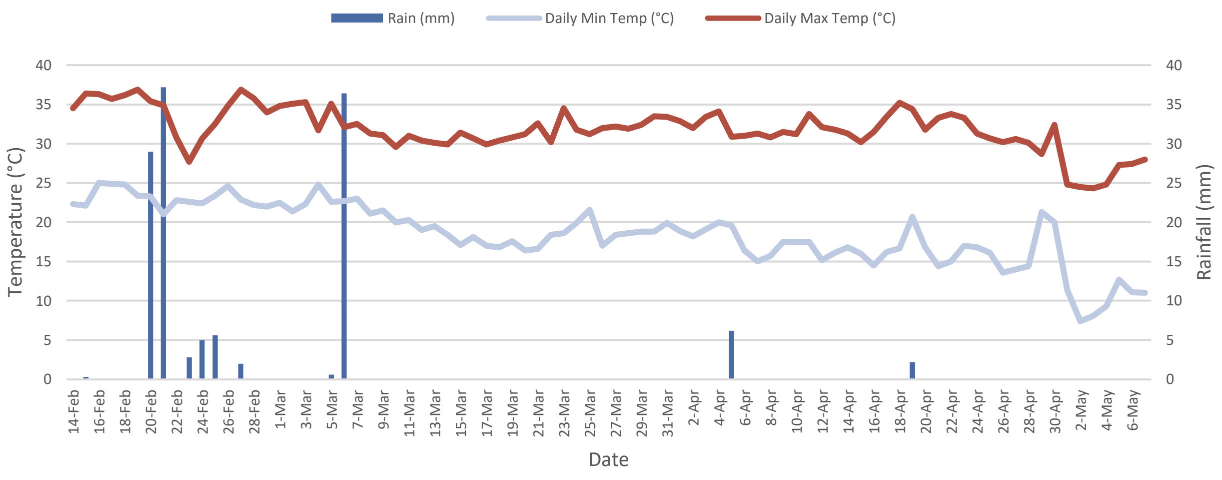

Figure 2. Weather data during trial period.

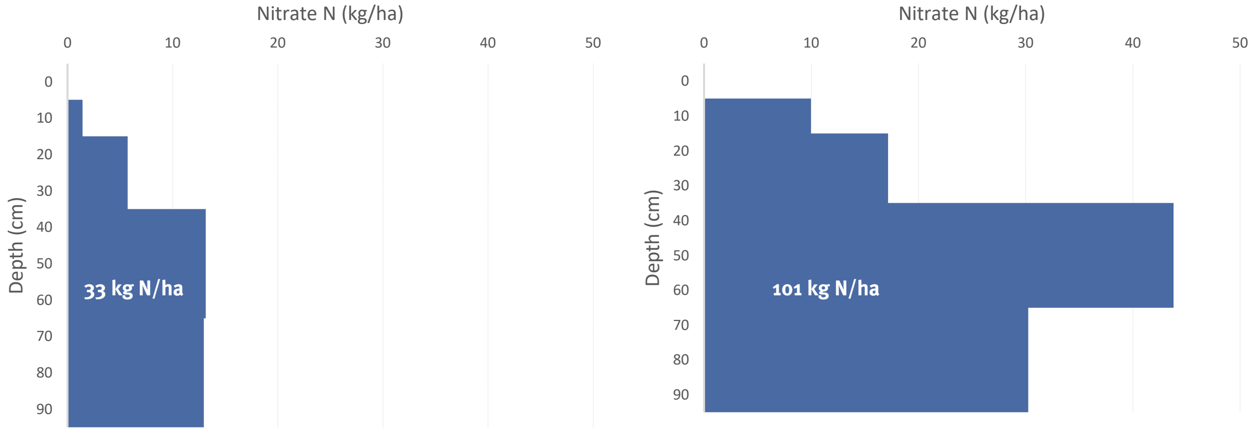

Figure 3. Analysis of soil nitrate levels at start of the fallow (October 2019) on the left and soil nitrate levels measured at planting (February 2020) on the right. These values were measured in the Nil N control treatments (baseline) for this experiment.

Nitrogen impacts

Starting N measured at planting was relatively high, which defied assumed mineralisation rates. Starting N after wheat harvest (cover crop) was 33 kg N/ha in the top 90 cm of the profile (Figure 3). By planting time this figure had increased to 101 kg N/ha in the top 90 cm (Figure 3); this means 68 kg N/ha was mineralised in 120 days or ~0.5 kg N/ha per day. This soil type has an organic carbon level of ~0.5% in the top 30 cm. The calculated mineralisation rate for this trial was therefore four times that of the annual estimated rate for soils with 0.8% organic carbon from published figures for Central Queensland (The Nitrogen Book, 2008).

This level of mineralisation could be one reason for the uniform response to the applied N treatments across the two trials; the starting N rates may have been adequate to supply the whole crop, with any applied N becoming surplus to the crop's requirements.

After harvesting, all plots were soil cored and nitrate N was measured down the profile to 120 cm. Remaining N levels can be used to calculate the amount of N that has been taken up by the crop by subtracting the starting N levels and adding the applied N used in each treatment. This data shows a general increase in the uptake of nitrate N from the profile as the amount that is applied is increased (Figure 4).

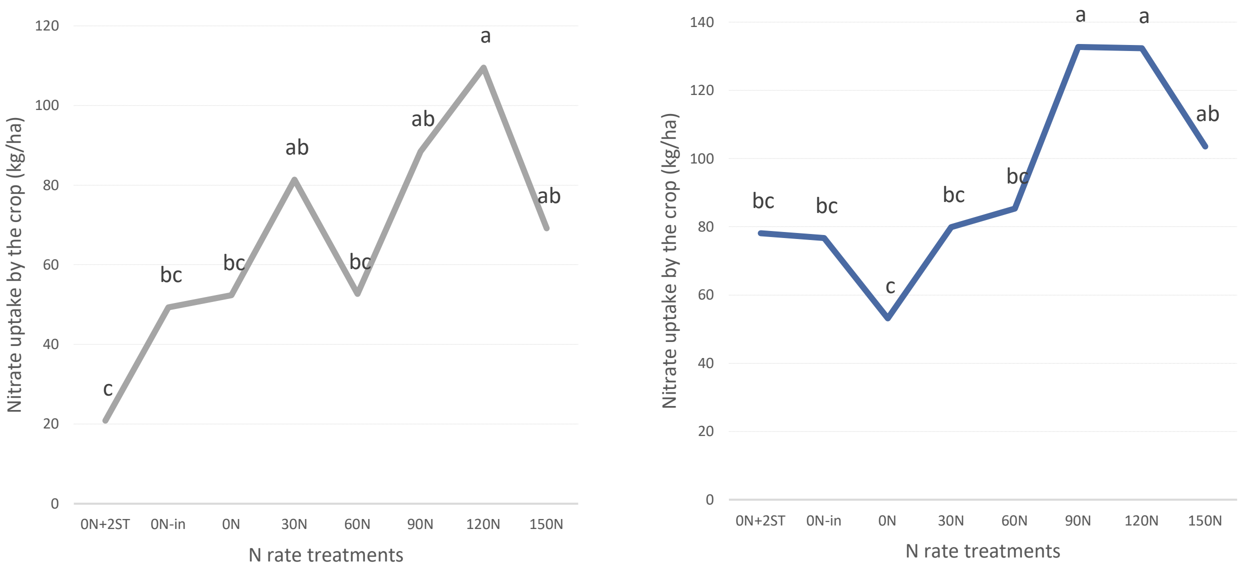

Figure 4. Mean removal of nitrate N from a 90 cm profile calculated from measured nitrates after mungbean harvest. Dryland trial results on the left and irrigated trial results on the right.

Means with the same letters are not significantly different at P(0.05).

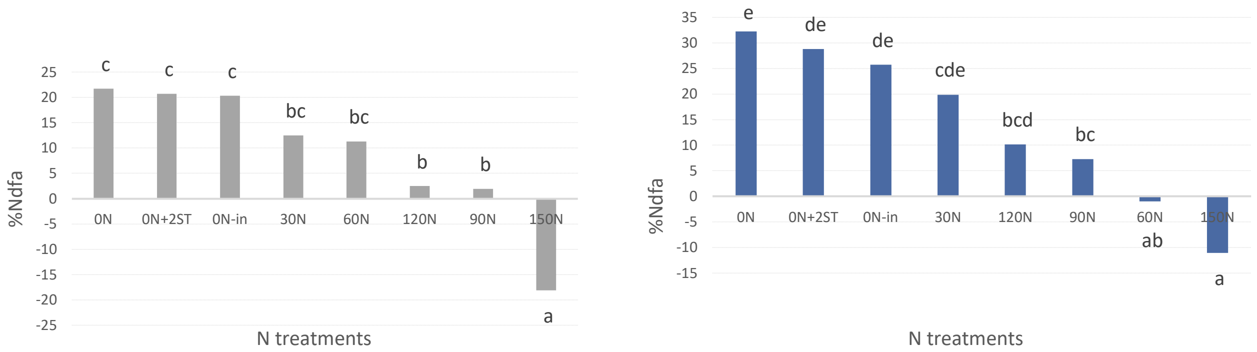

Figure 5. Mean N content in total dry matter (TDM) derived from atmosphere as a percentage of total N content in TDM (data generated from N15 isotope analysis). Dryland trial results (left) and irrigated trial results (right).
The letters on each bar are presented to show significant differences at P(0.05).

At these levels of nitrate uptake (Figure 4), it is worth noting how much N was fixed from the atmosphere within the treatments

The 15N data (Figure 5) shows that the maximum amount of N fixed by the plant is in the Nil N treatment (0N) that derived 20% (dryland) to 30% (irrigated) of its total N from the atmosphere (fixed by rhizobia). Assuming that the missing nitrate in the profile is the other 70–80% of total N uptake, then the total N content of the plant can be calculated (Figure 6). These calculations show nitrate uptake varying between 60 kg N/ha to 140 kg N/ha despite grain yields being not significantly different (Table 1 and 2). This suggests that the plant can take up luxury rates of nitrate without impacting on grain or total dry matter.

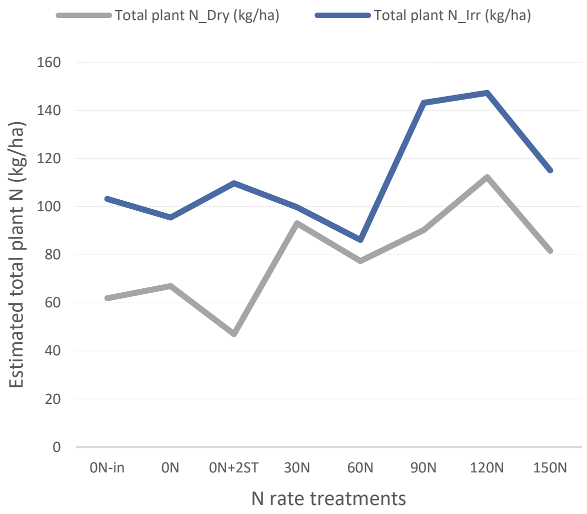

Figure 6. Mean calculated total plant N content values for both irrigated and dryland trials.

The percentage of nitrogen derived from the atmosphere (Ndfa%) data (Figure 5) and the nitrate uptake data (Figure 4), demonstrate the mungbean plant will take advantage of whatever soil nitrate is available and will only fix N when there is a short fall of available N.

Accessibility of the nitrate may be related to its depth and distribution. The distribution of nitrate in the profile after harvesting (Figure 7) shows a distinct drop off in nitrates in the 10-30cm zone. The crops were quite effective in taking up nitrates from this layer, particularly in those treatments where no additional N was applied (0N, 0N-inoculation and 0N+2ST).

This may be a good indicator of the area of the highest root activity and consequently the highest uptake of nutrient and water; even though soil water data (Figure 1) indicates that the top 60 cm of the profile supplied most of the water for the crop. Additionally, this may indicate that the efficiency of nitrate uptake by mungbean plants is related to the amount of nitrate available in the top 30 cm rather than the total amount of profile nitrate.

Fixation of N is highest where the N levels in the top 30 cm are the lowest (Figures 5 and 7), that is, in the low N treatments. Residual soil N increases with the higher rates of N applied and consequently almost no N fixation occurs. A considerable amount of the mineralised soil N was contained in the 60–90 cm layer of the soil profile (Figure 7). This soil layer also contained less soil water than the layers above (Figure 1), which may have restricted root access to this pool of nitrate.

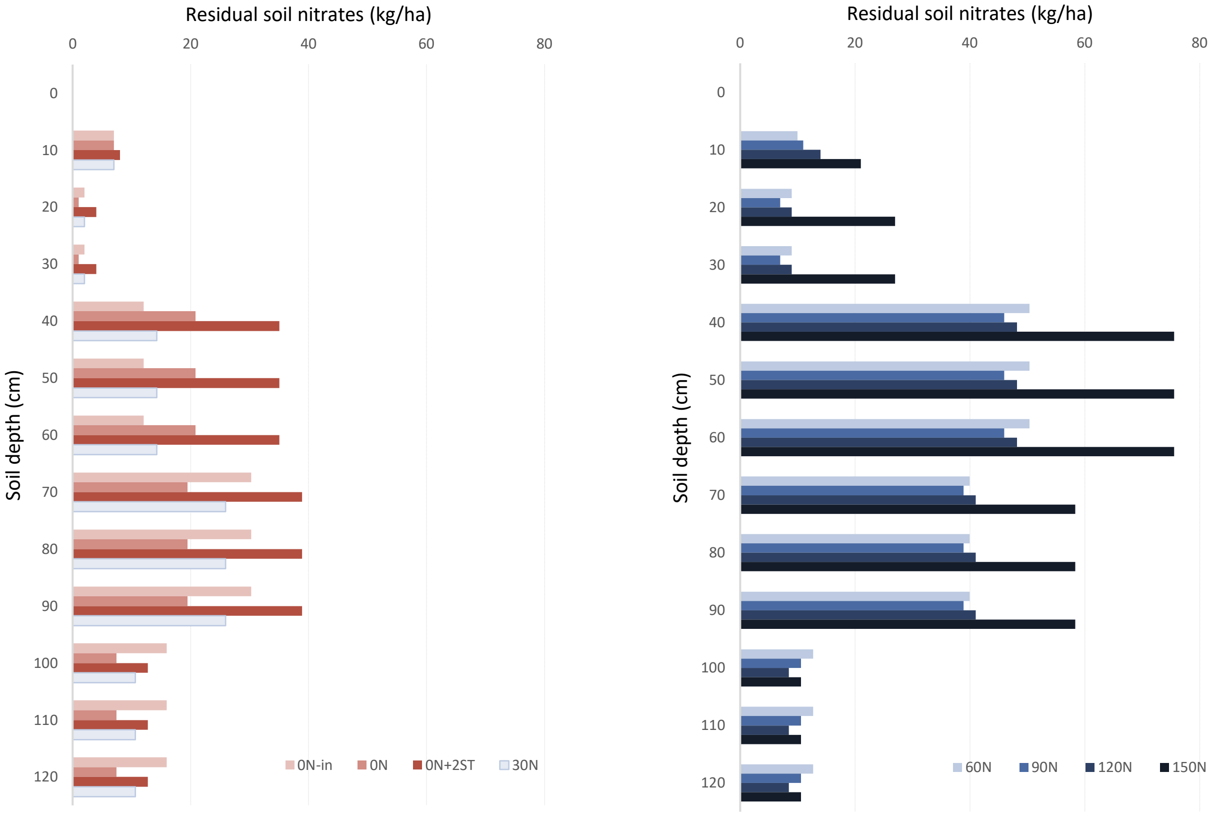

Figure 7. Mean soil nitrates remaining after harvest across all treatments in the dryland trial.

It is interesting to note that inoculation made no impact on the N uptake results (comparison between 0N and 0N-IN), nor did doubling the starter fertiliser (0N+2ST) rate. One off, selective visual assessments showed nodule counts between both 0N treatments were almost the same. This shows that there must have been some native rhizobia present in the soil; even the treatments with no inoculant still showed nodulation occurring. This means there is no conclusive benchmark for the contribution that inoculation can make without additional N applied.

PREDICTA® B sampling at planting revealed there was no detectable level of *Pratylenchus thornei* or *P. neglectus* (<0.1 nematodes/g soil) for this trial site. Root development should not have been impacted by nematodes in either of these trials. There were medium to high levels of charcoal rot (2.32 log(kDNA copies/g soil +1) and common root rot (1.43 log(pg DNA/g soil +1) detected. However, there were no obvious symptoms of charcoal rot causing whole plant dieback within the trial.

Implications for growers

After two years of trialling crop response to applied N, there is no evidence that grain or dry matter yield can be influenced by either rate or distribution of N. Not all scenarios have been tested yet, so the full picture of what the relationship is between mungbeans and N (either mineralised or applied directly) is not completely defined.

The residual nitrate results show an increasing uptake of nitrate N as fertiliser N rates increase and a decline in the amount of N that is fixed by rhizobia. This suggests that if nodules are present, then the plant can switch from using atmospheric N to taking up nitrate within the same season without any impact on grain yield or dry matter accumulation.

The plants' ability to take up available nitrates particularly in the top 30 cm of the profile does have some farming system impacts. The net addition of new or fixed nitrogen to the soil profile will depend greatly on the level of mineralised N available at planting.

Depending on the length of fallow prior to planting mungbeans the level of mineralised N may reduce the amount of fixed N to only 10-15% of total uptake or less. It is also possible that the plant can take up as much as 130 kg N/ha out of the profile, with up to 50kg N/ha exported off the paddock as grain. If only 15% of this N is fixed, then the plant is exporting more nitrate in grain than it is contributing to the paddock from fixation. Under this scenario, the mungbean crop is a net user of the N mineralised by the soil rather than a net contributor.

Acknowledgements

The Mungbean Agronomy Project (DAQ1805-003RTX) is funded by the Grains Research and Development Corporation and the Department of Agriculture and Fisheries. Tchnical management, data collection and monitoring of this trial was carried out by Peter Agius (DAF, Emerald)

Trial details

Location: Emerald Research Facility
Crop: Mungbeans
Soil type: Black /Grey cracking Vertosol
In-crop rainfall: 145 mm
Fertiliser: Supreme Z® at planting (30 kg/ha)

Selected soil fertility characteristics of the trial site:

Depth (cm)	Nitrate nitrogen	Phosphorus (Colwell)	Sulfur (KCl-40)	Exc potassium	BSES phosphorus	CEC
0-10	51	22	9	0.74	66	35
10-30	17	7	5	0.47	43	36
30-60	11	4	8	0.41	45	37

Pre-flowering mungbeans.

Mungbeans at pod fill.

Pigeonpea response to time of sowing—Emerald

Douglas Sands and Peter Agius
Queensland Department of Agriculture and Fisheries

Research questions: *What is the yield performance of currently available pigeonpea lines for different sowing times in Central Queensland? | Does the time of sowing change the phenology of pigeonpea? | How diverse are the current available lines of pigeonpea?*

Key findings

1. A combination of quicker maturing varieties and an early time of sowing have generated the best yields to date.
2. Early sowing produced the biggest differences between varieties.
3. Pigeonpea exhibits enormous flexibility, a beneficial trait for future development of varieties adapted to Queensland conditions.
4. Response to sowing time is possibly driven by day length as well as day degree accumulation.

Background

Pigeonpea (*Cajanus cajan*) has the potential to be a resilient, dryland summer grain legume for the drier, western cropping areas of Queensland and northern NSW. These are areas where the other common summer legumes (soybean, mungbean and peanut) struggle to consistently produce viable commercial yields.

The potential of pigeonpea needs to be proven through a series of trials to establish its productivity in a range of environments. These trials also offer opportunities to better understand the basic physiology of pigeonpea and the genetic diversity within the species.

What was done

A time of sowing (TOS) trial was established at the Emerald research facility (formerly Emerald Agricultural College) in the summer of 2019/20 with pigeonpea varieties sourced from the Australian Grains Gene bank facility in Horsham. The trial included seven varieties across three planting dates with three replicates in a randomised split plot design (Table 1). Seed supplies were limited so plots were limited to 2 m wide by 10 m long.

The original trial structure had allowed for 10 varieties; however, some varieties could not be sourced in time for the commencement of the trial so commercial seed for the variety Sunrise™ was used to plant the remaining plots in each replicate.

Plots were planted into standing wheat stubble with unplanted buffer areas surrounding each plot to allow for ease of harvest given the expectation for there to be large differences in maturities between varieties.

Table 1. Varieties, planting dates and harvesting dates used in the Emerald TOS trial.

Pigeonpea varieties	Sowing times	Harvest dates
ICPL 151	13/12/19	24/6/20
ICPL 85010	15/1/20	18/6/20
ICPL 86012	19/2/20	21/7/20
ICPL 88007		
ICPL 94		
QPL 1019		
ICPL 88039 (Sunrise equivalent)		
Sunrise (commercial seed)		

Drone image of Emerald pigeonpea trial site.

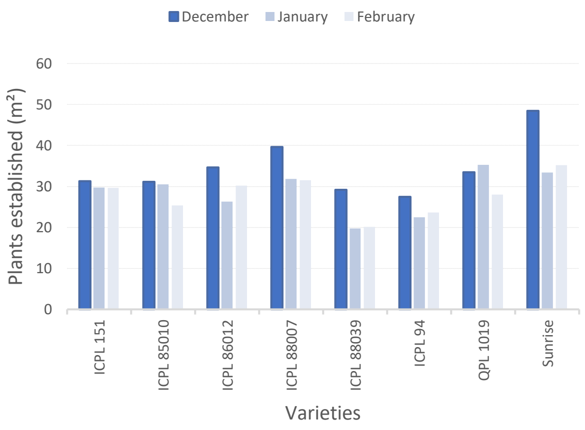

Figure 1. Established plant populations for the pigeonpea varieties in each time of sowing.

The established plant populations averaged around the target of 30 plants/m^2 (Figure 1) and ranged from 20 to 40 plants/m^2. A handful of plots did not reach this density because of waterlogging conditions after planting in the January TOS.

Measurements taken during the growing season included flowering observations, light interception, plant height at flowering and maturity, total and vegetative dry matter cuts, grain yield and yield components.

Soil cores were taken at planting and harvest to assess water use efficiency and starting nutrient levels.

Results

The most noticeable result from the TOS trial was the large difference in total dry matter (TDM) produced by the same varieties from different planting times. Mean TDM data (Table 2) showed a 3–3.5 t/ha difference between each sowing date with December producing the highest and February the lowest TDM.

The mean grain yield data for each TOS did not follow the same pattern as TDM. The January and February planting dates were quite similar and December was significantly better. This suggests that the relationship between yield and biomass is not always linked.

Table 2. Mean total dry matter and grain yield for each time of sowing.

TOS	TDM @ maturity (kg/ha)	Grain yield (kg/ha)
1. December	10080c	1869
2. January	6401b	1207
3. February	3572a	1406

Means with the same letter are not significantly different at P(0.05).

Links between dry matter and yield may vary depending on variety (Figure 2). There was no interaction between TOS and variety in relation to dry matter production (not shown), but there were small significant differences in TDM between varieties averaged over the three TOS (Figure 2). These varietal differences in TDM were not as large as the differences between the means for each TOS (Table 2). Time of sowing had a larger impact on TDM.

Example of establishment in the January sowing.

Example of growth at the start of flowering for the December sowing.

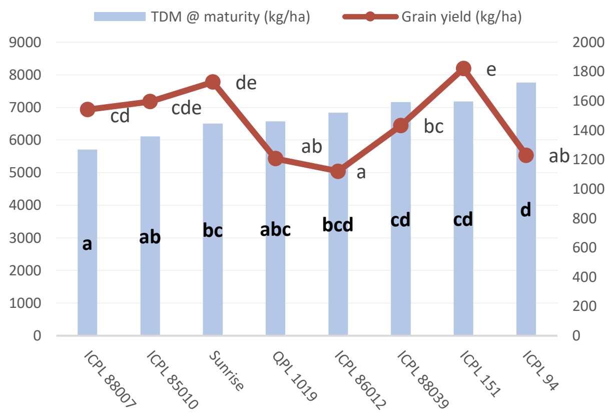

Figure 2. Mean grain yields and total dry matter of varieties averaged across all sowing times.

A breakdown of the yield data shows a significant interaction between varieties and TOS (Figure 3) with three apparent patterns:

1. Linear reductions in yield from December through to February planting (ICPL 85010, ICPL 88007).
2. Non-linear changes in yields with December and February being the best yields and January being the lowest for lines Sunrise, ICPL 151, QPL 1019, ICPL 86012.
3. An almost flat progression from the three TOS (ICPL 88039, ICPL 94).

Pigeonpea in flower.

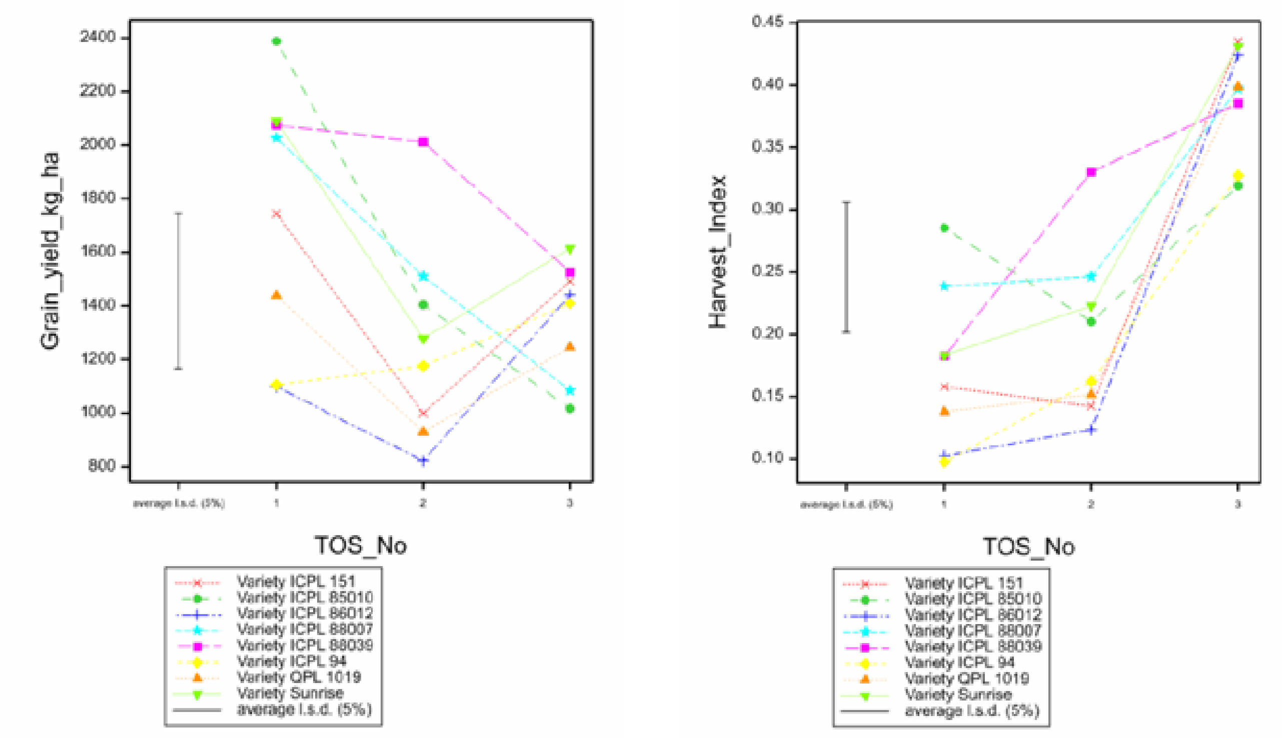

Figure 3. Mean grain yields and harvest index for each variety in each time of sowing.

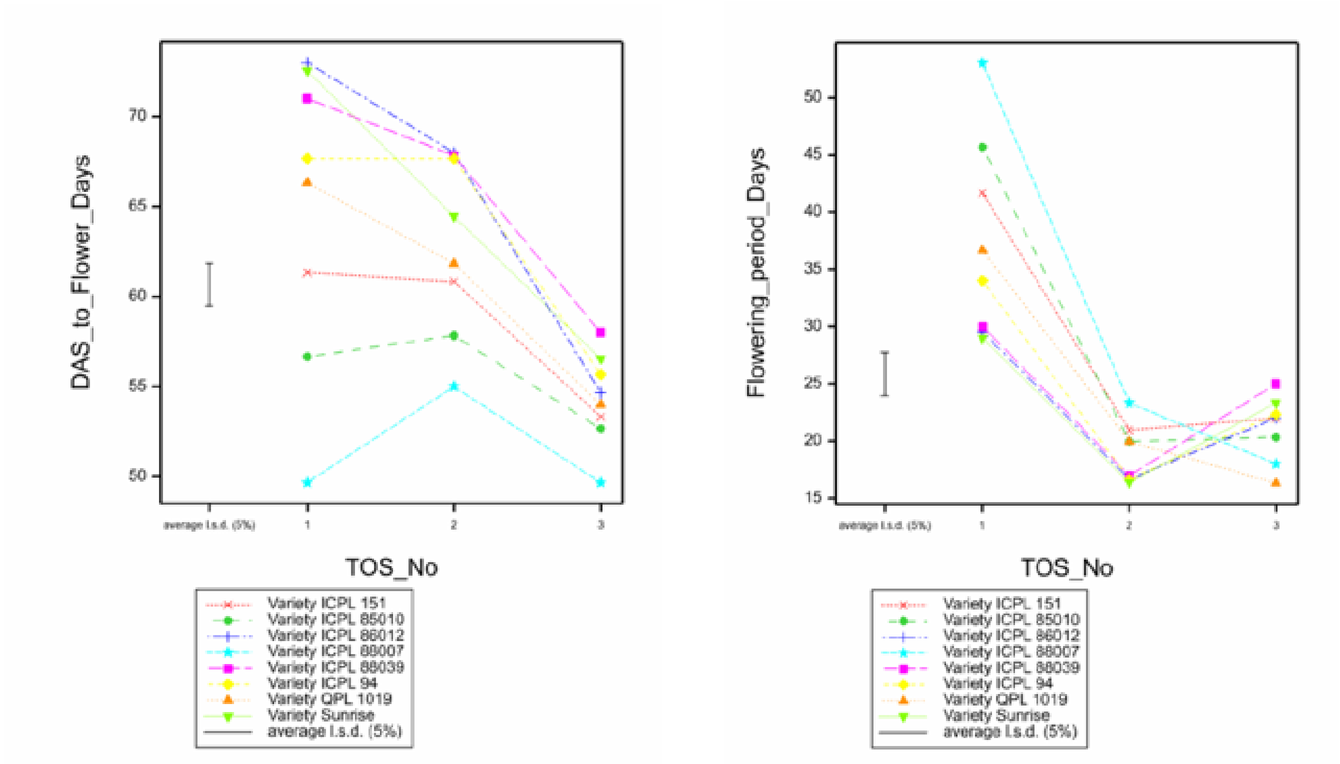

Figure 4. Mean vegetative period (days after sowing to flower) and mean flowering period (days) for all varieties in all times of sowing.

Seed set in pigeonpea.

Predictably the harvest index (HI) data also had a major interaction between TOS and variety (Figure 3). The pattern for HI was almost the inverse of that for yield. Much smaller plants with moderate grain yields in the February TOS produced a HI that was equivalent to a good chickpea crop (0.4–0.45). While the largest plants from the December sowing still produced the highest yields, they had a more modest HI (Figure 3). Once again, there was a lot of variability between varieties, although the later planting date seemed to narrow the varietal differences.

The December TOS showed the biggest differences between the varieties for yield, harvest index and flowering period (Figure 4). The spread of results significantly narrowed in range for the February sowing. The main difference in weather conditions between these planting dates was temperature and daylength. The December TOS experienced far higher day and night temperatures and more hours of sunlight, which could influence the performance of these pigeonpea varieties.

The December TOS yield data (Figure 3) showed that the top four performing varieties were ICPL 85010, ICPL 88007, ICPL 88039 and the variety Sunrise. The ICPL 88039 line is the original seed line that Sunrise was first developed from; they are the same genetics, so the yield difference in the January TOS is suprising. This leaves ICPL

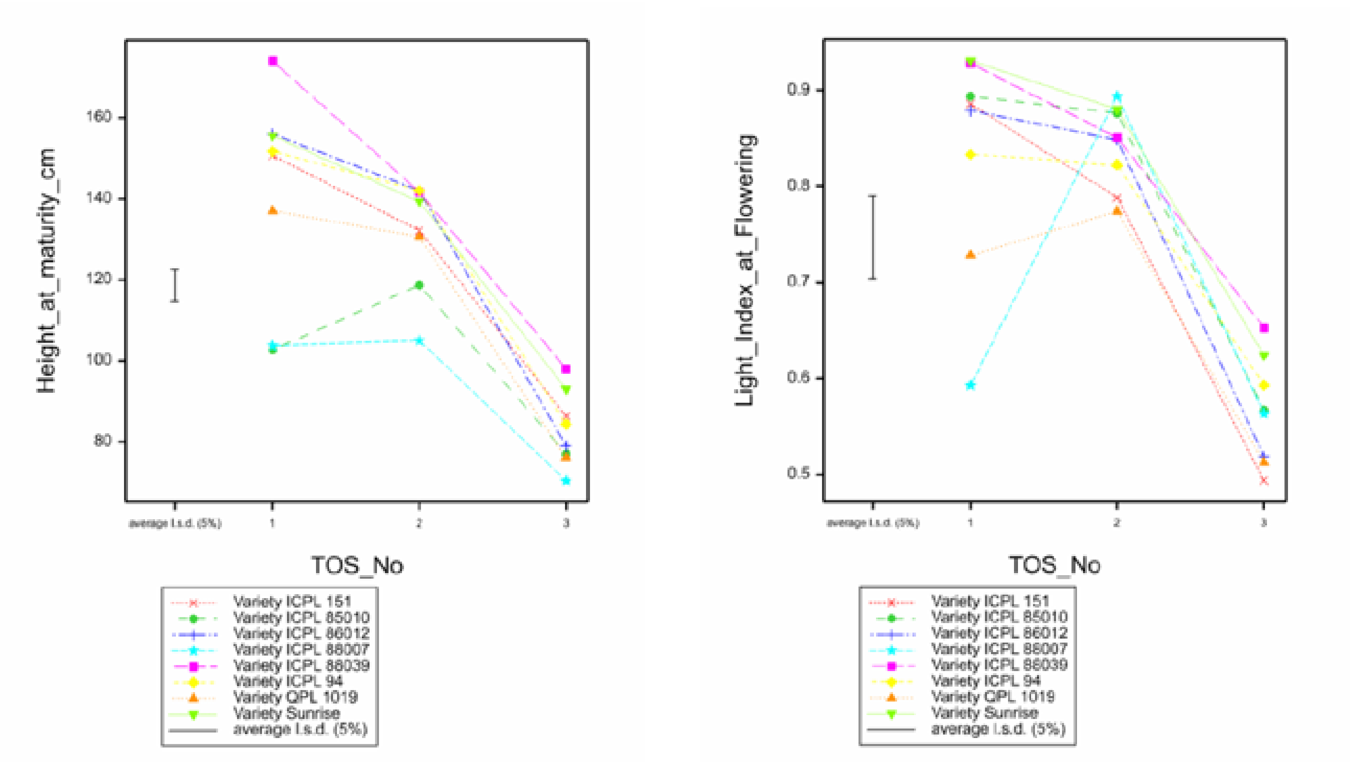

Figure 5. Mean plant height at maturity and mean light index at first flower for all varieties across all times of sowing.

85010 and ICPL 88007 as the best performing out of the new genetic lines, particularly in the December and January TOS.

It is worth noting some of the characteristics of these two best performing varieties (ICPL 85010 and ICPL 88007), they:

- Were the quickest to flower across all TOS, especially in the December TOS (Figure 4, 50–55 days),
- Had the longest flowering period on a December planting (Figure 4, 45–55 days),
- Had the best HI on the December Planting (Figure 3, 0.25–0.3), and
- Had the lowest DM prodcution at maturity (Figure 2) and the lowest plant height (Figure 5).

These attributes may indicate the desirable features that a commercial grain hybrid should have to suit our environment; a smaller plant stature (ease of harvest), relatively efficient conversion of biomass to grain yield (HI), quicker maturing (days to flower), and a longer flowering period to set up the best potential yield.

The only major difference between these two varieites was the light intercetion data at flowering (Figure 5), which indicated that ICPL 88007 was a bit slower to develop full canopy closure on the December TOS. Despite being a smaller plant and flowering earlier, CPL 85010 was close to full canopy closure by the time it started to flower.

Comparison of mature plant size between February (left) and December (right) sowings.

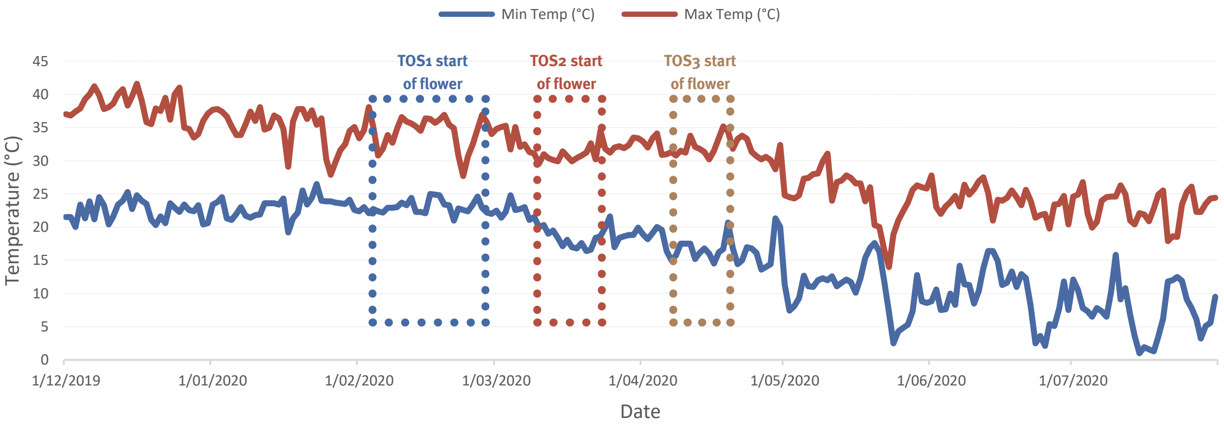

Figure 6. Daily maximum and minimum temperatures from December 2019 to June 2020. Dashed boxes indicated the start of flowering for all varieites in each Time of Sowing.

Weather data (Figure 6) shows the December TOS experienced the highest summer temperatures during its vegetative growth phase and started its flowering period with relatively high maximum temperatures (≥35 °C). The January TOS also experienced relatively high temperatures during its vegetative growth phase (Figure 6) but it also experienced a significant drop in temperatures during the start of its flowering period (≥30 °C). It is unclear whether this temperature difference in maximum temperatures was linked to the shorter flowering period in the January and February TOS (Figure 4) and consequently to the differences in grain yield (Figure 3).

Interestingly, time of flowering was not necessarily triggered by heat accumulation. The December and January plantings flowered at similar Day Degree (DD) accumulations, but DDs were almost 200 lower when flowering started for most varieties in February planting (Figure 7). This suggests there was some other factor influencing the timing of flowering in the later TOS.

All three sowings experienced different in-crop rainfall patterns (Figure 8). The December sowing had significant rainfall during its vegetative phase but very little after flowering began, while the January sowing had a more even spread of in-crop rainfall across vegetative and flowering phases. Both the December and January sowing had ~350 mm of in-crop rainfall, which makes it more difficult to explain the differences in grain yields.

The February TOS had only ~150 mm of in-crop rainfall, all of it in the first three weeks after planting. However, the February planting had a full soil moisture profile from the rain in January and December. This later planting also had lower evaporative demand after flowering, which would have helped conserve the moisture in the surface profile.

It remains unclear how the timing of rainfall and the temperature profiles have influenced grain yield in these TOS trials as there is too much variability between the varieties (Figure 3).

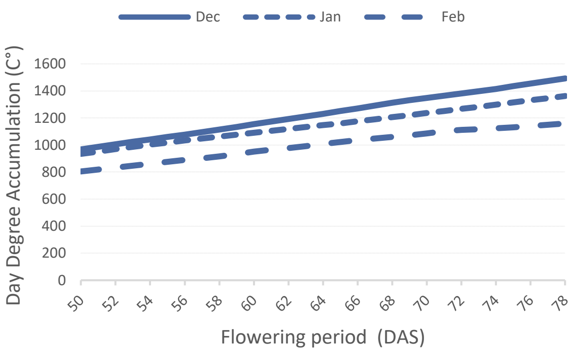

Figure 7. Day degree accumulation in relation to flowering period for the three Times of Sowing.

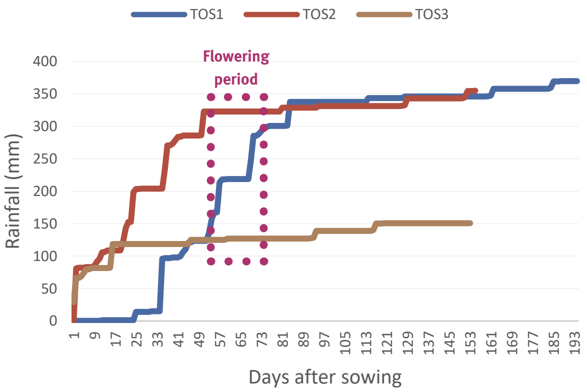

Figure 8. Accumulated rainfall for each Time of Sowing in relation to flowering period.

It is possible that the in-crop rainfall patterns have influenced the amount of TDM produced in each TOS but that has not necessarily flowed through into grain yield.

Implications for growers

This TOS trial has demonstrated a wide range of production levels for pigeonpea. Dry matter production varied from 2.5 t/ha to 14.0 t/ha and grain yields ranged from 0.8 t/ha to 2.4 t/ha.

This variability makes it hard to make definite conclusions about the productivity of this crop species from these initial trials. The higher-end yields indicate the potential of pigeonpea when existing varieties are matched to the environment; something that may be further improved with future breeding for our local conditions. In the meantime, this exploratory research has provided some initial indicators about the crop's physiology:

- Best yields (at least in this year) were from the combination of quicker maturing varieties and an early time of sowing.
- Early times of sowing produced the biggest differences in varieties, particularly in relation to time to flower and length of flowering period.
- Pigeonpea varieties have enormous flexibility in their dry matter production, days to flowering and flowering period in response to times of sowing.
- Pigeonpea changes in response to sowing time is not purely driven by day degree accumulation. It is possible that day length is also a considerable factor.
- The relevance of harvest index in relation to yield is still to be determined. Daylength and in-crop rainfall are big drivers of vegetative production, but grain yield may not be linked to this consistently.

These characteristics have implications for future variety selection and breeding. The expression of traits will change depending on the environment in which the plant is grown, and like many grain legumes may require specific varieties suited to different geographic regions.

The adaptation of pigeonpea to hot and dry conditions is important for Queensland dryland cropping systems. Mungbean and other dryland summer grain legumes have historically struggled when crops have been planted in early summer. It is worth noting that in this experiment, the December TOS had the best performance despite experiencing peak summer temperatures and high evaporative conditions. However, this is only one year's results and there was significant in-crop rainfall to help offset these hot conditions.

On the downside, this experiment also highlighted that the current commercial variety of pigeonpea (Sunrise) was close to the best performing variety across all TOS, a variety selected for its ability to attract insects as a refuge crop in a genetically modified cotton system, rather than for its high grain yields.

Pigeonpea appears to have promise. A breeding program focused on grain production and insect resistance will improve on the yield parameters that were recorded in this experiment.

Acknowledgements

The Pigeonpea agronomy project is funded solely by the Department of Agriculture and Fisheries. The technical management, data collection and monitoring of this trial was carried out by Peter Agius (DAF, Emerald)

Trial details

Location: Emerald Research Facility
Crop: Pigeonpea
Soil type: Black/Grey cracking Vertosol
In-crop rainfall: 369 mm
Fertiliser: Supreme Z™ at planting (30 kg/ha)

Selected soil fertility characteristics of the trial site:

Depth (cm)	Nitrate Nitrogen (kg/ha)	Phosphorus (Colwell)	Sulfur (KCl-40)	Exc Potassium	BSES Phosphorus	CEC
0-10	9	21	8	0.89	38	34
10-30	11	8	7	0.57	19	35
30-60	35	3	28	0.5	10	37

Nutrition research

The nutrition research of the Department of Agriculture and Fisheries' Soil productivity and Regional agronomy (research) teams has been strongly focused on their long-term collaboration with Professor Mike Bell (University of Queensland) on the stratification of the immobile nutrients, phosphorus and potassium. Understanding and quantifying the benefits of ameliorating their stratification with one-off applications of deep phosphorus (P) or potassium (K) has been central to this work over the last seven years with support from the Grains Research and Development Corporation (GRDC).

A series of trial sites have been established and cropped across these years, and with the final data now collected at all sites we are increasingly confident of where positive responses can be expected.

- In situations where subsoil P is low (<10 mg/k g) we will see yield benefits in winter cereal crops in southern Queensland (SQ), and in most summer and winter crops in Central Queensland (CQ).
- We are also confident that treatment benefits will last for at least 5 crops after the application of deep P.

There have been large responses and cumulative profitability benefits from these P applications across Queensland including:

- $575 – $700/ha over 6 crops at Jimbour West SQ
- $330 - $390/ha over 5 crops at Condamine South SQ
- $1375 - $1675/ha over 6 crops at Dysart CQ
- $655 - $800/ha over 4 crops at Comet River CQ
- $555 - $765/ha over 4 crops at Dululu CQ.

Despite these significant responses, questions remain on the long-term economics of deep nutrition in lower-yielding environments and will require on-going testing on farms.

This year articles summarise four years' results from deep applications of P and K in the Comet River district to show a gain of up to 1000 kg/ha grain yield from P but no consistent response to K and highlighted the impacts of re-applications of nutrients at Dululu.

This work at Dululu has shown that chickpeas produced a 24% yield benefit to residual P applied at 40 kg P/ha in 2015 along with an additional 31% gain where P was reapplied at 30 kg P/ha in 2018. Results from the residual deep K applied at 100 kg K/ha in 2015 and reapplication three years later at 50 kg K/ha in 2018 were similarly impressive; yield gains in the chickpeas were 16%, with an additional 38% on top of that from the reapplication. Only time, further research and on-farm testing by growers will confirm whether the responses are due to a need for higher rates in the first place, some level of immobilisation of the nutrient over time, or whether the reapplications simply provided a better distribution and so root uptake by the crops.

Re-applying deep phosphorus and potassium after three years further boosted chickpea yields—Dululu

Doug Sands[1], Dr David Lester[1], James Hagan[1] and Prof Michael Bell[2]
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[2] University of Queensland

RESEARCH QUESTION: *What is the residual value of deep-banded phosphorus and potassium after four years when re-applying to establish a new potential yield target in chickpeas?*

Key findings

1. Chickpeas produced a 24% yield benefit to a residual rate of phosphorus (40 kg P/ha) applied late 2015, however the re-application of another 30 kg P/ha in late 2018 increased chickpea yields by a further 31%.
2. A residual potassium rate of 100 kg/ha applied late 2015 produced a 16% yield improvement in chickpeas. However re-applying another 50 kg K/ha in early 2018 increased yields by a further 38%.

Background

The UQ00063 project (Regional soil testing guidelines) has monitored a series of nutrition trial sites across Central Queensland (CQ) for five years. These trial sites were chosen using soil tests to provide varying degrees of nutrient depletion in the surface and subsurface layers that is most evident for the non-mobile nutrients of phosphorus (P) and potassium (K). In some established zero tillage systems there is a marked difference between the nutrient concentration in the top 10 cm of the soil profile and the deeper layers (10-30 cm and 30-60 cm) that cannot be explained by natural stratification. This pattern of depletion is becoming more evident across CQ, particularly in brigalow scrub and open downs soils.

This project aimed to ascertain whether an application of P or K placed as a band in the subsurface profile could provide a grain yield benefit and whether that benefit (response) could be maintained over several years. In the final year of monitoring, P and K was reapplied to the lowest P rate treatment for the P trial and the lowest K rate treatment for the K trial in December 2018.

The data from these treatments should provide a useful comparison to the residual rates of banded P and K applied four years ago and help define the economic benefit of adding these non-mobile nutrients over successive cropping cycles.

What was done?

The Dululu trial site had four crops planted and harvested since it was first treated with deep-banded fertiliser in November of 2015: wheat in 2016, chickpea in 2017, mungbean in 2017/18 and chickpea in 2019. The original soil test from the site indicated adequate levels of P and K in the top 10 cm but lower levels in the deeper layers (Table 1).

Phosphorus trial

There were seven unique original treatments in the P trial, with eight plots per replicate. There were four P rates; 0, 10, 20, and 40 kg of P/ha, with the 0P treatment repeated (Table 2). All treatments had background fertiliser; 80 kg of nitrogen (N), 50 kg of K, 20 kg of sulfur (S) and 0.5 kg of zinc (Zn) per hectare applied at the same time to negate any other potentially

Table 1. Original soil analysis for the Dululu site.

Depth (cm)	Nitrate nitrogen (mg/kg)	Phosphorus Colwell (mg/kg)	Sulfur (KCl-40) (mg/kg)	Exc. potassium (meq/100g)	BSES phosphorus (mg/kg)	PBI	ECEC (meq/100g)
0-10	7	17	4	0.23	21	99	22
10-30	22	3	7	0.12	5	109	28
30-60	18	1	18	0.09	4	81	29

Table 2. Summary of nutrient application after reapplication in December 2018 (the new treatment labels are used in the results section).

	Original treatment	Nutrient rate (kg/ha)					New treatment (2018)	Nutrient rate (kg/ha)		
		N	P	K	S	Zn		N	P	K
Phosphorus	0P	80	0	50	20	0.5	0P+NK	90	0	50
	10P	80	10	50	20	0.5	10P/30P+NK	90	30	50
	20P	80	20	50	20	0.5	20P+NK	90	0	50
	40P	80	40	50	20	0.5	40P+NK	90	0	50
	0P-KS	80	0	0	0	0.5	0P-KS+N	90	0	0
	40P-KS	80	40	0	0	0.5	40P-KS+N	90	0	0
	FR	0	0	0	0	0	FR	0	0	0
Potassium	0K	80	20	0	20	0.5	0K+PN	90	30	0
	25K	80	20	25	20	0.5	25K/50K+PN	90	30	50
	50K	80	20	50	20	0.5	50K+PN	90	30	0
	100K	80	20	100	20	0.5	100K+PN	90	30	0
	0K-PS	80	0	0	0	0.5	0K-PS+N	90	0	0
	100K-PS	80	0	100	0	0.5	100K-PS+N	90	0	0
	FR	0	0	0	0	0	FR	0	0	0

limiting nutrients. A further two treatments were included with 0P and 40P but no background fertiliser except N and Zn (0P-KS, 40P-KS), along with a farmer reference (FR) treatment to act as a control; this had nothing applied beyond what the farmer applied in line with normal commercial practice (Table 2).

Treatments were banded using a fixed tyne implement that delivered the P and K at 25 cm depth; the N and S at 15 cm depth. The bands of fertiliser were placed in the same direction as the old stubble rows, 50 cm apart in 6 m wide by 28 m long plots. All plots were split 'with' and 'without' starter P, which effectively doubled the treatments from 8 to 16. With four replicates, there was a total of 64 plots in the trial.

The trial was modified on 10 December 2018 with the reapplication of some deep bands of fertiliser. The original 10 kg P/ha plots had another 30 kg P/ha applied. No other plots received any additional P. All plots were ripped and had additional background fertiliser of 90 kg N/ha and 50 kg K/ha applied, except the original 'no background fertiliser' treatments (0P-KS and 40P-KS) and the FR plots that were again left untreated. No background sulfur fertiliser was re-applied to this trial. Plot labels for each of the seven treatments have been modified to represent their new status (see Table 2).

Potassium trial

There were seven unique original treatments in the K trial, with eight plots per replicate. There were four K rates; 0, 25, 50, 100 kg of K/ha with the 0K treatments repeated (Table 2). All these treatments had background fertiliser; 80 kg of N, 20 kg of P, 20 kg of S and 0.5 kg of Zn per hectare applied at the same time to negate any other potentially limiting nutrients. Two further treatments included 0K and 100K without any background fertiliser except N and Zn (0K-PS, 100K-PS), along with a farmer reference (FR) treatment to act as a control; these plots had nothing applied except what the farmer applied in line with normal commercial practice (Table 2).

Modifications to the K trial were done in a similar manner as the P trial. Plots that had 25 kg K/Ha applied in the original treatments had a further 50 kg K/ha added through the deep banding tynes along with a reapplication of background fertiliser consisting of 90 kg N/ha and 30 kg P/ha. All other treatments were ripped down to 25 cm and had background N and P fertiliser applied but no extra K; except the 'no background fertiliser' treatments (100K-PS and 0K-PS) which were ripped with additional N but no P. The FR treatment was left undisturbed.

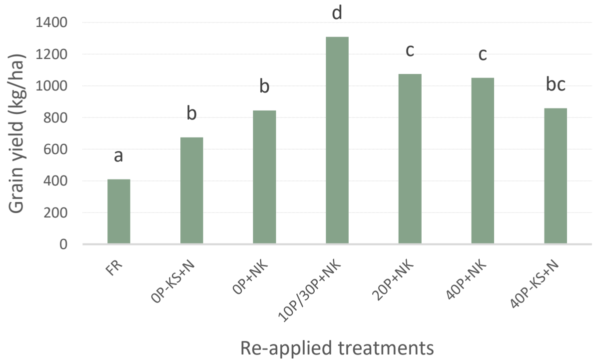
Applications were done in the same way as the phosphorous trial and the other trial details remain the same. There were no split starter P treatments in the K trial, so every plot received starter P (Granulock® Z @ 40 kg/ha).

Data was collected in the same way for both trials, including emergence plant counts, with starting soil water and starting nitrogen (N) measurements taken shortly after emergence. Total dry matter cuts were taken at physiological maturity and yield measurements were taken with a plot harvester when commercial harvesting started in the paddocks. A grain sample was kept from the plot for nutrient analysis. Both the dry matter samples and the grain samples were ground and subsampled for a wet chemistry analysis.

Results

Phosphorus trial

This trial site experienced a relatively dry winter season, with starting soil moisture levels in May 2019 averaging 77 mm to a depth of 120 cm (50-60% full). In-crop rainfall through to harvest on 17 September 2019 was 34 mm. The crop was planted to a depth of 15 cm as there was no planting rainfall for this crop. The modest yields achieved across the trial was not unexpected given the seasonal circumstances. However, the original P treatments applied in 2015 still achieved a 24–27% yield response over the 0P treatments after four crops (Figure 1).



Treatment labels	Mean grain yield (kg/ha)	Relative yield difference to 0P	
		kg/ha	%
FR	410a	-435	-51
0P-KS+N	675b	-170	-20
0P+NK	845b	0	0
10P/30P+NK	1309d	464	55
20P+NK	1075c	230	27
40P+NK	1051c	206	24
40P-KS+N	858bc	13	2

Figure 1. Mean grain yields for treatments in the P trial and relative response to deep P applications.
Means with the same letters are not significantly different at the P(0.05) level (lsd=195).

Re-applying deep P at a rate of 30 kg P/ha (10P/30P+NK) then doubled the residual P response, 27% to 55% over the 0P treatment. The size of this response to the re-treatment of P bands was unexpected after just four crops in three years. It is unclear whether this yield response has occurred because the residual P bands are losing their effectiveness (P availability reduced), whether more bands of fertiliser has given the plant better physical access to P, or whether the fresh application with added N and ripping has stimulated more root development.

Similar yields responses for the 20P and 40P in the residual treatments might indicate that access to the P bands is more important than the concentration of those bands. The significant difference between the FR treatment and the 0P-KS+N also indicates that just the ripping and additional N affected crop performance. The site was clearly constrained by moisture, which may have limited the true potential of the residual 40P treatment and perhaps even the re-treated plots (10P/30P+NK). Dry matter yields (Figure 2) followed the same pattern as grain yield, although there were less significant differences between treatments that had P applied either in 2015 (residual) or 2019 (reapplied).

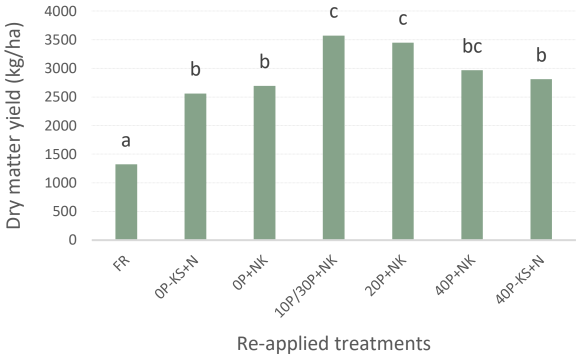


Figure 2. Mean dry matter production for all treatments in the P trial.
Means with the same letter are not significantly different at the P(0.05) level (lsd=530).

Plant analysis (Figure 3) reveals that the re-applied treatment (10P/30P+NK) had a significantly higher P content, and a higher subsequent P uptake. While the mechanism is still unclear, plants in the re-applied P treatment converted available soil moisture into grain yield rather than extra vegetative yield.

0P-KS plot in the foreground and 10P/30P in the background. Earlier cut out in higher yielding plots.

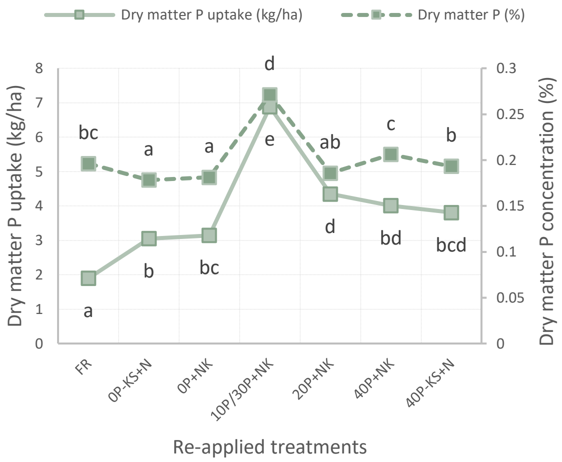


Figure 3. Mean dry matter P concentration and P uptake values for P trial treatments.

Means with the same letters are not significantly different at P(0.05).

10P/30P re-applied on the left and untreated buffer on the right.

Over the four crops on this P trial, the biggest responses have been recorded in chickpea (Figure 4) in 2017 and 2019. However, this only occurred when background K fertiliser was applied. Without background K (40P-KS and 0P-KS), the response has been negligible or negative.

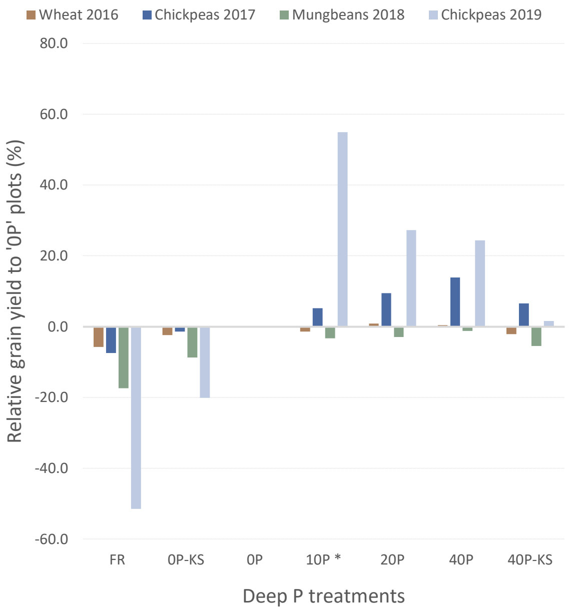


Figure 4. Relative response of deep P treatments as percentage of 0P treatment across four crops. The 10P* treatment includes the extra 30 kg P/ha applied in 2019.

The accumulated grain data (Figure 5) was similar, where the difference between each deep P treatment and the FR plots were added together for each crop. Without background K (40P-KS, 0P-KS), accumulated yields were ~400 kg/ha lower than the associated treatment with background K added.

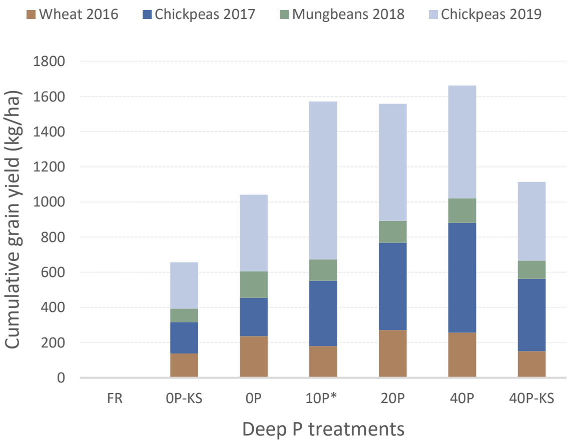
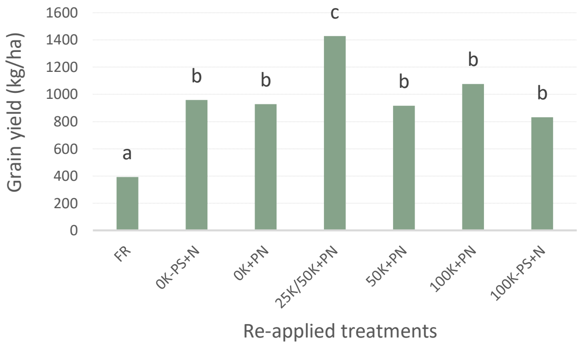


Figure 5. Accumulated grain yield increases over FR treatment for deep P treatments across four crops. The 10P* treatment includes the extra 30 kg P/ha applied in 2019.

It is also worth noting that the accumulated grain in the 10P and 40P treatments was the same over the four crops. Most of the 10P production has been made up in 2019 after an extra 30 kg P/ha was added. Both treatments have now had 40 kg P/ha applied and have achieved the same accumulated yield gain, however the 10P has done it at greater expense with two applications.

Potassium trial

Grain yields in the K trial (Figure 6) show a distinctive response to the re-treatment of 50 kg K/ha (499 kg/ha). The residual K appears to have run out of effectiveness with no significant difference between the 0K treatment and the other residual K applications (50K+PN, 100K+PN, 100K-PS+N). Although not statistically significant, the difference between the 100K+PN and the 100K-PS+N was ~200 kg/ha for the addition of background P. This was similar to the extra production in the P trial from the reapplication of deep P.



Treatment labels	Mean grain yield (kg/ha)	Relative yield difference to 0K	
		kg/ha	%
FR	392a	-536	-58
0K-KPS+N	958b	30	3
0K+PN	928b	0	0
25K/50K+PN	1427c	499	54
50K+PN	916b	-12	-1
100K+PN	1076b	148	16
100K-PS+N	832b	-96	-10

Figure 6. Mean grain yields for treatments in the K trial and relative response to deep K applications.
Means with the same letters are not significantly different at P(0.05) (lsd=222).

The yield responses to additional K indicate that the residual bands of K run out a lot quicker in K limited soils than the residual bands of deep P. This makes sense as plants require far more K than P for normal growth. Additionally, more K being extracted from the deeper subsurface profiles (10-30 cm) and then returned via stubble in the surface soil horizon (0-10 cm), exacerbates the stratification process.

Total dry matter data responses (Figure 7) reflected grain yield data, although the relative differences are much smaller and less significant. The plant tissue analysis (Figure 8) suggests that the extra 50 kg K/ha that was applied in 2019 has changed the concentration of K in the plant significantly, with total K uptake nearly double that from the older residual treatments. The residual K bands (50K+PN, 100K+PN) have assisted the plants taking up an extra 5 kg K/ha over those without any K applied (0K-PS+N, 0K+PN). However, the re-applied K treatment has taken up four times that amount, indicating that the residual K bands were mostly used up, or some other factor prevented uptake.

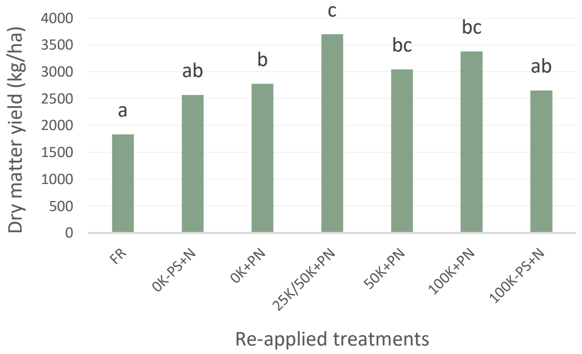


Figure 7. Mean dry matter yields for all treatments in the K trial.
Means with the same letters are not significantly different at P(0.05) (lsd=783).

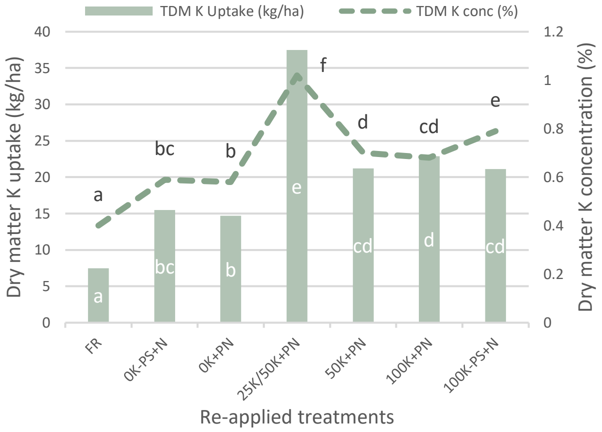


Figure 8. Mean dry matter K concentration and K uptake values for K trial treatments.
Means with the same letters are not significantly different at P(0.05).

Deep K responses at this site were more consistent than for P. Wheat was the only crop out of four that did not respond to the highest rate of K application (Figure 9) when background P was applied. Only mungbean responded to the highest rate of K when no background P was applied (Figure 9, 100K-PS). It is unclear whether this is a particular characteristic of mungbean, or due to seasonal variation.

0K+PN in foreground, 0K-PS in middle ground, 25K/50K + PN in the background.

100K-PS+N on the right side and untreated buffer on centre left.

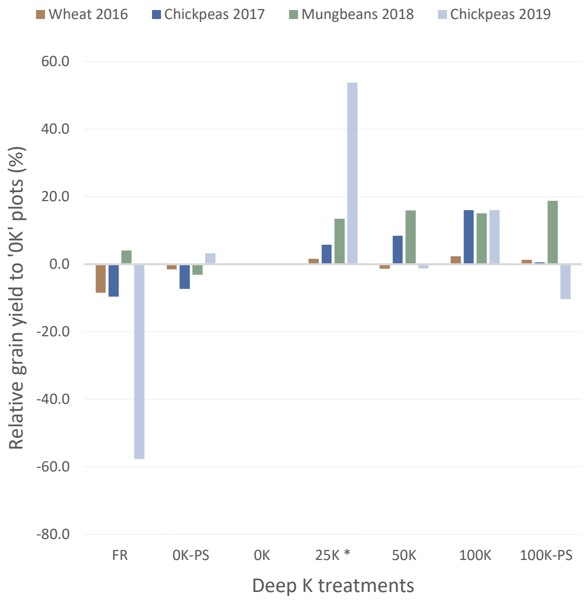


Figure 9. Relative response of deep K treatments as percentage of 0K treatment across four crops. The 25K* treatment includes the extra 50 kg K/ha applied in 2019.

Accumulated grain yield responses to K were greater than those in the P trial (Figure 10). The highest rate of K (100K) provided ~800 kg/ha more than the 0K treatment, while the highest rate of P (40P) in the P trial provided a ~600 kg/ha gain. While the reapplication of 50 kg K/ha to the 25K treatment produced the same accumulated production as the 100K treatment, the 50K treatment was almost 500 kg/ha behind both these treatments. It appears that the K at this site was used at a faster rate than the P, and reapplication will be needed sooner than normally expected for P responsive sites.

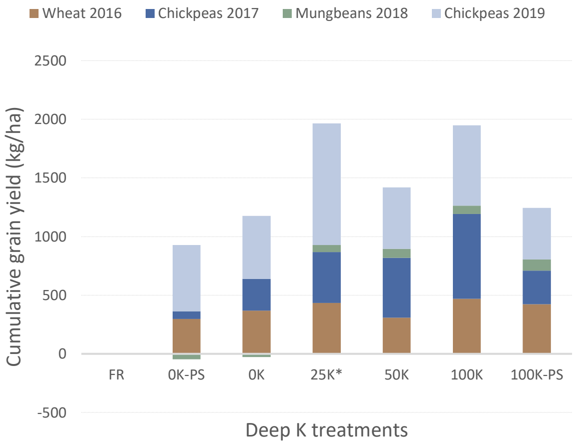


Figure 10. Accumulated grain yield increases over FR treatment for deep K treatments across four crops. The 25K* treatment includes the extra 50 kg K/ha applied in 2019..

Finally, the grain accumulation responses to background P were far greater when more K is added. There was a 700 kg/ha difference in accumulated grain yield between the 100K and 100K-PS treatments, with only a 260 kg/ha difference between the 0K and the 0K-PS treatments. This site may be marginally more responsive to K than P, but increased yields from K fertilisers will also increase the need for P, especially when P is limited in the subsurface layers.

Implications for growers

This trial site shows the need for subtle differences in management when soils are more restricted by K than P. Plant uptake of K (36 kg K/ha) was much higher than P (7 kg P/ha) when the K and P were reapplied. This five-fold difference presents a challenge of how much K should be applied and how long it will last. In the K trial in 2019, the reapplied treatment used up 15 kg of K more per hectare than the 100K residual treatment. This means that of the 50 kg K/ha that was applied in 2019, almost a third of it has been taken up by the 2019 chickpea crop.

When the same calculation is done in the P trial from 30 kg P/ha applied only 4 kg of P was used, which is just 13% of the total amount applied. While there are other variables at play with deep placement of P and K; these calculations suggest reapplications of K will be needed sooner on very K deficient sites than for P re-applications on P deficient sites. The significant grain yield benefit (54%) from re-applying K in a dry season, after just three years, may justify this shorter reapplication period, especially as K applied in late 2015 offered no statistically significant grain yield response in 2019 from the 50 kg K rate or the 100 kg rate (Figure 6).

Growers must make sure they know whether K or P is their primary limitation. If it is K, then they will need to increase the rate of the initial K applications; or be prepared to reapply more often.

Acknowledgements

Thanks to the trial co-operators for hosting these trials. This work is funded by University of Queensland, the Department of Agriculture and Fisheries and the Grains Research and Development Corporation under the UQ00063 project: 'Regional soil testing guidelines for the northern grains region'.

Further recognition should also be given to the DAF Technical Officers at Emerald who were involved in the monitoring and data collection at this trial site; Peter Agius and Max Quinlivan.

Trial details

Location:	Dululu
Crop:	Chickpeas
Soil type:	Grey, Brown Vertosols (Brigalow scrub) on minor slopes
In-crop rainfall:	34 mm
Pre-plant fertiliser:	Nil

Deep placement of phosphorus and potassium: Wheat response in the fourth year of cropping—Comet River

Doug Sands[1], Dr David Lester[1], Prof Michael Bell[2] and James Hagan[1]
[1] Queensland Department of Agriculture and Fisheries
[2] University of Queensland

Research question: *What is the residual value of deep-placed bands of phosphorus and potassium on wheat yields in the fourth year of cropping post-application?*

Key findings

1. Over four years there has been over 1000 kg/ha of extra grain yield from the deep placement of 40 kg P/ha.
2. Soil type variability influenced the response to deep phosphorus through different stored soil moisture levels at planting, which were exacerbated by the lack of in-crop rainfall.
3. There was no response in the 2019 wheat crop to the residual bands of deep phosphorus and potassium.
4. There has been no consistent yield response to deep potassium over four years.

Background

The UQ00063 project (Regional soil testing guidelines) has monitored a series of nutrition trial sites across Central Queensland (CQ) since 2013. Sites were chosen using soil tests to provide varying degrees of nutrient depletion in the surface and subsurface layers. Subsurface depletion was particularly evident for the non-mobile nutrients phosphorus (P) and potassium (K). In some established zero tillage systems there was a marked difference in nutrient concentrations in the top 10 cm of the soil profile and the deeper layers (10-30 cm and 30-60 cm), that cannot be explained by natural stratification. This pattern of depletion is becoming more evident across CQ, particularly in brigalow scrub and open downs soils.

This project aimed to ascertain whether one-off applications of either P, K or sulfur (S) placed in these deeper depleted layers would provide grain yield benefits, and in addition, whether these yield benefits can be maintained for several years, and if the economic benefit of adding these non-mobile nutrients can be justified over several crop rotations.

What was done?

The Comet River trial had four crops planted and harvested since it was fertilised in November 2015; chickpea in 2016, wheat 2017, chickpea 2018 and wheat in 2019. The original soil test from the site (Table 1) indicated adequate levels of P and K in the top 10 cm but deficient levels in the deeper layers (10-30 cm, 30-60 cm).

Table 1. Original soil analysis.

Depth (cm)	Nitrates	Colwell P	Sulfur (KCl-40)	Exc. K	BSES P	ECEC
0-10	8	22	4.5	0.46	24	20
10-30	10	5	5.3	0.12	5	21
30-60	7	<2	4.3	0.1	3	27

Phosphorus trial

There were seven unique treatments, including four P rates; 0, 10, 20, and 40 kg of P/ha, with the 0P repeated to make eight plots per replicate (Table 2). Background fertiliser; 80 kg of nitrogen (N), 50 kg of K, 20 kg of S and 0.5 kg of zinc (Zn) per hectare, was applied at the same time to negate other potentially limiting nutrients. However, two P treatments (0P and 40P) were also included without K and S in the background fertiliser to compare 0P and 40P without added K or S (0P-KS, 40P-KS). The last treatment was a farmer reference (FR) as a benchmark control treatment. The FR treatments had nothing applied except what the farmer applied in normal commercial practice each season (Table 2).

Table 2. Summary of original nutrient application rates for phosphorus and potassium trials.

Treatment		Nutrient application rate (kg/ha)				
		N	P	K	S	Zn
Phosphorus	0P	80	0	50	20	2
	0P	80	0	50	20	2
	10P	80	10	50	20	2
	20P	80	20	50	20	2
	40P	80	40	50	20	2
	0P-KS	80	0	0	0	2
	40P-KS	80	40	0	0	2
	FR	0	0	0	0	0
Potassium	0K	80	20	0	20	2
	0K	80	20	0	20	2
	25K	80	20	25	20	2
	50K	80	20	50	20	2
	100K	80	20	100	20	2
	0K-PS	80	0	0	0	2
	100K-PS	80	0	100	0	2
	FR	0	0	0	0	0

Treatments were banded using a fixed-tyne implement that delivered the P and K at 25 cm depth, and the N and S at 15 cm. The bands of fertiliser were placed in the same direction as the old stubble rows, 50 cm apart in 32 m long by six m wide plots. Finally, all plots were split, ‘with’ and ‘without’ starter P, which effectively doubled the treatments from 8 to 16. There were six replicates of each treatment for a total of 96 plots in the trial.

In the 2019 wheat crop, Granulock® Z was the starter P treatment at 30 kg/ha and the variety Suntop$^{\phi}$ was planted at a rate of 45 kg/ha into good surface moisture conditions. The crop received 51 mm of in-crop rainfall, mostly in two falls a month apart in June and July.

Potassium trial

The K trials had a similar design, with seven unique treatments. There were four K rates; 0, 25, 50, 100 kg of K/ha, with the 0K repeated to make eight plots per replicate (Table 2). Background fertiliser; 80 kg of N, 20 kg of P, 20 kg of S and 0.5 kg of Zn per hectare, was again applied at the same time to negate any other potentially limiting nutrients. Two treatments (0K and 100K) were included without P and S in the background fertiliser (0K-PS, 100K-PS). The last treatment was again a farmer reference (FR) that contained only what the farmer applied in normal commercial practice each season, to act as a second control.

There were no split starter P treatments in the K trial, so every plot received starter P (Granulock® Z @ 30 kg/ha). All other applications were done in the same way as the phosphorous trial.

Table 3. List of commercial granular products used in nutrient treatments.

Nutrient	Product source of nutrient in applications
Nitrogen (N)	Urea (46% N), MAP (10% N), GranAm® (20% N)
Phosphorus (P)	MAP (22% P)
Potassium (K)	Muriate of potash (50% K)
Sulfur (S)	GranAm® (24% S)
Zinc (Zn)	Agrichem Supa Zinc™ (Liquid) (7.5% Zn w/v)

Data was collected in the same way for both trials. Plant counts, starting soil water and starting N measurements were taken post emergence. Total dry matter was measured at physiological maturity and yield measured with a plot harvester when commercial harvesting started in the paddock. Grain samples were taken at harvest from each plot and processed for nutrient analysis.

Results

Phosphorus trial

The 2019 wheat data showed some inconsistent responses to the deep P treatments, making it difficult to draw clear conclusions on either the deep or the starter responses (Figure 1).

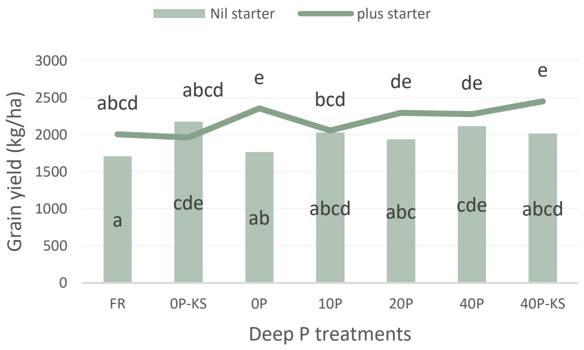


Figure 1. Mean grain yields for deep phosphorus treatments ‘with’ and ‘without’ starter phosphorus.
Means with the same letters are not significantly different at P(0.05) (lsd = 294).

For example, the deep P treatment without starter (0P-KS) and the 40P treatment were significantly better than the 0P treatment, but not significantly different to each other. Additionally, of those treatments with starter P applied at planting, only the 0P and the 40P-KS treatments were significantly different to the 10P, 0P-KS and FR treatments. Ultimately, the highest rate of deep P (40P-KS) and the lowest rate (0P) have produced similar yields.

Total dry matter data was more consistent with a small interaction between the starter and deep P treatments (Figure 2). The 40P treatment with starter had a significant yield response against the 0P minus starter and both FR treatments (39%). This pattern was repeated in the P uptake data (Figure 3, 28% response). The starter P and residual deep P treatments did not produce significant increases in dry matter on their own and required a combination of the two for a significant response (1752 kg/ha). The plant tissue data backs this up; when plants had access to both the residual and starter bands, they accessed 2 kg P/ha more than plots that relied on the existing soil P. The dry matter response provide evidence that plants had access to the starter. It is possible that with only 51 mm of in-crop rainfall (Figure 7) the plants only had access to those bands for a limited amount of time.

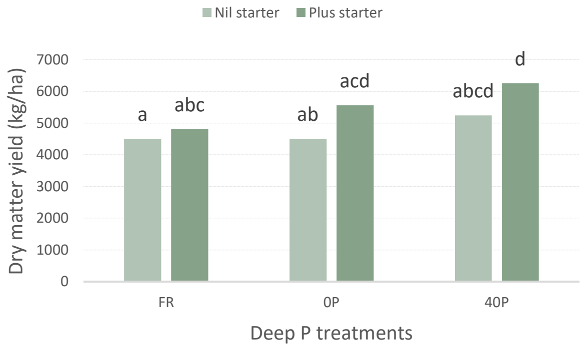


Figure 2. Comparison of mean dry matter yields for deep phosphorus treatments in 2019 wheat across starter treatment.

Means with the same letters are not significantly different at at P(0.05) (lsd = 1147).

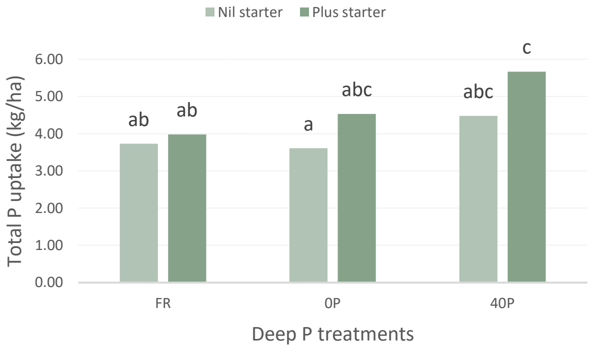


Figure 3. Comparison of mean phosphorus uptake in total dry matter across deep phosphorus and starter treatments.

Means with the same letters are not significantly different at at P(0.05) (lsd = 1.34).

Historical production from this trial (Figure 4) has shown a strong response to the deep P bands, all-be-it heavily influenced by crop species and in-crop rainfall. Over the four years this site has shown a 1064 kg/ha extra grain yield for the 40P treatment over the 0P treatment and a 718 kg/ha improvement by the 20P treatment.

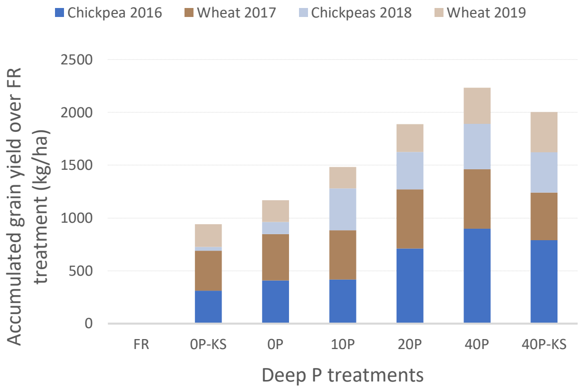


Figure 4. Mean accumulated grain production increases over Farmer Reference treatments for deep phosphorus applications.

Significant responses have been more pronounced in chickpea crops than wheat (Figure 5). While in-crop rainfall was also a factor in the 2016 chickpea (Figure 6) crop, there was also significant difference in the 2018 chickpea crop despite receiving a similar level of in-crop rainfall to both wheat crops (Figure 6). Both wheat crops had no significant yield differences between P treatments (Table 4).

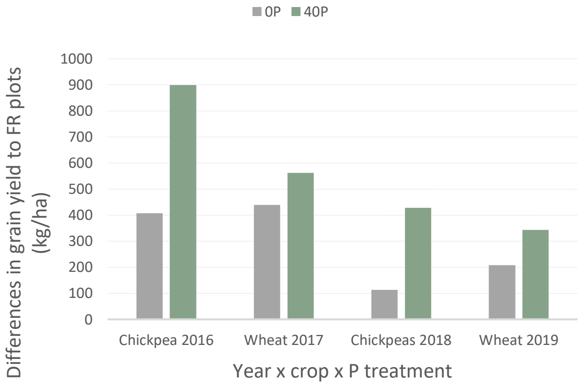


Figure 5. Mean differences between 0P and 40P treatments and the corresponding Farmer Reference treatments across all crops and years.

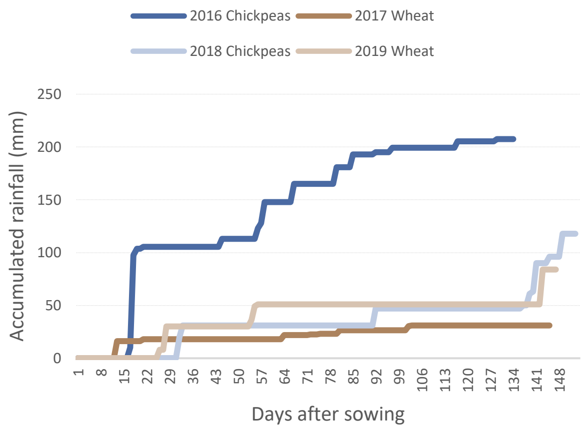


Figure 6. Comparison of in-crop rainfall across the four crops grown on site in relation to days after sowing (DAS).

Table 4. Analysis of variance (ANOVA) for treatment means for crops harvested in the phosphorus trial.

Treatments	Chickpea 2016	Wheat 2017	Chickpea 2018	Wheat 2019
FR	1624a	678b	1413b	1853
0P-KS	1934b	1058a	1448b	2069
0P	2031b	1118a	1527b	2061
10P	2041b	1144a	1810a	2055
20P	2335c	1238a	1768a	2114
40P	2523c	1241a	1841a	2196
40P-KS	2413c	1128a	1796a	2233
lsd	231	204	210	ns*

ns – not significant

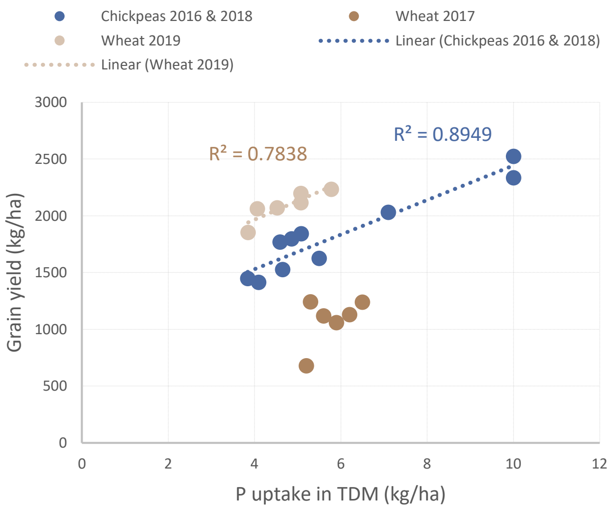


Figure 7. Comparison of trends for phosphorus uptake in total dry matter versus grain yield across all crops in phosphorus trial.

This crop species difference is more clearly illustrated in plant tissue analyses (Figure 7). There is a strong and uniform linear trend for chickpeas in relation to P uptake in total dry matter (TDM) and grain yield across seasons. There is a much weaker relationship for wheat as a considerable increase in yield between 2017 and 2019 crops has not changed the range of P uptake values in the crop (Figure 7). This indicates that grain production in chickpea is far more responsive to improved access to P than wheat.

A complicating factor was the inherent variability in the soil analysis across the site and the uneven nature of wetting up the soil profile. Intensive soil coring in 2018 across all FR plots in the P trial showed high variability in the natural Colwell P status within each replicate (Figure 8), particularly in the 10-30 cm layer. This kind of variability is outside the normal expectations for a P limited site and may also explain the inconsistent responses to deep P bands across the replicates.

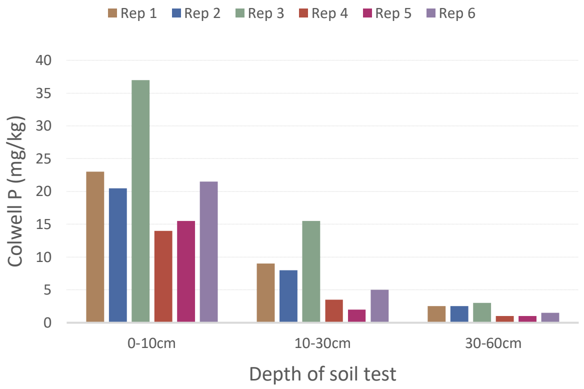


Figure 8. Soil analysis for soil cores taken from the Farmer Reference plots in each replicate, measuring for Colwell phosphorus.

The other indicator of variability at this site is the measured plant available water (PAW) at planting for each crop (Figure 9). Data from each replicate showed differences of up to 80 mm in some years across the trial. These differences will have a major impact on crop performance, especially when in-crop rainfall (Figure 6) is not sufficient to compensate.

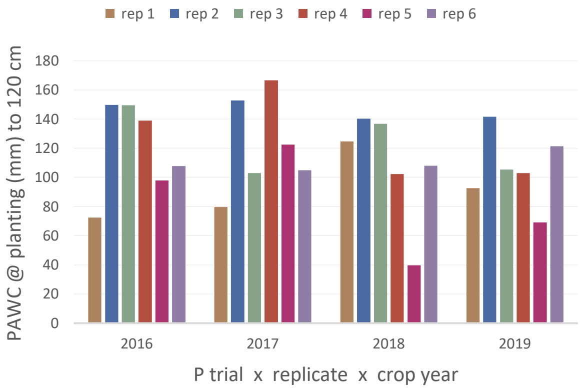


Figure 9. Mean plant available water (PAW) for the phosphorus trial, measured at planting for each replicate across all years.

In-crop rainfall was 50 mm or less in 2017, 2018 and 2019 crops. The resulting large standard errors from this variability mean that big responses were needed to get statistically significant differences between treatments. The only year where in-crop rainfall exceed 50 mm was in 2016 (>200 mm), which gave the largest yield improvement to deep P bands (Table 4 and Figure 5, 490 kg/ha or 24%). This in-crop rainfall may have overcome water variability at planting (lower standard error within treatments), allowed longer periods of uptake from the bands (better access), which in turn led to larger yields differences from better nutrition to reach its higher water limited yield potential.

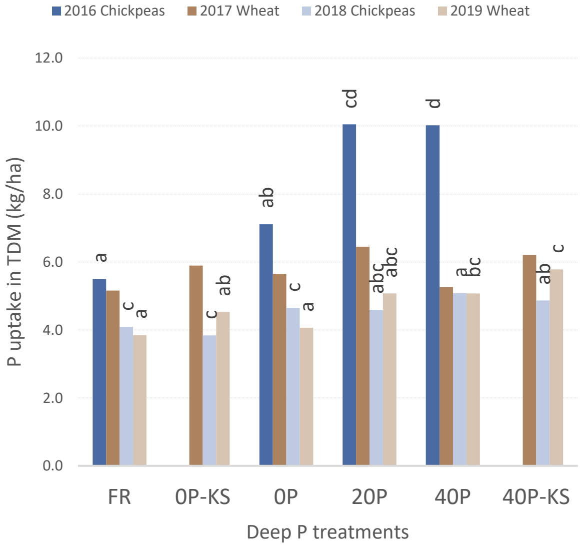


Figure 10. Comparison of mean phosphorus uptake in total dry matter across all treatments in each of the four crops tested.

Means with the same letters for each crop are not significantly different. No letters mean there were no significant differences for that crop.

Despite the site variability, there is evidence in the plant tissue data (Figure 10) that three out of the four crops have managed to increase plant uptake of P from the deep-banded treatments. In most cases (2016, 2018 and 2019) the 40P treatment has increased P uptake over the 0P treatment by 1-3.5 kg P/ha (25–50%, Figure 10). The deep bands were being accessed by the plants but the response in yield to this uptake remains dependant on soil moisture and crop species.

Potassium trial

There was no response to K in the 2019 wheat crop; the only significant difference being the FR plots grew less than all the other treatments (Figure 11). This was consistent across all four cropping years (Table 5) despite soil testing analysis suggesting restrictive K levels in the subsurface (Table 1). These subsurface K levels were consistent across the K trial (Figure 12) and so did not introduce variability in the results, unlike the Colwell P analysis in the P trial (Figure 8).

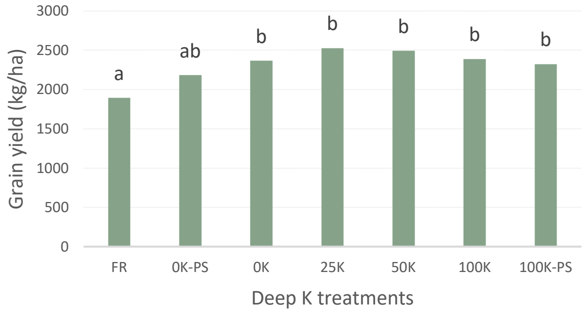


Figure 11. Mean grain yield comparison for deep potassium treatments for 2019 wheat crop.

Means with the same letters are not significantly different at at P(0.05) (lsd = 316).

Table 5. Analysis of variance (ANOVA) for treatment means for each crop harvested in the potassium trial.

	Chickpeas 2016	Wheat 2017	Chickpeas 2018	Wheat 2019
FR	1692a	719a	1309b	1896a
0K-PS	1928ab	980ab	1425ab	2182ab
0K	2568d	1102bc	1508ab	2367b
25K	2506cd	1132bc	1634a	2527b
50K	2254c	1217bc	1579ab	2494b
100K	2658d	1358c	1571ab	2389b
100K-PS	2204bc	1303c	1477ab	2323b
lsd	279	261	260	316

Means with the same letters are not significantly different.

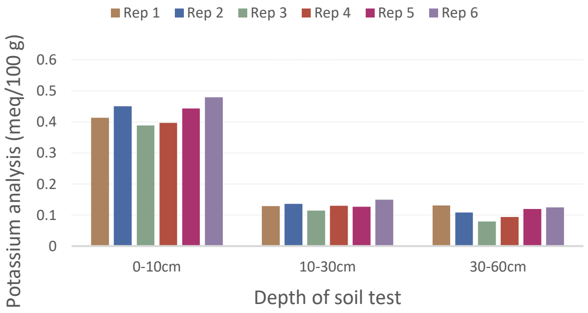


Figure 12. Soil analysis for soil cores taken from the Farmer Reference plots in each replicate, measuring for exchangeable potassium.

Similarly, the only major significant difference in grain yields across the life of the K trial was between treatments with background PS applied and those that did not (0K-PS, FR, 100K-PS). Phosphorus appears to be the first and most limiting nutrient at this site despite the marginal exchangeable K analyses.

This difference is particularly apparent in the 2016 chickpea crop (Table 5) where there is a 640 kg/ha yield difference between 0K and 0K-PS treatments, however in all the other crops the differences were less than 200 kg/ha and not significant. The 2016 year also had the most in-crop rainfall (Figure 6), and plant tissue data suggest that plants had far better access to K in 2016 and took up nearly double the amount of K as subsequent years (Figure 13). Clearly, soil moisture conditions during crop growth have a big impact on responses to deep banding.

There was little difference in uptake between the 0K treatment and the 50K and 100K treatments in 2016 data (Figure 13), which suggests that most of this K came out of the surface soil (0-10 cm) rather than deep placement bands.

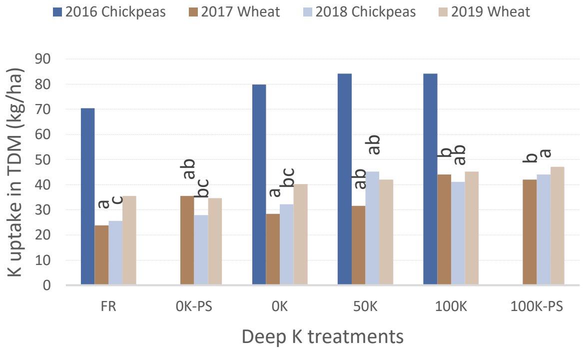


Figure 13. Comparison of mean potassium uptake in total dry matter across all treatments and all years in the potassium trial.

In the 2017 wheat crop, there was a significant difference in K uptake between the 0K and the 100K treatments of nearly 16 kg/ha. There was also significant difference in K uptake between the 0K and the 100K-PS treatment of 11.1 kg/ha in the 2018 chickpea crop, although this was very close to the least significant difference (lsd) of 10.8 kg/ha. These differences in K uptake in 2017 and 2018 indicate that the deep bands of K are being accessed by the plant. However, there was no ensuing grain yield response.

Plant available water (PAW) measured at planting across all six replicates in the K trial (Figure 14) shows similarly high variability as the data from the P trial (Figure 9).

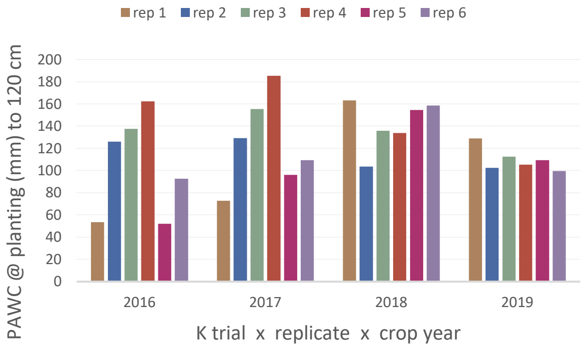


Figure 14. Mean plant available water (PAW) for the potassium trial, measured at planting for each replicate across all years.

This variability in PAW at planting in conjunction with low levels of in-crop rainfall (<50 mm) may again increase the variability of the yield results for those cropping years of 2017, 2018 and 2019. Root access to the deep bands would have varied greatly depending on how consistent the soil moisture was at planting.

While annual K responses were limited, there was a 430 kg/ha (22%) accumulated grain response over the four crops from the 100K treatment over the 0K treatment (Figure 15). However, there was again some inconsistency in this long-term result as the 50K treatment largely performed the same as the 0K treatment. This makes it difficult to be confident of the long-term response to K at this site.

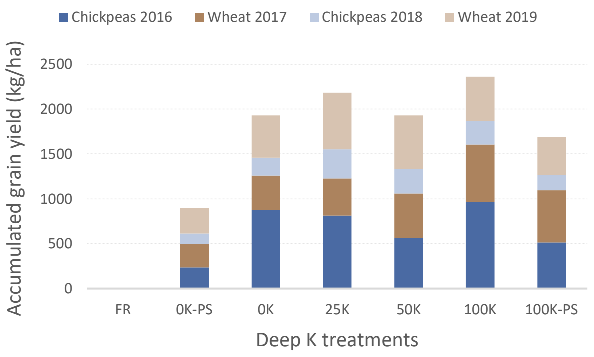


Figure 15. Mean accumulated grain production increases over Farmer Reference treatments for potassium application.

Implications for growers

Soils and their inherent nutrient variability in most dryland farming systems may become more apparent as they age and their nutrient levels decline. Small differences in nutrient supply may then provide relatively large plant responses. Overall paddock responses to nutrients like P or K will depend on the severity of the deficiency and how widely it is spread across the paddock. Paddocks with a mixture of soil types and nutrient supply will require careful assessment of this variability.

Fertiliser applications often 'even up' crop responses across paddocks as the applied nutrient becomes unlimited. The crop then has the capacity to take advantage of all the other nutrients available. This is particularly relevant for P that's needed for new growth. For example, increasing P may provide more extensive root development, leading to more access to water and other critical nutrients in the soil, such as K, N and S.

Different soil may also have different structures, which can affect how efficiently each soil 'wets-up' after rainfall. This was evident at the site, with major differences in stored moisture at planting, which appears to have impacted on the how long fertiliser bands were moist and accessible to crops, especially in dry seasons with little in-crop rain.

The success of deep placement of P and K depends on plants being able to access those bands through moist soils for as long as possible. When a crop is grown on a full profile of stored moisture, it is estimated that 60-70% of that moisture will come from the top 40–50 cm of soil. That is why the deep bands are placed at 20-25 cm, in the middle of that critical stored moisture zone, to ensure that the plant roots have the longest possible access to those bands.

Despite the variability of this trial site, there has been a strong response of 1000 kg/ha extra grain produced from deep P over the four years. Individual crop responses have been variable due to in-crop rainfall and the species of crop grown. Typically, responses to deep-banded P and K are enhanced when crops are grown on stored moisture. However, this site has shown that responses to deep placement can be variable when the profile is not fully wet before planting. The crops must be able to access the fertiliser bands through moist soil.

Ultimately, it is important to assess paddock variability carefully using tools such as EM38 surveys, yield maps and various drone images. Assessment of the soil type in relation to nutrient and water-holding capacity across the paddock will help define the parameters for yield and the subsequent need for deep P and K to ensure that the water-limited yield is achieved. Where in-crop rainfall is not reliable, the bucket of stored moisture needs to be as large as possible to access deep-applied fertilisers and achieve their full impact on crop yields.

Acknowledgements

It is greatly appreciated to have the continued support of trial co-operators, by hosting this trial site. This work is funded by the Grains Research and Development Corporation and the Department of Agriculture and Fisheries under UQ00063 'Regional soil testing guidelines for the northern grains region'. Further recognition should also be given to DAF Technical Officers at Emerald who were involved in the monitoring and data collection at this trial site; Peter Agius and Max Quinlivan.

Trial details

Location:	Comet River
Crop:	Wheat
Soil type:	Grey, Brown Vertosols (Brigalow scrub) on minor slopes
In-crop rainfall:	50 mm
Pre-plant fertiliser:	At planting - 30 kg/ha of Granulock® Z

Soils research

Following a decade of research, development and extension (RDE) to help understand and manage soil organic matter and soil organic carbon for healthy soils, the Regional agronomy (research) team is continuing its RDE to better understand other soil constraints to profitable grain production. These physical, chemical and biological soil constraints are estimated to cost the Queensland grains industry approximately $147M in lost production annually. The main constraint (sodicity) is currently the focus of the research, with a series of four projects assessing the potential to ameliorate sodicity and its related soil constraints to grain production.

Activities are being done with collaborators in the New South Wales Department of Primary Industries, the University of Queensland and the University of southern Queensland to test methods to identify the occurrence of these constraints across the northern grain region, test options to ameliorate the effects of these constraints on crop production, assess the economics of these options, and to test the best options with farmer groups across the region.

Ameliorating sodicity may be a costly and slow process. While the 2021 winter crop will provide more data on progress, results to date have been included in this edition of *Queensland grain research*. So far, the most impressive results have been from the deep ripping of nutrients into the root zone for better crop access. It appears that the physical ripping has been beneficial, but the deep placement of nutrients has been the critical factor. Together yields have been increased by up to 25% in the 2019 sorghum at Millmerran and up to 60% in the wheat at Drillham in 2020.

Time will tell how long any ripping effect lasts, and the duration of the deep nutrient benefits across different seasons and growing conditions. The options tested by grower groups across the northern grain region will also be of special interest over the coming years.

Ameliorating soil sodicity with deep ripping, gypsum and soil organic matter addition

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[4] Soil Management Designs

RESEARCH QUESTION: *Can soils constrained by sodicity be improved to increase grain yields?*

Key findings

1. Benefits of subsoil amendments are more likely in poorer seasons.
2. Deep ripping and nutrient supply to the root zone can increase yields by up to 30%.
3. Adjustment in agronomy may be necessary to take advantage of improved subsoil conditions.
4. Small-seeded crops such as canola are less suited to planting into rough surfaces after deep ripping.

Background

Model analyses suggest a yield gap between water-limited potential yield and currently achieved production exists across northern Australian grain regions. This yield gap is a function of physical, chemical, and biological factors in each soil, including capacity of soil to store and release water for efficient plant use.

Many regions where yield is constrained contain dispersive soil within the surface 50 cm and deeper. Sodicity (a high exchangeable sodium percentage) is a major cause of aggregate dispersion and may compromise soil structure. Dispersive behaviour decreases both soil water availability and nutrient acquisition, increases risk of runoff and erosion, and impairs biological (soil microbial and plant root) activity. Acidity, salinity (presence and absence) and compaction further constrain yield potentials.

Amelioration of subsoil constraints is an expensive process. The engineering challenges and energy requirements are not insignificant. It is important to acknowledge that production benefits from subsoil amendment are more likely to be observed in poorer seasons. In good seasons, root function and activity, and soil moisture, will be able to sustain yield from surface activity and extraction where soils are often less constrained. However, in poorer seasons, where subsoil moisture is required to finish a crop, subsoil amelioration will have a proportionately larger impact on yield. Hence, in good seasons we would not expect return on investments in subsoil amelioration to be observed.

A series of linked investments is assessing the economics of ameliorating constrained surface and subsurface soils in the northern region. The program has four areas covering:

a. Spatial soil constraint identification,
b. Amelioration and management of soil constraints,
c. Economics of adoption, and
d. Overarching communications and extension program.

The research into soil amelioration and management is focusing on sodicity is led by University of Southern Queensland (USQ). A set of six small-plot core experiments are exploring detailed amelioration research. There are three sites in northern and central New South Wales (NSW) managed by the University of New England (UNE), and three sites in southern Queensland managed by the Department of Agriculture and Fisheries (DAF).

This report describes the treatments being studied and the adaptations needed to deliver these treatments to depth in our constrained soils and reports on the first season of field trial responses.

What was done

Core site selection

The project surveyed 30 fields across central and northern NSW and southern Queensland. The field surveying included capture of yield maps if available, satellite NDVI imagery (a measure of total plant growth), and soil mapping with electromagnetic monitor imagery (EMI). Using a combination of yield, site elevation and EMI maps, bare soil colour imagery and grower experience four survey points were selected for soil sample collection and analysis before the six 'core' experimental sites were selected: three in NSW (Armatree, Forbes, Spring Ridge) and three in Queensland (Millmerran, Drillham and Talwood).

Core site characterisation

All sites were generally alkaline in the upper profile with exchangeable sodium percentages (ESP) well over the 6% nominal threshold for healthy crop growth. Profile chloride (Cl) values were generally low, indicating that sodicity was likely to be the primary restriction.

Chemical characteristics of the six core experiments are listed under *Trial details*.

Experiment treatments

Experiments were designed to assess ways to eliminate sodium from the top 50 cm of the soil profile and the effects on soil water storage and grain yields. Gypsum rates were designed to remediate the ESP to ≤3% in, either or both, the top 20 cm of soil and half of the soil volume in bands from 20 cm down to 50 cm depth. Organic matter (OM) treatments were also included as OM limits aggregate dispersion, provides nutrients and improves soil structure. Gypsum rates (often ≥15 t/ha) were compared against a high-rate subsoil (~20 cm deep), compost (Qld)/lucerne pellet (NSW) application (~10 t/ha), and applications of elemental sulfur to dissolve calcium carbonate to produce gypsum in situ.

The rates chosen are considerably higher than the likely economically viable rates and were deliberately chosen to determine if subsoil remediation to remove dispersive constraints would result in improved production outcomes beyond the first year. With that in mind, it is worth considering that the cost in diesel of ripping to depth without adding the necessary amendment is unlikely to be recovered. Repeated, smaller gypsum/OM applications coupled with deep ripping to place them is cost prohibitive. Hence, single, large, additions may ultimately be best practice.

Table 1. Treatment structure for core soil constraints sites.

Treatment		Shallow rip (~20 cm)	Surface gypsum	Deep NP(K)Zn (~20 cm)	Deep rip (>20 cm)	Deep gypsum (~20 cm)	Deep OM (~20 cm)	Deep sulfur (~20 cm)
1	Control							
2	Shallow rip	Y						
3	Banded fertiliser	Y		Y				
4	Surface gypsum + shallow rip	Y	Y	Y				
5	Deep rip	Y		Y	Y			
6	Deep gypsum	Y		Y	Y	Y		
7	Surface deep gypsum	Y	Y	Y	Y	Y		
8	Surface gypsum + deep rip	Y	Y	Y				
9	Elemental sulfur + surface gypsum	Y	Y	Y	Y			Y
10	Nutrient control	Y	Y	Y (*)	Y			
11	Surface deep organic matter (OM)	Y	Y		Y		Y	
12	Elemental sulfur + organic matter	Y	Y		Y		Y	Y
13	All	Y	Y		Y	Y	Y	Y

Deep NP(K)Zn rate is 50 kg N, 30 kg P, 50 kg K and 1.5 kg Zn apart from * rate which matches N and P addition from deep compost application.

The treatments were similar across the sites. However, the organic amendment in Qld was composted feedlot manure, while lucerne pellets were used in NSW (Table 1).

Surface gypsum treatments were spread onto the soil, and then incorporated by ripping to 20 cm. Actual application rates for gypsum varied with each site based on calculations that capture the required calcium (Ca) to lower the ESP to <3%, but the overall structure of the experiment stayed the same.

The applied gypsum rate for subsurface placement was banded with 50% of the total needed for the whole 20–50 cm layer of soil. For example, if a total of 20 t/ha of gypsum was theoretically needed to remediate the 20–50 cm layer, in this application 10 t/ha was applied to ensure the right amount of gypsum within each band. In NSW, it was assumed that the band only treated 25% of the profile, so only 25% of the total gypsum needed – 5 t/ha in the example.

Results

Millmerran was planted to sorghum for 2019-20, while Drillham, Armatree, Forbes and Spring Ridge all had winter crops in 2020. At Talwood, the lack of rainfall and planting opportunity in 2020 resulted in a missed winter cropping window, meaning this site is not included in this article's results. While experiments are similar across the Qld and NSW components, the results are reported separately.

Grain responses in Queensland

In Queensland, yield increases have been recorded at both the harvested sites.

Grain yields at Millmerran increased up to ~25% or 750 kg/ha (Table 2). Treatments with combinations of surface gypsum and subsurface NPK (i.e. treatments 4, 7, 8 and 13) generally had the largest yield gains.

Table 2. 2019-20 grain yield for sorghum at Millmerran.

Trt No.	Yield (kg/ha)	SE	Relative grain yield		*	Protein (%)
			Delta (kg/ha)	%		
1	2970	133	0	0	a	11.1
2	2910	188	-60	-2	a	10.7
3	3300	188	330	11	abcd	10.7
4	3580	133	610	21	bcd	10.4
5	3430	188	460	15	abcd	10.6
6	3120	188	150	5	ab	10.9
7	3750	133	780	26	d	10.7
8	3750	188	780	26	cd	10.2
9	3250	188	280	10	abc	10.6
10	3500	188	530	18	bcd	11.0
11	3370	188	400	13	abcd	10.4
12	3360	188	390	13	abcd	10.5
13	3700	188	730	25	cd	10.5

*Means with the same letter are not significantly different at P(0.05).

Grain yields at Drillham increased up to ~60% or 1250 kg/ha (Table 3). The largest increases were from treatments 10, 12 and 13 that all had tillage to 30 cm, with high nutrient supplies from either the high NP rates (treatment 10), or the composted feedlot manure (12 and 13). Deeper ripping (to 30 cm) and lower nutrient inputs (50N, 30P) increased yields by 800 kg/ha (40%), but it appears the higher nutrient supply plots supported greater yields.

Table 3. 2020 grain yield for wheat at Drillham.

Trt No.	Yield (kg/ha)	SE	Relative grain yield		*	Protein (%)
			Delta (kg/ha)	%		
1	2110	66	0	0	a	13.7
2	2200	133	90	5	ab	13.5
3	2520	133	410	20	bcd	14.4
4	2320	133	210	10	abc	14.0
5	2990	133	880	42	fgh	13.3
6	2860	133	750	35	defg	13.8
7	2580	133	470	22	bcde	13.8
8	2910	133	800	38	efg	13.8
9	2690	133	580	27	cdef	13.5
10	3310	133	1200	57	hi	13.9
11	3010	133	900	43	fgh	13.7
12	3200	133	1090	52	ghi	13.6
13	3420	133	1310	62	i	13.6

*Means with the same letter are not significantly different at P(0.05).

Grain responses in New South Wales

The Armatree site produced a 4.5 t/ha crop at around 15% protein and had significant differences between treatments in both grain yield and biomass at flowering (Table 4). In general, deep ripping and the addition of nutrients (as banded fertiliser or contained in the organic amendment) increased growth and yields by approximately 20%. However, the organic matter treatments (i.e. 11-13) ran out of water during grain fill due to the very large biomass produced. This resulted in similar yields to the controls, but with higher protein and screenings levels. We speculate that a later planting date at Armatree may have allowed enough water to remain post-anthesis for nutrient rich, ripped treatments to fully express their increased yield potential.

Table 4. 2020 grain yield for wheat at Armatree.

Trt No.	Yield (kg/ha)	SE	Relative grain yield		*	Protein (%)	Scr. (%)
			Delta (kg/ha)	%			
1	4470	188	0	0	abcd	15.5	0.8
2	4740	210	270	6	abcde	15.8	1.2
3	5040	210	570	13	abcde	14.8	0.9
4	5210	210	740	17	bcde	15.4	1.2
5	5390	210	920	21	cde	14.7	1.1
6	5460	210	990	22	cde	15.0	1.1
7	5110	188	640	14	bcde	14.6	1.2
8	5330	188	860	19	cde	15.0	1.0
9	5630	210	1160	26	e	14.9	1.0
10	5340	210	870	19	bcde	14.8	1.1
11	4390	210	-80	-2	abc	16.3	2.1
12	4570	210	100	2	abcde	17.0	3.1
13	4340	188	-130	-3	ab	17.1	2.2

***Means with the same letter are not significantly different at P(0.05).**

Forbes had no significant differences in canola grain yield, but the OM treatments did increase protein and reduce the oil content (Table 5). The site was waterlogged for most of winter, and still had moisture in the profile at harvest, so any differences in plant available water capacity, or root penetration to depth, were unlikely to have shown up in this season. The plant population was also extremely variable due to the surface roughness from the ripping and waterlogging from 70 mm of rain immediately after sowing. This variation has been included in the statistical analysis, but also suggests that small-seeded canola is not the best crop for growing immediately after a ripping program.

Table 5. 2020 grain yield for canola at Forbes.

Trt No.	Yield (kg/ha)	SE	Relative grain yield			Protein (%)	Oil
			Delta (kg/ha)	%			
1	2470	194	0	0	ns	19.9	44.9
2	2530	222	60	2	ns	19.9	44.3
3	3070	193	600	24	ns	20.3	43.9
4	2710	192	240	10	ns	20.4	45.0
5	2680	176	210	9	ns	20.8	43.2
6	2650	193	180	7	ns	21.4	42.7
7	3010	172	540	22	ns	20.6	43.7
8	2840	192	370	15	ns	20.4	44.0
9	2700	193	230	9	ns	20.4	43.7
10	2750	193	280	11	ns	20.2	44.2
11	2630	173	160	6	ns	22.4	40.6
12	2570	192	100	4	ns	22.5	40.4
13	2590	192	120	5	ns	21.6	41.7

Spring Ridge also had no significant differences in biomass at flowering, or barley grain yield (Table 6). The high yield reflects the good season in 2020 and suggests that the site may not be as constrained as originally thought. We are uncertain if this lack of observed yield constraint is long term, or due to the above average rainfall in early 2020, which may have resulted in short-term leaching of the salinity found in the initial sampling.

Table 6. 2020 grain yield for barley at Spring Ridge.

Trt No.	Yield (kg/ha)	SE	Relative grain yield		
			Delta (kg/ha)	%	
1	6520	226	0	0	ns
2	6030	253	-490	-8	ns
3	6170	256	-350	-5	ns
4	6410	254	-110	-2	ns
5	6320	256	-200	-3	ns
6	6360	256	-160	-2	ns
7	6700	227	180	3	ns
8	6050	227	-470	-7	ns
9	5760	256	-760	-12	ns
10	6460	254	-60	-1	ns
11	6170	256	-350	-5	ns
12	6270	254	-250	-4	ns
13	6310	227	-210	-3	ns

Implications for growers

These results to date are from just one year, after a very wet summer/autumn that allowed all plots to refill after treatment application; the exception was the Talwood site that was sown to sorghum in mid-January 2021. The 2021 crop will give a better indication of long-term effects of treatments, and (possibly) under more typical conditions. What is already clear is that increases in yield from ripping may also require extra nutrients to achieve the increased yield potential.

Re-engineering soils is a slow process and takes several years to fully assess any significant impacts on grain yields as well as broader farming systems. Growers and agronomists are advised to take a 'watch and wait' approach when considering these results as one years' worth of results isn't indicative of future performance.

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.

Trial details

Queensland and NSW core sites (location, soil type and brief chemical characterisation) are listed in the below tables.

Location: Armatree – NSW

Soil type: Brown Sodosol, not dispersive (0-10 cm) to dispersive (10-20 cm) surface, to strongly alkaline and dispersive at depth, compact surface layers.

Selected soil fertility characteristics of the trial site:

	Depth (cm)			
	0-10	10-20	30-40	60-70
pH (H2O)	6.0	7.8	9.3	9.4
pH (CaCl2)	5.3	6.8	8.3	8.4
EC (1:5)	0.20	0.20	0.45	0.58
Ca (cmol/kg)	3.7	8.5	13.1	12.3
Mg (%)	3.4	7.9	12.6	13.4
Na (mg/kg)	0.91	2.63	5.78	6.35
K (mg/kg)	1.00	0.83	0.81	0.96
ECEC	9.0	19.9	32.3	33.0
ESP (%)	10	13	18	19
Cl (mg/kg)				
P (mg/kg)	58	7	8	6

Location: Forbes – NSW

Soil type: Brown Vertosol, not dispersive (0-10 cm) to dispersive (10-20 cm) surface, to strongly alkaline and dispersive at depth.

Selected soil fertility characteristics of the trial site:

	Depth (cm)			
	0-10	10-20	30-40	60-70
pH (H2O)	6.3	7.9	9.1	9.1
pH (CaCl2)	6.1	6.9	8.2	8.3
EC (1:5)	0.39	0.30	0.64	0.85
Ca (cmol/kg)	8.7	15.4	12.5	11.3
Mg (%)	7.7	10.2	11.3	10.4
Na (mg/kg)	2.13	4.76	8.14	9.57
K (mg/kg)	0.77	0.55	0.49	0.56
ECEC	19.3	30.9	32.5	31.9
ESP (%)	11	15	25	30
Cl (mg/kg)				
P (mg/kg)	89	12	4	1

Location: Spring Ridge – NSW

Soil type: Black Vertosol, moderate ESP and salinity in surface, increasing to high ESP and salinity at depth, but both are non-dispersive due to the salinity.

Selected soil fertility characteristics of the trial site:

	Depth (cm)			
	0-10	10-20	30-40	60-70
pH (H2O)	8.2	8.2	8.3	8.3
pH (CaCl2)				
EC (1:5)	0.54	0.62	1.94	2.52
Ca (cmol/kg)	31.7	37.2	31.0	28.7
Mg (%)	41.7	43.5	51.5	56.7
Na (mg/kg)	3.3	5.2	13.9	19.5
K (mg/kg)	2.4	1.4	1.0	1.1
ECEC	79.1	87.3	97.4	106
ESP (%)	4	6	14	18
Cl (mg/kg)				
P (mg/kg)	100			

Location: Drillham – Qld

Soil type: Grey/Brown Vertosol (nominally Ulimaroa). Surface soils not spontaneously dispersive, subsurface highly dispersive.

Selected soil fertility characteristics of the trial site:

	Depth (cm)			
	0-10	10-20	30-40	60-70
pH (H2O)	8.5	8.8	8.1	6.8
pH (CaCl2)	7.7	7.8	7.3	6.7
EC (1:5)	0.21	0.25	0.46	0.66
Ca (cmol/kg)	18.1	15.8	15.4	12.0
Mg (%)	8.0	9.8	12.3	12.8
Na (mg/kg)	2.73	3.99	7.10	8.83
K (mg/kg)	0.93	0.61	0.45	0.48
ECEC	29.8	30.3	35.3	34.1
ESP (%)	9	13	20	26
Cl (mg/kg)	43	53	102	275
P (mg/kg)	9	14	4	8

Location: Millmerran – Qld

Soil type: Grey/Brown Vertosol (nominally Moola). Surface and subsurface soils not spontaneously dispersive, very compact soil through the profile.

Selected soil fertility characteristics of the trial site:

	Depth (cm)			
	0-10	10-20	30-40	60-70
pH (H2O)	6.6	8.7	6.9	6.4
pH (CaCl2)	6.3	7.4	6.2	5.5
EC (1:5)	0.15	0.24	0.38	0.43
Ca (cmol/kg)	8.4	10.6	9.5	10.2
Mg (%)	6.6	9.0	15.	16.4
Na (mg/kg)	2.37	3.36	6.82	8.79
K (mg/kg)	0.31	0.20	0.14	0.18
ECEC	17.7	23.2	31.4	35.5
ESP (%)	13	14	22	25
Cl (mg/kg)	153	330	428	457
P (mg/kg)	38	5	3	2

Location: Talwood – Qld

Soil type: Red/Brown Vertosol (nominally Arden). Surface soils not spontaneously dispersive, subsurface highly dispersive at 60-70 cm.

Selected soil fertility characteristics of the trial site:

	Depth (cm)			
	0-10	10-20	30-40	60-70
pH (H2O)	8.3	8.7	8.9	9.2
pH (CaCl2)	7.6	7.9	7.8	7.9
EC (1:5)	0.17	0.23	0.36	0.44
Ca (cmol/kg)	27.5	27.8	22.5	20.3
Mg (%)	4.7	7.0	9.4	9.9
Na (mg/kg)	1.8	3.8	7.0	9.9
K (mg/kg)	1.3	0.7	0.4	0.5
ECEC	35.5	39.3	39.4	40.7
ESP (%)	11	10	18	24
Cl (mg/kg)	22	26	73	163
P (mg/kg)	18	3	2	2

Farming systems research

The Regional agronomy (research) team continues to place a large focus on conducting Farming systems research, development and extension to support the farming systems of the future.

The major investment continues to be an extensive field-based farming systems research program in collaboration with CSIRO and the New South Wales Department of Primary Industries (NSW DPI). This Northern Farming Systems project, now entering its eighth year of an eleven year program is a clear demonstration of these research agencies and the Grains Research and Development Corporation (GRDC)'s commitment to continually improve our local farming systems.

This project is focussed on developing systems to better use the available rainfall; to increase productivity and profitability, and investigate the soil water costs, benefits and legacy impacts of different cropping sequences on the cropping systems, that is,

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 project; providing insights into the systems performance across the whole grains region, and collating rigorous data on the performance of local farming systems at key locations across the region.

This research began with local growers and agronomists in 2015 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 across the northern region.

Experiments were established at seven locations; with a large factorial experiment managed by CSIRO and the Department of Agriculture and Fisheries (DAF) at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres, managed 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 reports provide details of the systems being studied at Queensland sites (Emerald, Billa Billa and Mungindi), how they are implemented locally and the results to date. Key messages across the sites include:

- Cropping systems decisions can have large and ongoing consequences on system profitability – varying by up to $200/ha/year in gross margin generated
- Cropping intensity was the most influential driver of system productivity and profitability across most sites
- Understanding soil water to guide crop sowing decisions is critical to maximise conversion of rainfall into profit in most locations. For example, the water use efficiency with which crops use in-crop rainfall is improved by sowing crops onto good levels of stored soil water, ideally 120 mm of plant available water for crops that grow in low-rainfall years
- Managers must account for legacy effects of different crop choices on fallow water accumulation and disease risks. For example, mungbean resulted in the greatest increase in arbuscular mycorrhizae but also elevated the risk for charcoal rot and root-lesion nematode compared to sorghum, cotton, maize, sunflower and millet.

Other farming systems research included this year are the final reports on the cover crop work jointly supported by GRDC and the Cotton Research and Development Corporation. This work has shown that well managed cover crops at Goondiwindi recovered the 40-60 mm water deficit taken to grow them by the end of the fallow in most experiments, which modelling suggests may happen in ~70% of years. Cover crops that produced >2 t/ha dry matter were also able to reduce the erosion risk by >96%.

As this work ended, the Regional agronomy team began two new GRDC supported projects; one to work with growers and agronomists to identify the opportunities to use companion cropping in northern farming systems, while the other is assessing the performance and opportunities for the long coleoptile wheat varieties that are 'under-development'. These new initiatives will be reported in future editions of *Queensland grains research*.

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) – crops, sowing rates, row spacings and 'strategic tillage' are included to manage weeds and herbicide resistance	*					

Northern farming systems site report—Emerald

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Research question: *What are the long-term impacts on systems performance (e.g. productivity, profitability and soil health) when six strategically different farming systems are applied to one geographic location over five years?*

Key findings

1. The *Higher soil fertility* system is now comfortably outperforming the other five systems across all key comparison indices, including yield, biomass production, water use efficiency and gross profit.
2. The 2020 winter crop was unable to extract as much water below 60 cm as previous crops that had similar plant available water at planting.
3. The 2020 crop, on average produced around 60% of the biomass and 80% of the yield compared to the 2019 crop with less than half the 2019 rainfall.

Background

In early 2015, the Northern farming systems project consulted growers and agronomists to identify and implement six farming systems relevant to Emerald and the wider northern grain region. A range of agronomic practices (i.e., rows spacing, plant population), crop types and rotations, crop frequencies, planting time/windows, tillage practices, fertiliser rates and planting moisture triggers were employed and strategically used to develop six farming system treatments:

1. **Baseline** is a conservative zero tillage system targeting one crop/year. Crops include wheat, chickpea and sorghum, with nitrogen rates for cereals targeting median seasonal yield potential for the plant available water at planting.
2. **Higher crop intensity** focuses on increasing the cropping intensity to 1.5 crops/year when water allows. Crops include wheat, chickpea, sorghum, mungbean and forage crops/legumes with nitrogen rates on cereals again targeting median seasonal yield potential for the plant available water at planting.
3. **Higher legume** increases the frequency of pulses compared to the *Baseline* system. The target is to grow a pulse crop every two years, with nitrogen rates on cereals targeting median seasonal yield potential for the plant available water at planting.
4. **Higher nutrient supply** increases nitrogen and phosphorus rates to target 90% of the seasonal yield potential for the plant available water at planting. The crop choices and other practices are the same as the *Baseline* system.
5. **Higher soil fertility** intially applied an additional ~60 t/ha of manure to increase soil organic matter and change the starting soil fertility level. The crops and all other practices are the same as the *Baseline* system. Nitrogen and phosphorus rates match those of the *Higher nutrient supply* system (i.e. targeting 90% of yield potential based on soil moisture at planting).
6. **Integrated weed management** (IWM) is a minimum tillage system focused on one crop/year but with capacity to employ a wide range of practices to reduce the reliance on traditional knockdown herbicides used in Central Queensland (CQ) farming systems. Crops include wheat, chickpea and sorghum.

Table 1. Cropping cycles since the trial's commencement in 2015.

Cropping cycle	Baseline	Higher crop intensity	Higher legume	Higher nutrient supply	Higher soil fertility	IWM
Winter 2015	Wheat	Wheat	Chickpea	Wheat	Wheat	Wheat
Summer 2015/16	Fallow	Mungbean	Fallow	Fallow	Fallow	Fallow
Winter 2016	Chickpea	Wheat	Wheat	Chickpea	Chickpea	Chickpea
Summer 2016/17	Fallow	Fallow	Fallow	Fallow	Fallow	Fallow
Winter 2017	Wheat	Wheat	Chickpea	Wheat	Wheat	Wheat
Summer 2017/18	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum	Sorghum
Winter 2018	Fallow	Fallow	Fallow	Fallow	Fallow	Fallow
Summer 2018/19	Fallow	Fallow	Fallow	Fallow	Fallow	Fallow
Winter 2019	Wheat	Chickpea	Chickpea	Wheat	Wheat	Wheat
Summer 2019/20	Fallow	Fallow	Fallow	Fallow	Fallow	Fallow
Winter 2020	Wheat	Wheat	Wheat	Wheat	Wheat	Wheat
Summer 2020/21	Fallow	Fallow	Fallow	Fallow	Fallow	Fallow

Note: colours used for crops and treatments in this table correspond to colours used in the figures (see crop key below).

Key: Crops grown at the Emerald site

🟫 **Wheat** 🟦 **Chickpea** 🟥 **Grain sorghum** 🟩 **Mungbean** ⬜ **Fallow**

What was done (2019–2020 operations)

Harvest for the 2019 winter crop was completed by 19 September, and the results reported in the 2019-20 trial book. Despite achieving reasonable yields, water use at depth was limited, particularly in the systems with Chickpea (Figure 1). The tail of 2019–20 was particularly hot and dry with a total of 8.4 mm of rain received between 12 July 2019 and 7 January 2020. Fortunately, rain did arrive in mid-January and the site received over 300 mm of rain to mid-March, including 81 mm in a storm on 17 January 2020 (Figure 8). The intensity of this rainfall exacerbated significant planter wheel tracks that developed on the site over time and left many of the north/south planting runs very raised and exposed.

The paddock was cultivated to pull dirt back onto the wheel tracks and flatten out the beds and the site was planted on a relatively full profile to Condo$^{\Phi}$ wheat across all systems on 29 April 2020. As the last crop of the first phase of the project, this allowed crop effects on system modifications to be compared after six years. Five systems (*Baseline*, *Higher crop intensity*, *Higher legume*, *Higher nutrient supply* and *Higher soil fertility*) were planted on 50 cm row spacings, with a target population of 1 million plants per ha, while the *IWM* system was planted on 25 cm row spacing and a target density of 1.5 million plants per ha.

Wheel track compaction has worsened, exacerbated by heavy downpours between January and March 2020. A light renovation in early April 2020 was followed by two light rainfalls and a light irrigation to top up the moisture loss as part of the renovation process. Tynes running over the wheel tracks were not low enough to engage the soil. The purpose was only to spread soil from the raised centre out to the wheel tracks, not renovate compaction.

Results

Rainfall capture and use

Plant available water (PAW) extraction at depth has typically been lower than expected; the 2019 winter crop was no exception. Over the 12-month period from harvest 2019 to harvest 2020, PAW levels did not change below 120 cm. The PAW from 90–120 cm was only slightly drawn upon by the 2019 crop, with no additional PAW accumulated below 90 cm during the 2019-2020 fallow (Figure 1).

The four systems that grew wheat in 2019 (*Baseline*, *Higher nutrient supply*, *Higher soil fertility* and *IWM*) had 150 mm (range 140 to 160 mm) PAW at planting in 2020, while the *Higher crop intensity* and *Higher legume* systems had 120 mm and 130 mm PAW respectively at planting following chickpea in 2019. With only 43 mm of rainfall in-crop, the *Higher soil fertility* systems was the only 2020 crop able to extract PAW below 60 cm.

The 2019 winter crop did leave the block very dry and heavily cracked. This enabled the systems to refill from rain in late summer 2020 and allowed a winter planting for 2020.

Despite 2020 having half the in-crop rainfall of 2019 (99 mm versus 43 mm), cracks in the soil were not as visible as they were in 2019.

Table 2. Crop water use efficiency (WUE; kg/mm) for 2019 and 2020.

System	2019	2020
Baseline	15.4	17
Higher crop intensity	4.5	14.9
Higher legume	11	15.2
Higher nutrient supply	16.8	19.9
Higher soil fertility	15.7	16.4
IWM	13.6	17.3

The table shows how many kilograms of grain were produced per millimetre of plant available water accessed by the crop. Brown indicates wheat, blue indicates chickpea (the two chickpea crops were frost-affected in 2019).

Water use efficiency (WUE) for the 2020 trial was excellent, surpassing the impressive numbers from the 2019 wheat crops (Table 2).

Both yield and biomass production for all systems were lower than in the 2019 wheat despite starting with a higher PAW in 2020 (Table 3). It appears the excellent WUE values in 2020 were due to the residual water that was left behind after harvest; great for WUE values, but not ideal for converting available water into revenue.

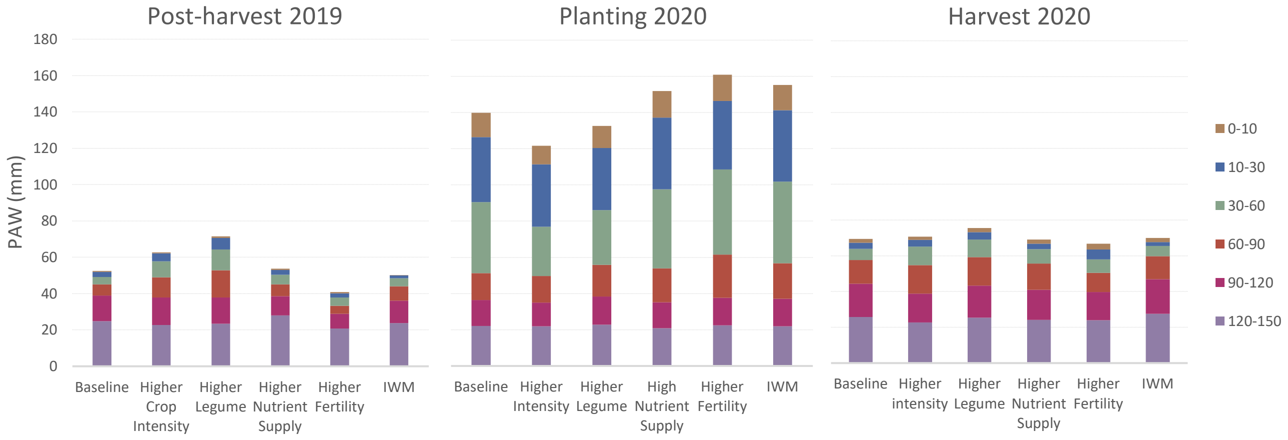

Figure 1. Plant available water changes down the soil profile, from harvest 2019 through to harvest 2020.
These three stacked graphs show average plant available water for each depth increment across all six systems. One of the key observations to make from these graphs is how little water was used below 60 cm in the 2020 season.

Table 3. A comparison between winter crops. In-crop rainfall received was 99 mm in 2019 and 43 mm in 2020.

Systems	Difference betwen 2020 and 2019 (%)			
	Starting PAW	Harvest PAW	Biomass production	Grain yield
Baseline	-18%	+32%	+54%	+73%
Higher crop intensity (ex Cp)	+1%	+13%	+63%	+213%
Higher legume (ex Cp)	-20%	+6%	+68%	+120%
Higher nutrient supply	+6%	+29%	+55%	+74%
Higher soil fertility	+3%	+63%	+59%	+91%
IWM	+5%	+40%	+62%	+77%

Crops in 2020 received 44% less in-crop rainfall than the 2019 crops. The table shows the difference in starting and finishing plant available water between the two years, and how much biomass and grain was produced in 2020 relative to what was produced in a much wetter 2019.

Grain and biomass production

In line with the reduced rainfall received over the 2020 growing season, both biomass production and grain yields declined. 2020 only received 44% of the in-crop rainfall of the 2019 season. Biomass production dropped on average to 57% of 2019, and grain yields were 79% of the of 2019 (Table 3, Figures 2 and 3).

The *Higher soil fertility* system only produced 59% of the 2019 biomass, yet still managed to yield 91% of the 2019 crop. It was the highest yielding system for both biomass and grain. *IWM* was the next most productive system of 2020, and despite the higher population and narrower row spacing, still produced on average 1 t/ha less biomass than the *Higher soil fertility* system.

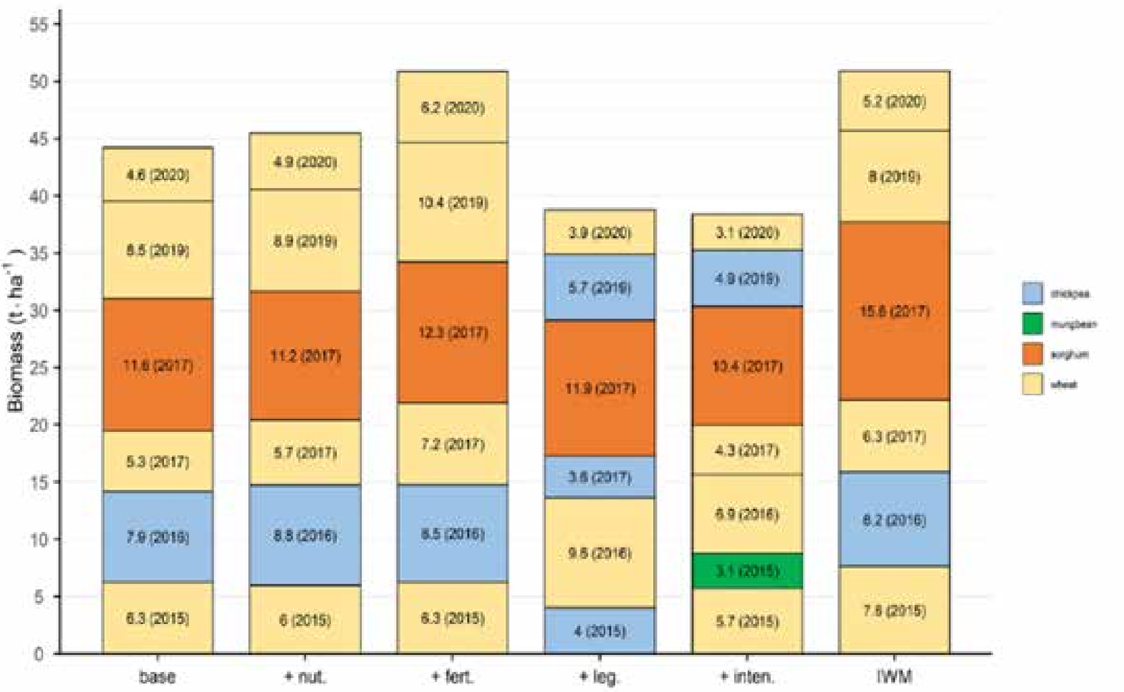

Figure 2. Cumulative biomass production for the Emerald systems to date. Despite the higher population and narrower row spacings of the *Integrated weed management* system, the *Higher soil fertility* system is producing a similar biomass. The *Higher crop intensity* system continues to fall behind even the *Baseline* system despite having grown an additional crop over the past 6 years.

Figure 3. Cumulative grain production for the Emerald systems to date. *Higher soil fertility* continues to extend its lead over the other systems, while *Higher crop intensity* struggles against all the other systems.

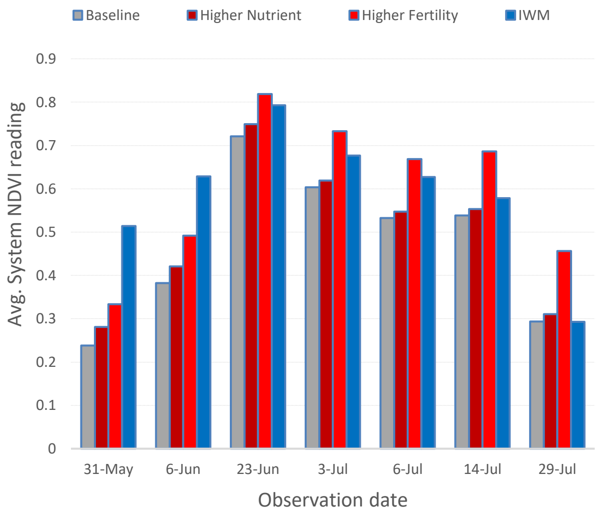

Figure 4. NDVI observations for the four wheat-on-wheat systems during the 2020 growing season.

NDVI observations in 2020 correlated with final biomass production and grain yields (Figures 2, 3 and 4). As expected, the *IWM* system with narrower row spacing and higher population had higher NDVI levels in the first six weeks of development. By flowering (7 July), the other systems had caught up. Interestingly, the *Higher soil fertility* system matured more slowly than the other systems and maintained higher NDVI levels than the other systems.

Nitrogen cycling

The mineralisation of nitrogen (N) from this site continues to remain quite remarkable. For a site with average organic carbon levels of 0.6% in the top 10 cm, the expected mineralisation over a summer fallow is about 35 kg N/ha. In the fallow period from harvest 2019 to pre-plant testing in late February, this site mineralised between 37 and 125 kg of nitrogen per hectare (kg N/ha) down to 90 cm (Figure 5). It is important to note that little has changed with N levels below 60. Even excluding the *Higher soil fertility* system, the average mineralisation for the other systems is 56 kg N/ha.

For the crop of 2020, soil mineral N decreased 16 kg N/ha on average; the *IWM* system reducing the most at 32 kg N/ha and the *Higher legume* system only reducing by 4 kg N/ha (Table 4). This suggests that the systems had an additional 35 kg N/ha mineralise during the season (February to late August) as average N removal by the grain was 52 kg N/ha.

The *Higher soil fertility* system appears to have accessed most of this with 57 kg/ha, while the *IWM* system only accessed 23 kg/ha of the mineralised N.

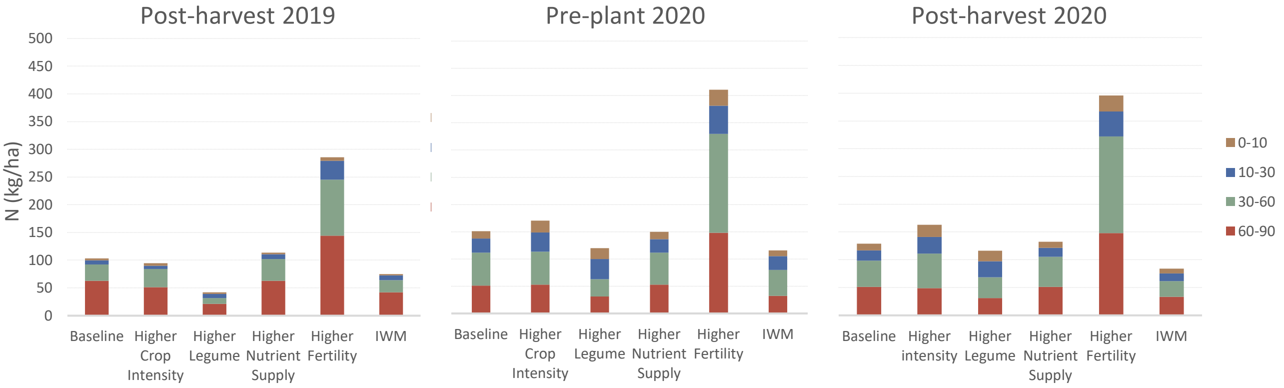

Figure 5. Profile nitrogen from harvest 2019 to harvest 2020.

Table 4: Fallow and in-crop nitrogen mineralisation in 2019/2020. Significant jumps in nitrogen were measured over the period, despite no significant rainfall until mid-January 2020.

System	2019/20 Fallow accumulation of N (kg/ha)	2020 Pre-plant N (kg/ha)	2020 Harvest N (kg/ha)	Observed reduction in soil N (kg/ha)	N removed in grain (kg/ha)	Estimated in-crop mineralisation (kg/ha)
Baseline	48	151	129	22	53	31
Higher crop intensity	76	170	163	7	39	31
Higher legume	78	120	116	4	41	37
Higher nutrient supply	37	150	132	18	51	33
Higher soil fertility	125	411	396	15	72	57
IWM	41	116	84	32	55	23
System average	68	186	170	16	52	35

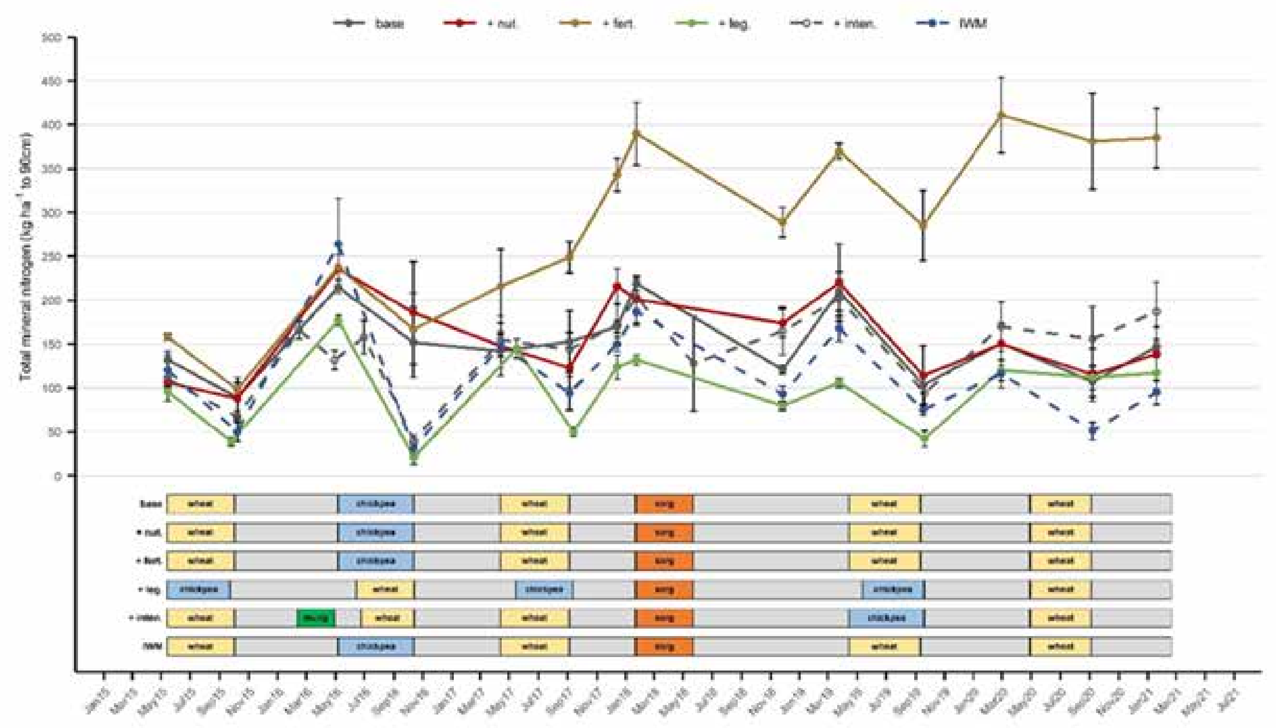

Figure 6. Total mineral nitrogen over the life of the Emerald systems. *Higher soil fertility* is now well clear of all other systems. *Higher legume* and *Integrated Weed Management* systems seem to be continuing their trend of flat or declining fertility, despite remaining more productive than the *Baseline* system.

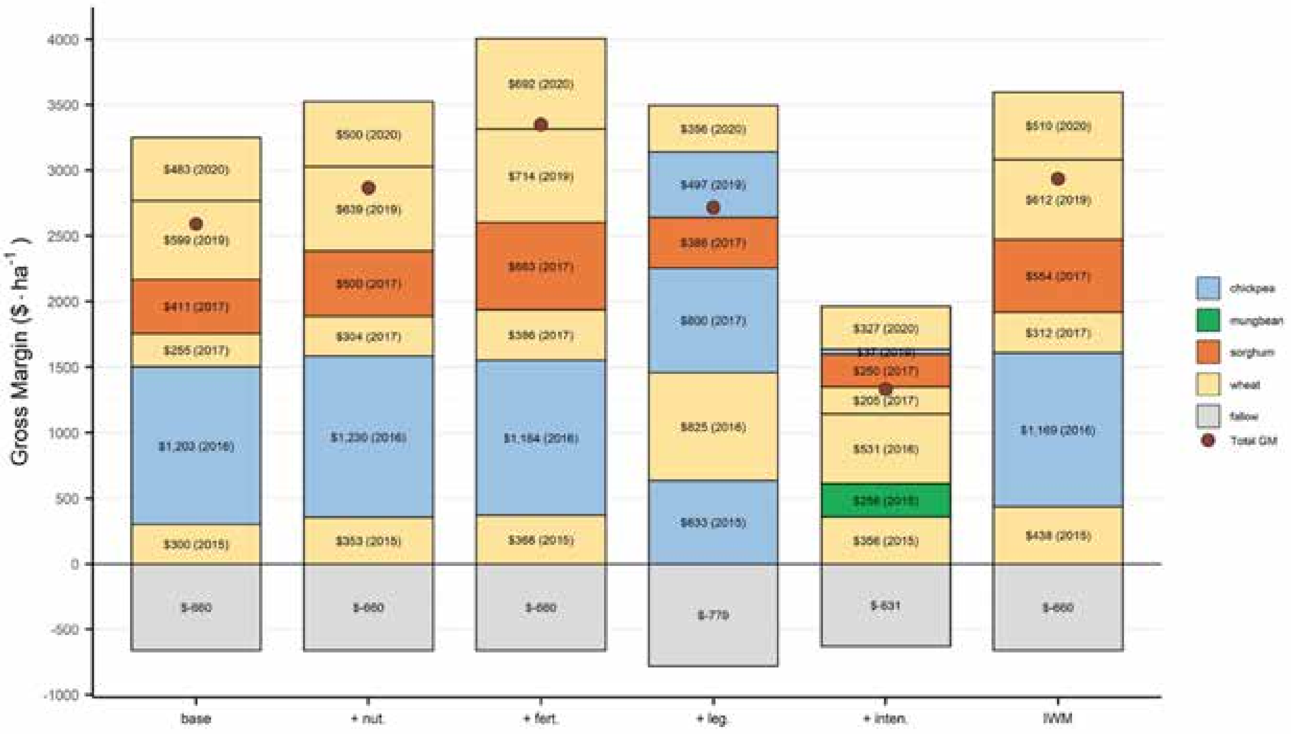

Figure 7. Stacked bar graph of system gross margins graph as at harvest 2020. Grey area indicates fallow costs per ha for the past six years, and the yellow, blue, orange, and green bars indicate the gross margin for each of those crops for each system. The red dot shows the current gross margin, with the *Higher soil fertility* system well in front, both in terms of crop income and overall gross margin.

The *Higher soil fertility* system at Emerald continues to maintain more available N than all the other systems (Figure 6). These other systems performed similarly with a flat to negative trend in soil N levels continuing for both the *Higher legume* and *IWM* systems. Surprisingly, the *Higher nutrient supply* system has not increased soil N levels relative to the *Baseline* system. This appears to be a legacy of the high mineralisation rates that despite below average rainfall, have maintained high soil N levels and not required additional N application for several crops now.

Economics

Following the 2020 winter crop, we are seeing the widest and possibly most defined gross margin difference between the systems (Figure 7). The *Higher crop intensity* system has had the lowest individual crop gross margins since 2016, and as such has the lowest system gross margin. The conservative *Baseline* system has proven to be the second lowest of the six systems with an almost $760 lower gross margin per hectare than the best performing system (*Higher soil fertility*). The *Higher legume* system had been performing well, but the frost damage in the 2019 chickpea crop and the lower yields in 2020 from the lack of chickpea stubble and lower fallow efficiency, has seen it tumble from second to fourth most profitable system.

The top three systems all made notable changes to the *Baseline* system (i.e. nutrition, crop management) and these changes are showing benefits. The small additional inputs to the *Higher nutrient supply* system, especially over the last two years, has improved the cumulative gross margin by $277 per ha. Conversely, the *IWM* system with its high plant population has produced more biomass, and with the high mineralisation rates has done so economically to date through the tough conditions since 2016.

Implications for growers

As at harvest 2020, the *Higher soil fertility* system is the top performing system across almost all indices measured, not just economic. This system was designed to replicate how the higher fertility of a 'younger' soil with higher organic carbon levels may have performed, and whether we could maintain a more fertile soil with additional fertiliser inputs. It was not intended to test of the economic feasibility of applying 60 t/ha of feedlot manure, or to recommend it. However, the addition of manure has increased production in the five years by $760/ha over the *Baseline* system and the $480/ha gain over the *Higher nutrient supply* system. With apparent improvements in water extraction, water holding capacity and fertility, the proposition of applying manure may be economically feasible.

Moving forward, consultation with local growers and consultants as part of new funding to continue the project has added four new systems to the existing trial. High nutrition applications will be added to both the *IWM* and *Higher legume* systems. This new *Higher legume* system will include nitrogen applications to all crops, including the pulses.

A *Higher crop diversity* system and a *Lower crop intensity* system will also be added to match the other six sites in the project and contribute to insights across the wider northern grain region. The addition of these four new systems will make the project and the Emerald site even more interesting as the systems continue to differentiate over the coming seasons.

Acknowledgements

We would like the thank the local growers and consultants who have actively supported and continue to contribute towards this project. The CSIRO staff who assist in data management and consistency across all sites and the broader Research agronomy team in Emerald, Toowoomba, and Goondiwindi.

We would also like the thank the Grains Research and Development Corporation, along with the Department of Agriculture and Fisheries in Queensland and the New South Wales Department of Primary Industries who have supported this long-term project.

Trial details

Location:	Emerald
Crop:	Wheat
Soil type:	Cracking, self-mulching, Grey Vertosol, >1.5 m deep, estimated plant available water of 220 mm.
In-crop rainfall:	44.3 mm (see Figure 8)
Fertiliser:	Calculated starter Z requirements for the 2020 season: • the four 50th percentile systems (*Baseline*, *Higher crop intensity*, *Higher legume* and *Integrated Weed Management*) - 13 kg/ha • *Higher soil fertility* - 25 kg/ha • *Higher nutrient supply* - 21 kg/ha.

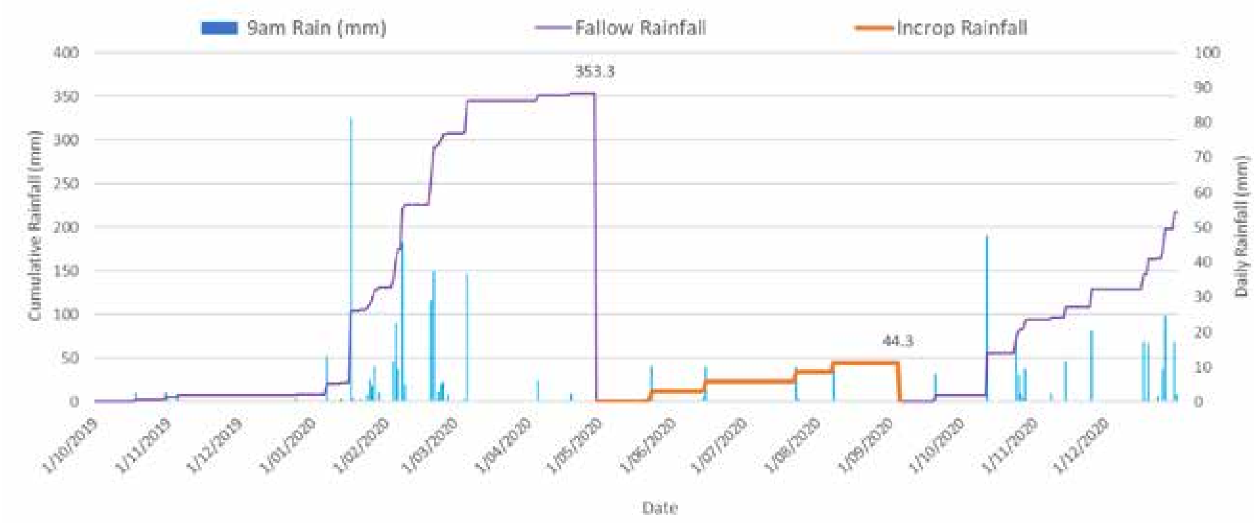

Figure 8. Rainfall accumulation post-harvest 2019 to the end of 2020. The purple line shows accumulated rainfall over the fallow period, the orange line shows rainfall in-crop (2020 winter crop). The blue columns show daily rainfalls amounts received across the period.

The Emerald Northern farming systems site on 5 July 2020 as the crop approached 50% flowering.

Northern farming systems site report—Billa Billa

Andrew Erbacher and Liv Bisset
Queensland Department of Agriculture and Fisheries

RESEARCH QUESTIONS: *Can systems performance be improved by modifying farming systems in the northern grains region? | In Goondiwindi, what have been the implications of these system modifications since 2015?*

- *What are the trends that are expected in our farming systems?*
- *How will these changes impact on the performance and status of our farming systems?*

Key findings

1. Nitrogen mineralisation can continue on small rainfall events through droughts. Mineralisation remained high (85 to 150 kg N/ha) in the dry 2019 fallow.
2. Lack of deep stored water prevented crops reaching grain yield potential with high grain screenings. Measuring plant available water below 90 cm remains valuable to assess season yield potential.

Background

Grain production systems at Goondiwindi are based on winter cropping. Most farms use zero or minimum tillage systems, with a strong reliance on stored fallow moisture. Summer crops are an important part of the system; grown as a disease break and typically planted in spring with a greater stored soil water profile than needed for winter crops to insure against hot growing seasons with variable rainfall.

The Farm Practices Research project (DAQ00192) was established in 2014 with the first crops planted winter 2015. Billa Billa, one of six research sites in the project, is located 50 km north of Goondiwindi on a Duplex soil. The original belah and brigalow trees were cleared and the paddock used as long-term pasture before it was developed for crops in the late 1990s.

This report investigates the activities and insights from the Billa Billa site in the 2019–20 summer and 2020 winter seasons. Previous activities and insights can be found in *Queensland grains research* – 2015, 2016, 2017–18, 2018–19 and 2019–20.

What was done

Consultation meetings in late 2014/early 2015 developed nine locally relevant systems which were implemented from 2015. Renewed funding through project DAQ2007-002RTX will allow the full impacts of the systems on their overall performance to be assessed. All systems were reviewed and refined by a local reference group to ensure continuing relevance, and the underlying systems have continued apart from a split in the pasture plots with half reverting to a *Baseline* cropping system and the remainder continuing as a ley pasture.

1. **Baseline** is typical of local best commercial practice under a zero tillage farming system with ~one crop per year based on moderate planting moisture triggers of 90 mm plant pvailable water (PAW) to plant winter crops and 120 mm PAW for summer crops. Crops grown are limited to wheat/barley, chickpea and sorghum. They are fertilised with nitrogen (N) and phosphorus (P) to achieve median seasonal yield potential for the PAW prior to planting.
2. **Lower crop intensity** reflects a more conservative approach, accumulating at least 150 mm PAW prior to planting the next crop. This system uses long fallows to provide a cropping frequency of two crops in three years (approximately 0.7/year) with the same nutrient management as the *Baseline* system.

3. **Higher crop intensity** aims to minimise the fallow periods within the system and potentially grow three crops every two years. Crops are planted on a lower PAW (50 mm for winter and 70 mm for summer crops) with greater reliance on in-crop rainfall. Crop choice is the same as the *Baseline* system, but with mungbean added as a short double-crop option. These crops are fertilised (N and P) to achieve average seasonal yield potential for the PAW prior to planting.
4. **Higher crop diversity** allows a greater suite of crops to be grown to better manage disease, root-lesion nematodes and herbicide resistance. Moderate PAW levels used as triggers for planting (90–120 mm) have been identified to manage individual crop risk and to target one crop per year. Crops are fertilised to achieve the average seasonal yield potential. The unique rules for this system focus on managing root-lesion nematodes, with 50% of the selected crops to be resistant to *Pratylenchus thornei*, and 1 in 4 crops resistant to *Pratylenchus neglectus*. To manage herbicide resistance, two crops requiring herbicides with the same mode-of-action cannot follow each other. Crops grown in this system include wheat/barley, chickpea, sorghum, mungbean, faba bean, field pea, canola/mustard, millet, cotton, safflower, linseed and sunflower. These crops are fertilised (N and P) to achieve median seasonal yield potential for the PAW prior to planting.
5. **Higher legume** aims to minimise the use of N fertiliser by growing every second crop as a pulse (legume); preference is given to pulse crops that produce greater biomass and greater carry-over nitrogen benefits. Crops grown in this system are similar to the *Baseline* (wheat/barley, chickpea, sorghum) with additional pulse options (faba bean and mungbean). Moderate planting triggers of 90–120 mm PAW are used and crops are fertilised (N and P) to achieve average yield potential for the PAW. Nitrogen is only applied to the cereal crops.
6. **Higher nutrient supply** applies N and P fertiliser for crops to achieve 90% of the maximum seasonal yield potential for the PAW measured at planting; there is a risk that crops will be over fertilised in some years. This system is planted to the same crop as the *Baseline* each year, so that the only difference is the amount of nutrients applied.
7. **Higher soil fertility** (*Higher nutrient supply* + organic matter) is treated the same as the *Higher nutrient supply* system. However, it had an additional 10 t/ha organic carbon (70 t/ha compost) applied in 2015 to raise the inherent fertility of the site. The aim is to see if this fertility level can be sustained with the higher nutrient inputs.
8. **Grass ley pasture** uses perennial Bambatsi grass pasture to increase the soil carbon levels naturally; the pasture is removed after three to five years and returned to the *Baseline* cropping system to quantify the benefits gained by the pasture phase. The pasture is managed with simulated grazing with a forage harvester to utilise a pre-determined amount of biomass.
9. **Grass ley pasture + nitrogen** fertiliser repeats the *Grass ley pasture* system but with 100 kg N/ha (217 kg/ha urea) applied each year over the growing season. This will boost dry matter production, which is nearly always constrained by nitrogen deficiency in grass-based pastures, to increase the rate of soil carbon increase.

Wheat establishing between 2 m sorghum rows at Billa Billa, 2020.

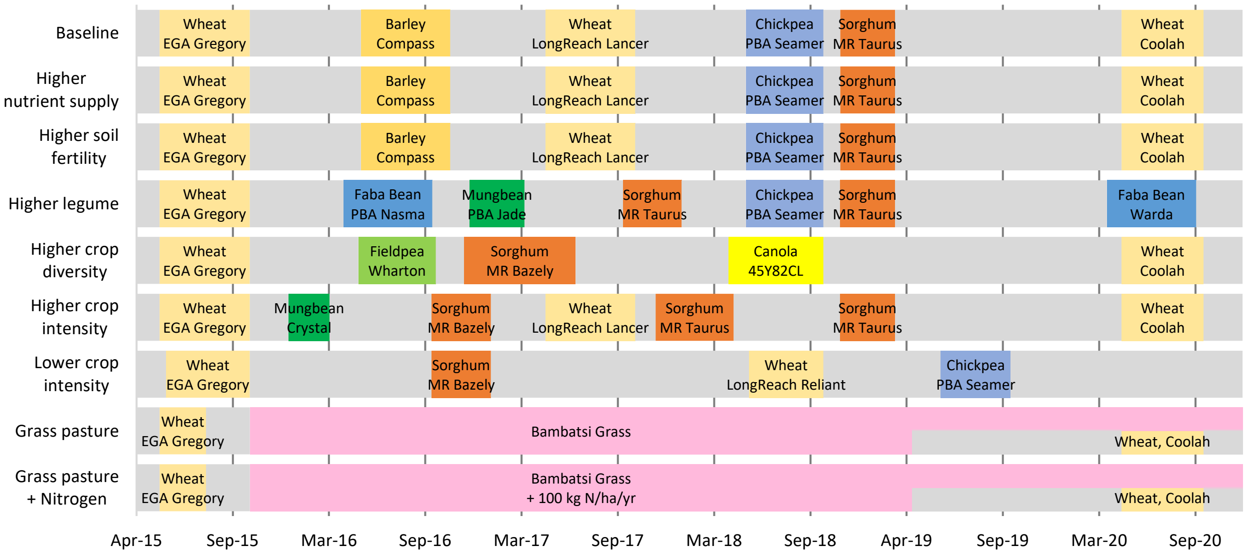

Figure 1. Crop sequences grown at Billa Billa following the defined system rules, plotted on a time scale. Colours represent the crop type as indicated in Table 1.

Results (summer 2019 – winter 2020)

2019 was one of the driest years on record with significant rainfalls only received in February 2020. As a result, there were no crops planted in the 2019–20 summer.

With 290 mm of rainfall over January to March 2020, eight of the nine systems accumulated enough soil water to plant the 2020 winter crop. *Lower crop intensity* needed another 40 mm PAW to plant in April 2020 but didn't receive the required rainfall to hit this planting trigger until December 2020.

Faba beans were planted in the *Higher legume* system on 15 April into wide row (2 m) sorghum stubble from 2018–19 summer (Figure 1, Table 1). After the wet start to 2020, rainfall in April to July was dominated by small events of 5–12 mm. The space between the two metre sorghum rows had become quite bare over the 12-month fallow, and rain was shedding off these areas. As a result, the 'skip' between the sorghum stubble had a dry surface, while the sorghum row was sufficiently wet to establish a crop. The run-off from the skips was captured in the furrow left by the planter in these faba bean plots, so it was decided to plant wheat into all but the *Higher legume* and *Lower crop intensity* systems on 13 May, and 12 mm of rain a week after planting was captured in the furrows to establish an even population of 650 000 plants/ha.

Crops grown at the Billa Billa site are represented by specific colours for all figures and graphs throughout this report (Table 1).

Table 1. Crops grown at the Billa Billa site.

🟨	Wheat	🟦	Faba bean	🟧	Sorghum
🟨	Barley	🟩	Field pea	🟨	Canola
⬜	Fallow	🟦	Chickpea	🟩	Mungbean
🟪	Grass pasture				

Nitrogen

This site had 360 kg N/ha at the commencement of the experiment in 2015. In the *Baseline* system, nitrogen (N) was budgeted to achieve average seasonal yield potential for the PAW prior to planting, and this led to soil N levels reducing to 125 kg N/ha by April 2019. Despite the very dry conditions in 2019, the eight fallowed systems accumulated an additional 85 to 150 kg N/ha by April 2020. Again, no nitrogen fertiliser was required for the 2020 crops.

Nitrogen mineralisation continued at a high rate in winter 2020. Six of the eight systems planted to winter crop (*Baseline*, *Higher nutrient supply*, *Higher soil fertility*, *Higher crop intensity*, ex-*Grass ley pasture* and ex-*Grass ley pasture + nitrogen*) had more nitrogen available post-harvest than was present prior to planting (Table 2). The remaining two systems, *Higher crop diversity* and *Higher legume*, reduced mineral N by 30 and 70 kg N/ha under the crop. However, there was sufficient nitrogen available at harvest in all systems to meet the demands of the next crop (195 kg N/ha to 389 kg N/ha) (Table 2).

Table 2. Pre-plant (30 March 2020) and post-harvest (28 October 2020) soil sampling results for mineral nitrogen (nitrate-nitrogen ammonium-nitrogen) and plant available water (PAW).

	Mineral nitrogen		Plant available water	
System	30/03/2020	28/10/2020	30/03/2020	28/10/2020
Baseline	250	279	110	18
Higher nutrient supply	249	249	107	23
Higher soil fertility	379	389	100	17
Higher legume	329	297	76	47
Higher crop diversity	264	195	102	28
Higher crop intensity	270	290	76	37
Lower crop intensity	275	346	104	136
ex-Grass pasture + nitrogen	174	205	98	19
ex-Grass pasture	279	323	108	23

Nitrogen is measured to 90 cm and PAW to 150 cm. PAW is calculated using wheat lower limits, so negative values are excluded.

Soil water

Seven of the systems had approximately 105 mm (98–110 mm) PAW by 30 March 2020. In contrast, the *Higher crop intensity* and *Higher legume* had only 76 mm PAW (Table 2). Part of this difference is a carry-over effect of deep stored water; these two systems were 20 mm drier in the 90-150 cm layers at the beginning of the 2019-20 fallow. In fact, *Higher crop intensity* hasn't stored any PAW below 90 cm since wheat harvest in 2015.

It is interesting to note that the two ex-pasture systems were amongst the seven systems with ~100 mm PAW by 30 March 2020. The pasture in these systems was sprayed-out in March 2019 and the soil water levels were below wheat crop lower limits in April 2019. A combination of higher stubble load and deep ripping to apply phosphorus fertiliser at depth, meant these two systems were able to capture 70 mm more PAW than the *Baseline* over the same fallow period. However, this PAW recharge was only in the top 90 cm of soil, with these ex-pasture systems still very dry, below crop lower limits, in the 90-150 cm layers.

At harvest all the wheat crops had dried the soil profile to 150 cm with 20 mm PAW left in the surface layers (0–30 cm) from rain at harvest. In comparison, the faba beans (*Higher legume*) left an additional 20 mm of residual PAW in the 30–90 cm layers.

Crop performance

The performance of the crops in each system is summarised in Figure 2.

Faba bean in *Higher legume* produced 3800 kg/ha (3.8 t/ha) of biomass for a grain yield of 1 t/ha.

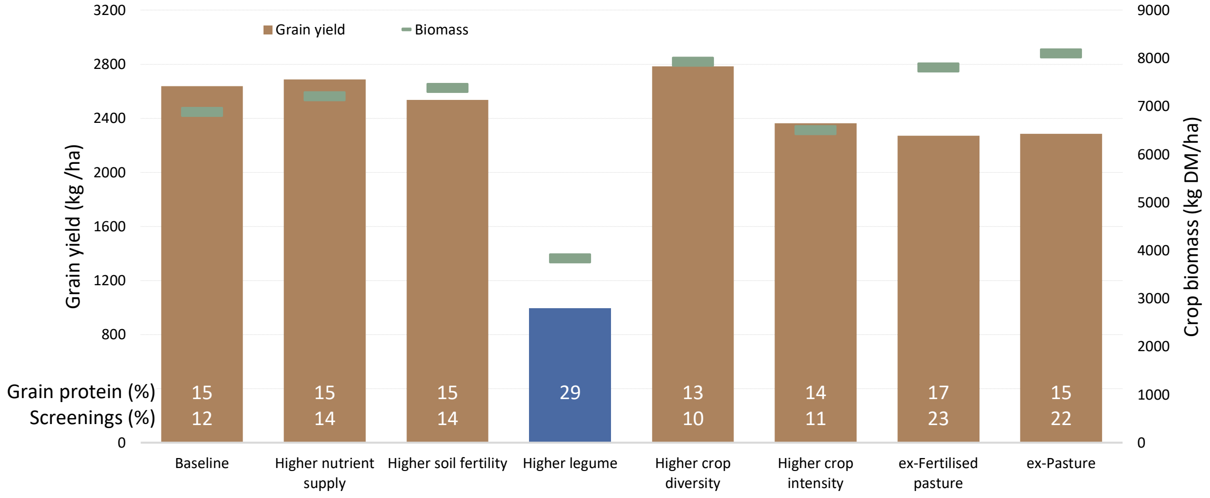

Figure 2. Grain yield on the left axis and crop biomass on the right axis for winter crops at Billa Billa in 2020. The relationship between biomass and grain yield is the harvest index, which was 38% in the *Baseline*. Systems with a larger difference between biomass and grain have a lower harvest index.

The *Baseline* wheat produced 6.8 t/ha biomass for a grain yield of 2.6 t/ha with 15% protein and 12% screenings. Yield and quality were similar in the *Higher nutrient supply* and *Higher soil fertility* systems. The *Higher crop diversity* system also produced similar grain yield to the *Baseline* but had slightly higher biomass yield (7.9 t/ha) with lower grain protein (13%) and screenings (9.5%). The *Higher crop intensity* systems had similar grain quality to the *Baseline* (14% protein and 11% screenings) but had lower biomass (6.5 t/ha) and grain yield (2.3 t/ha).

The ex-pasture systems had the highest biomass production (8 t/ha). However, the pastures dried the soil 20 mm below crop lower limits and did not recharge as much, so the crops were not able to access as much deep stored moisture to meet their potential. Consequently, grain yields were 2.3 t/ha (similar to *Higher crop intensity*) and screenings were above 20%. In contrast, the *Baseline* was able to extract 5 mm of water below previously measured crop lower limits in the deep soil and convert this biomass to grain yield, maintaining a higher harvest index. The ex-pasture fertilised with nitrogen also returned a higher (17%) grain protein than the unfertilised pasture and *Baseline* (15%).

The continuing *Grass ley pasture* systems were forage harvested in March 2020 for the first time since March 2018. This grew 4.4 t/ha in the unfertilised pasture and 5.7 t/ha with nitrogen fertiliser. This translated to harvested biomass (feed) of 1.6 t/ha at 12% protein in the unfertilised pasture and 2.5 t/ha at 14% protein in the fertilised pasture. With a late break, the scheduled 'spring cut' wasn't until January 2021. This cut grew 8.1 t/ha unfertilised and 10.8 t/ha with nitrogen fertiliser. The harvested portions of this second cut were 3.5 t/ha at 7.2 % protein for the unfertilised pasture and 4.5 t/ha at 9.9% protein for the fertilised pasture.

Implications for growers

It is widely accepted that nitrogen mineralisation requires moist soil. However, the high levels of mineralisation during the very dry period from 2018 to 2020 highlights the ability for mineralisation of nitrogen to continue with small amounts of rain. Therefore, caution must be taken following droughts and managers should not assume there will be little nitrogen available. Testing is recommended, so you know your nitrogen status and can more precisely determine nitrogen budgets for future crops.

It is important to measure plant available soil water below 90 cm prior to planting, as crops may need to access this water in a dry spring finish. Winter 2020 was heavily reliant on stored water and showed the value of deep stored moisture for finishing wheat crops. In their first crop since the Bambatsi pasture was terminated, the two ex-pasture systems had similar PAW to the Baseline at planting, but the soil below 90 cm was 20 mm drier than what wheat can extract (crop lower limit). These systems grew more biomass, but without access to water deep in the soil profile they finished with lower grain yield and harvest index and higher grain screenings.

This season also highlighted the ability of cereal crops (wheat) to extract more soil water than pulse crops (faba bean). Crop lower limits should be adjusted when budgeting for pulse crops to account for the extra water left in the soil; typically 20 mm, but can be even more in sodic or saline soils.

Acknowledgements

The team would like to thank the trial co-operator, local growers and consultants for their ongoing support and contribution to the project. Thanks also to the Grains Research and Development Corporation and the Department of Agriculture and Fisheries for funding these projects (DAQ00192 and DAQ2007-002RTX).

Trial details

Location:	Billa Billa
Crops:	Bambatsi grass, wheat, faba bean
Soil type:	Belah, Duplex
2020 rainfall:	535 mm

Billa Billa harvest, 2020.

Northern farming systems site report—Mungindi

Andrew Erbacher and Christabel Webber
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Research questions: *Can systems performance be improved by modifying farming systems in the northern grains region? | What are the trends that are expected in our farming systems? | How will these changes impact on the performance and status of our farming systems?*

Key findings

1. Root-lesion nematode (*Pratylenchus thornei*) populations doubled in the 2020 wheat and chickpea crops, increasing the risk to the next crop.
2. Stubble had a minor impact on plant available water this year. Unlike other years, the rain fell on a dry cracked soil close to planting and was stored (did not run off).

Background

Dryland farming in the western areas of the northern grains region is based around winter cropping, primarily cereals (wheat and barley) with rotation to pulses (chickpeas). There is limited summer cropping with sorghum and dryland cotton, primarily for disease control. Most farms operate on a zero or minimum tillage system with a fairly set rotation of wheat/wheat/chickpea.

Australia is a dry continent and the availability of water to the crop is the key determinant of yield. Rainfall in this region is low and highly variable. It is challenging to maintain a reliable and profitable long-term farming system.

Winter crops in south-western Queensland rely heavily on stored soil moisture from late summer rain, which is generally only sufficient to support one crop per year. Increasingly unreliable summer rainfall has reduced growers' confidence in dryland summer cropping, limiting double cropping opportunities and meaning long fallows are used when rotating between summer and winter crops.

The Farm Practices Research project commenced in 2014 and a new Northern Farming Systems project was funded in 2020 to continue the research. The Mungindi site is one of seven in the project and is located 22 km north-west of Mungindi on a Grey Vertosol soil with a plant available water capacity (PAWC) of 180 mm. The site has been cropped for over 30 years. It is representative of cropping in this dryland western region and has relatively high root-lesion nematode populations.

What was done

Consultation meetings in late 2014 and early 2015 developed five locally relevant systems to investigate at Mungindi (which was expanded to six systems in 2016). These were implemented until 2020 when the systems were reviewed and refined by a local reference group to maintain relevance for the future.

This review maintained four systems with refinement of their planting windows for some crop choices. However, one significant change was the introduction of a *Moderate crop intensity* system with a cropping intensity between the *Baseline* (which has quite a high intensity) and the two *Lower crop intensity* systems.

This *Moderate crop intensity* system replaced the *Lower crop intensity* system that previously included dryland cotton, while the cotton cropping option was included in the second system that retained the *Lower crop intensity* label.

It was also considered more logical to implement the *Higher nutrient supply* strategy to this new moderate intensity system that had higher planting soil water than the high intensity *Baseline* that it had been applied to previously. That way the higher nutrients had more scope to impact on crop performance and avoid 'burning off' crops.

The six systems from 2020 are:

1. **Baseline** represents an aggressive (high intensity) cropping system used in the Mungindi region. The area is winter cropping dominant with wheat, barley and chickpeas on a fairly set rotation of wheat/wheat/chickpea. Aggressive moisture triggers of 50 mm plant available water (PAW) are employed for all crops, with an aim to grow a crop every year. A nitrogen (N) budget is calculated on a median yield potential and applied to cereal crops as required. Phosphorus (P) is applied as starter to all crops at 4 kg of P per hectare.
2. **Moderate crop intensity** is similar to the *Baseline* system and is still focused on wheat, barley and chickpea, but is only planted when the soil profile is at least ½ full (90 mm PAW). Sorghum and cotton have been included with higher PAW triggers (150 mm) as options in a wet spring/summer. This system is investigating a middle ground between the *Baseline* (a higher intensity system) and the *Lower crop intensity* system; by planting on 90 mm PAW, the aim is to reduce the number of 'failed crops' without having to wait for an almost full profile (as in *Lower crop intensity* systems). Nutrient management is the same as the *Baseline* system.
3. **Lower crop intensity** is a conservative system that only plants when the soil profile is at least 80% full (150mm PAW). This system allows wheat, barley, chickpea, sorghum or cotton to be planted – crop choice is dictated by the most profitable option when the water trigger is met. Cover crops may be grown to manage low cover situations (<30%), and a wheat cover crop may be harvested if above average yields are expected. Nutrient management is the same as the *Baseline* system.
4. **Higher crop diversity** is investigating alternative crop options to help reduce and manage nematode populations, other soil-borne diseases and herbicide resistance. The profitability of these alternative systems is critical. A wider range of crops may enable growers to maintain soil health and sustainability as the period of continuous cropping increases. In this system, 50% of the selected crops must be resistant to *Pratylenchus thornei*, and one in four crops resistant to *Pratylenchus neglectus*. To manage herbicide resistance, two successive crops requiring herbicides with the same mode-of-action cannot be used. Crop options for this system include wheat/barley, chickpeas, sorghum, maize, sunflowers, canola/mustard, field pea, faba bean, mungbean and cotton. Nutrient strategies match the *Baseline* system with PAW triggers adapted to suit the individual crop's risk.
5. **Higher legume** is focused on improving soil fertility and reducing the amount of nitrogen fertiliser needed by growing more pulse (legume) crops. One in every two crops is a legume and the suite of crops available for this treatment is wheat/barley, chickpeas and faba beans; all based on the *Baseline* moisture triggers and nutrient strategy. Nitrogen is only applied to cereal crops.
6. **Higher nutrient supply** aims to identify the impact of fertilising for a higher yield potential, as fertiliser use is very conservative in the Mungindi region, This system has a N budget calculated for 90% of yield potential, and 100% replacement of P in a declining nutrient environment. The same crop as the *Moderate crop intensity* system is grown each year, to compare the two systems.

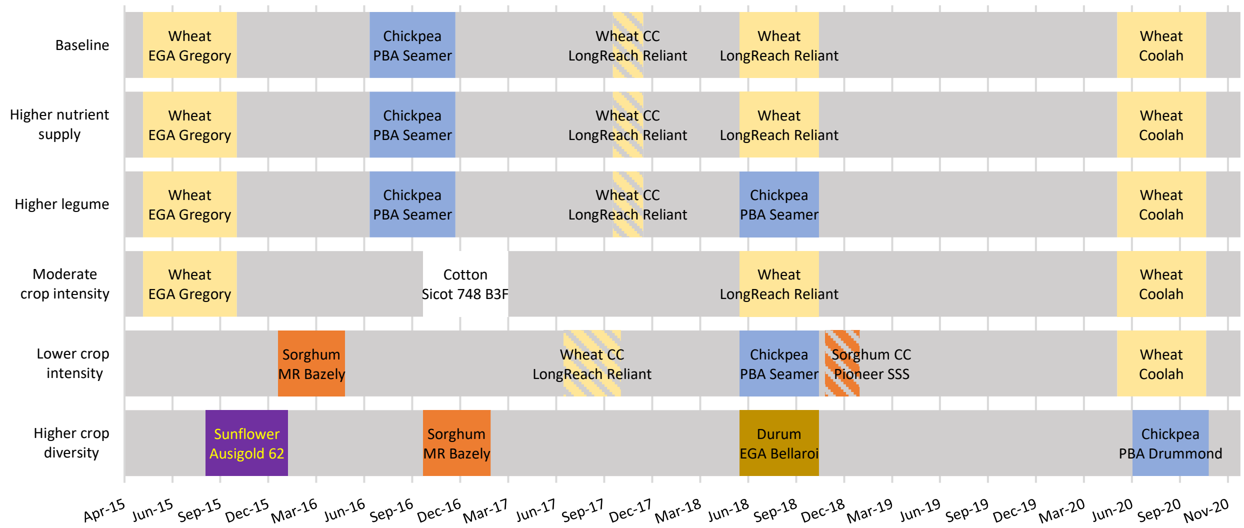

Figure 1. Crop sequences implemented at Mungindi as a consequence of implementing the system rules.
Striped segments indicate cover crops.

Results

The trial received 200 mm of rainfall in the first four months of 2020, so the whole site was planted to winter crops for first time since 2018. Only one wheat crop, a low yielding one, had been grown since 2016. So, all systems had 140 to 230 kg N/ha, enough to support yields of 3.3 t/ha to 5.4 t/ha of prime hard wheat, so no nitrogen fertiliser was required to achieve the seasons target yields based on the starting PAW.

After a long fallow from a low yielding crop in 2018, the site had low ground cover (10-30%) so wheat was planted in five of the six systems. *Baseline*, *Moderate crop intensity*, *Lower crop intensity*, *Higher legume* and *Higher nutrient supply* were planted to Coolah$^{\phi}$ wheat on 6 May 2020.

Higher legume had the least ground cover (10%) and had 80 mm PAW at planting; the other four systems planted at this time had slightly more cover (30%) with 110 mm PAW. An additional 103 mm of rainfall was received in-crop.

The *Higher crop diversity* system was durum in 2018 and had reasonable ground cover (40%). It was planted to PBA Drummond$^{\phi}$ chickpea on 4 June 2020. The chickpea had 145 mm PAW at planting and received 71 mm of in-crop rainfall.

The five systems planted to wheat in 2020 grew similar biomass (7.8 t/ha), but *Higher legume* produced a slightly lower grain yield due to its lower PAW at planting (Figure 2).

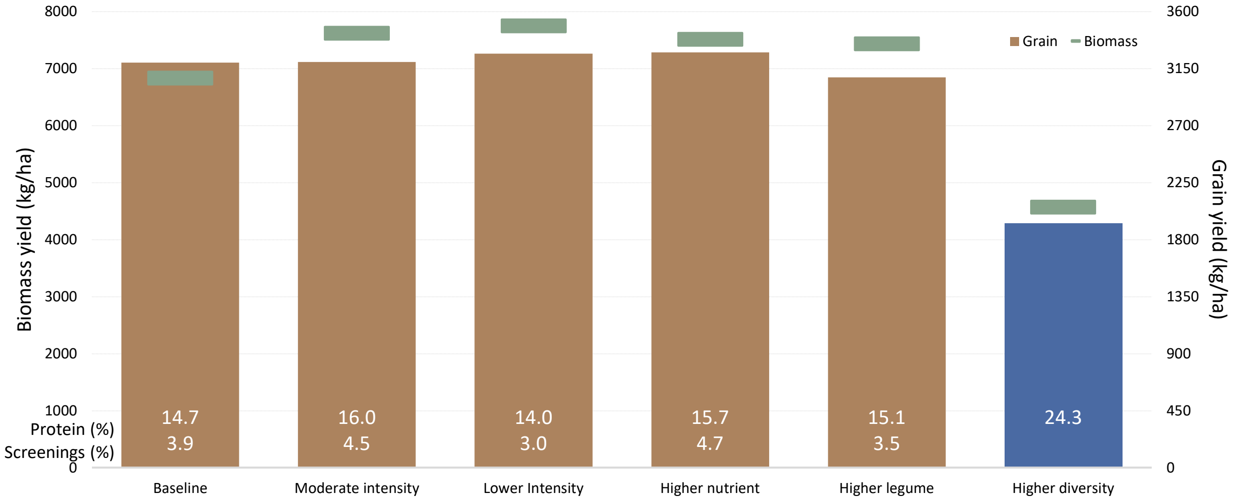

Figure 2. Crop biomass (left axis) and grain yield (right axis) of crops grown in 2020. Average harvest index (the relative difference between grain and biomass) in 2020 was 40%.

The *Baseline*, *Moderate crop intensity*, *Lower crop intensity* and *Higher nutrient supply* produced 3.2 t/ha grain, while the *Higher legume* system yielded 3.0 t/ha. With plenty of nitrogen available, grain protein and screenings were similar for these five systems that grew wheat.

The chickpeas in *Higher crop diversity* produced 4.9 t/ha of biomass and 1.9 t/ha grain yield. This was a similar harvest index and grain nitrogen (kg N/ha) removal as the wheat crops grown in the other five systems.

Using 10-year averaged farm-gate prices, the 2020 income from the chickpea was approximately $100/ha more than the wheat crops grown in this season, but gross margins were similar for wheat ($727/ha to $776/ha) and chickpea ($775/ha). This was because of the higher cost of growing chickpea (seed, herbicide, fungicide, insecticide) while the wheat required no N fertiliser.

Soil sampling at harvest showed all systems had some mineral nitrogen (nitrate-nitrogen and ammonium-nitrogen) left at harvest. Four systems with wheat (*Baseline*, *Moderate crop intensity*, *Lower crop intensity* and *Higher legume*) and the chickpea (*Higher crop diversity*) reduced mineral nitrogen by approximately 100 kg N/ha (range 95-115 kg N/ha). However, the *Higher nutrient supply* system only reduced mineral nitrogen by 56 kg N/ha despite having the same N removal in grain.

This *Higher nutrient supply* system had higher application rates of nitrogen fertiliser throughout the trial, and despite having no additional N in 2020, appears to have cycled more available N between the April and November sampling dates.

This Mungindi site had high root-lesion-nematode (*Pratylenchus thornei*, *Pt.*) at the beginning of the trial in 2015 (11-18 /g soil, Figure 3). However, dry seasons forced long fallows and reduced the *Pt* populations at planting of the 2020 winter crop.

Both wheat and chickpea are susceptible, so *Pt.* increased in all systems 1.5 to 2-fold in the 2020 crop. *Higher crop diversity* and *Lower crop intensity* grew resistant crops in 2015 and 2016 and maintained lower populations (0.4-0.6 *Pt*/g soil versus 1.6-2.6 *Pt*/g soil) through to April 2020. These two systems had also doubled their *Pt.* populations by harvest but started at lower levels and consequently remained in the low-risk category. The *Baseline*, *Moderate crop intensity*, *Higher legume* and *Higher nutrient supply* systems started at higher background levels and finished with populations in the 'medium' risk category by harvest of the 2020 crop.

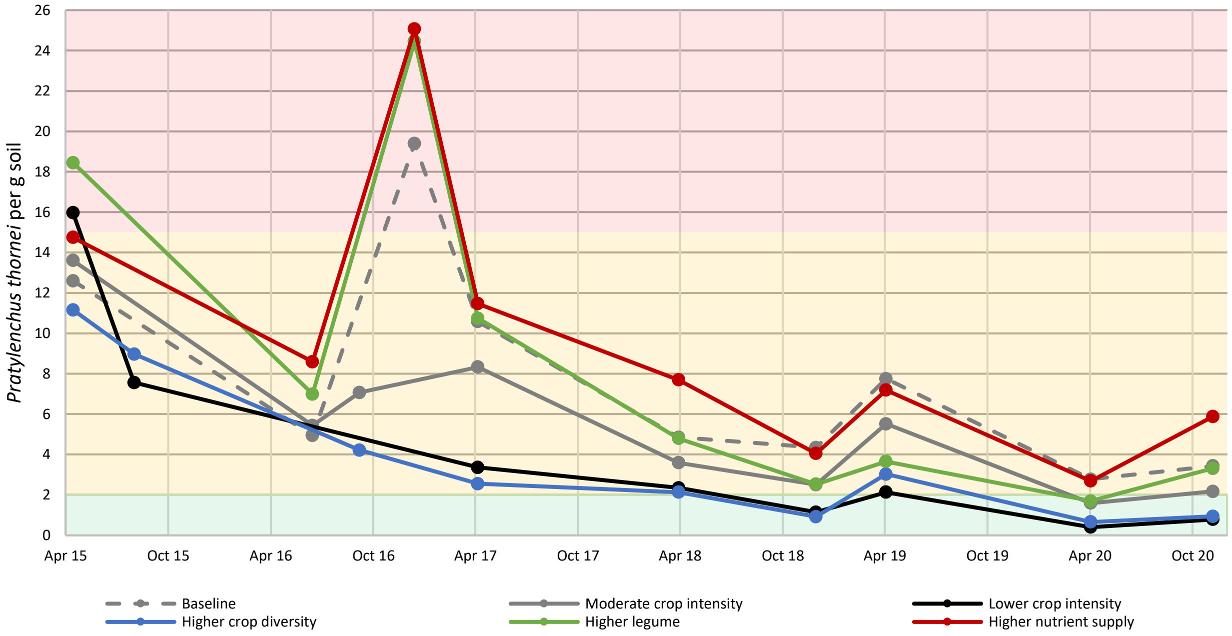

Figure 3. Root-lesion-nematodes, *Pratylenchus thornei*, per g of soil over time at the Mungindi farming systems trial. Background colours represent risk categories for yield reduction in intolerant crops; Green – low risk, Yellow – medium risk, Red – high risk.

Implications for growers

'Cover is king'. This was reinforced at the Mungindi site in 2019; wind erosion was prevalent across bare paddocks and stubble captured sand drift. However, the impact of ground cover from wheat stubble and cover crops had an unusually small impact on PAW at planting 2020.

Most of the rain in 2019-20 fell close to planting on a dry, cracked soil surface, so there was no run-off and the evaporation in autumn was low. The impact of stubble on fallow efficiency was much lower than if the rains had occurred earlier in the fallow and were exposed to evaporation. Consequently, the impact of fallow cover on grain yield was also small, especially with early in-crop rainfall.

In fallows with bare soil and large cracks, the best course of action may be to do nothing. Once the surface wets up enough to close cracks, tillage may then be needed to add surface roughness. Autumn rainfall can then be used to plant winter cereals that will restore cover to bare soil and avoid ongoing low fallow efficiencies from low cover.

It is important to know the presence and populations of pathogens in each paddock when making rotation decisions, especially on sites that have historically high root-lesion nematode (*Pt*) populations. The drought years of 2017 to 2019 at this site helped drive these populations down to a low risk. However, the crops grown in 2020 doubled the existing populations. The two systems that grew resistant crops prior to 2017 were at a much lower population after 2020 and maintained their ‘low’ risk, whereas the risk in other four systems increased to ‘medium’. Careful selection of crop sequences (and varieties), such as those seen in the *Higher crop diversity* and *Lower crop intensity* systems may have a yield benefit from reduced nematode pressure in the next season.

Acknowledgements

The team would like to thank the trial co-operator, local growers and consultants for their ongoing support and contribution to the project. Thanks also to the Grains Research and Development Corporation and the Department of Agriculture and Fisheries for funding the project.

Trial details

Location:	Mungindi
Soil type:	Grey Vertosol
2020 rainfall:	370 mm

Technical Officer Christabel Webber checking insects in chickpeas.

Soil water extraction of different crops and the legacy impacts on farming systems

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RESEARCH QUESTION: *How do previous crops in a rotation influence the soil water available to subsequent crops?*

Key findings

1. Shorter season crops can leave residual water available after shallower water extraction or late season rains.
2. Legumes such as faba bean, field pea, and chickpea often leave 20-40 mm extra residual soil water than canola and winter cereals.
3. In summer, mungbean regularly leaves 20 mm more residual soil water than sorghum/maize, and 40 mm more than cotton.
4. Higher residual water at harvest doesn't always translate into higher soil water at sowing of the next crop. Crops with higher and more resilient cover (e.g. wheat) can catch up over the fallow by capturing and storing more water than legume crops that may have low cover levels.
5. If extra residual water after harvest can be maintained, it may increase grain yields and lead to higher marginal water use efficiencies (i.e. extra yield per mm of extra soil water available). This may improve the economics of the next crop and the wider crop sequence.

Background

Soil water at sowing drives the productivity and efficiency of grain crops across many parts of Australia's cropping zone. Crops with higher plant available soil water at sowing frequently result in higher grain yields, especially when rainfall is limited around flowering.

Stored soil water has a higher marginal water use efficiency (i.e. the yield increase per extra mm of soil water at sowing). This occurs because it takes a certain amount of water to grow crop biomass before the crop uses the remaining water for grain-fill. So, the less/more available water at sowing often means there is less/more water left to efficiently convert this residual water into grain during grain filling. This impact is larger in seasons with limited in-crop rain, while the effect diminishes in wetter growing seasons when crops are likely to have enough available water. Hence, management to influence the availability of soil water for subsequent crops can have a large impact on crop yield, water use efficiency and profit.

The Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and CSIRO have been collaborating since 2015 on an extensive field-based farming systems research program focused on developing farming systems to better use the available rainfall to increase productivity and profitability. Experiments were established at seven locations; a large factorial experiment at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres (Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie). A common set of farming system strategies have been employed to examine how changes in the farming system effect multiple aspects of the farming systems' performance.

What was done?

Systems with best commercial practices (*Baseline*) at each location were compared to alternative systems; those with higher and/or lower crop intensity, higher crop diversity, higher legume frequency, higher nutrient supply and higher fertility (with the addition of organic matter).

Sites were selected to represent a range of climatic conditions, soil types, nutritional status and paddock history. Soil water was measured to a depth of 150 cm at planting and harvest of each crop at all sites.

In this report we use individual crop data collected from farming systems research projects to explore the question - How do previous crops in your rotation or sequence influence the soil water available in subsequent crops?

This is influenced by both differences in crop water extraction, which can influence the residual soil water left at harvest, and subsequent fallow water accumulation prior to sowing the next crop. Understanding how different crops influence the available water in the system for subsequent crops is also important to help design crop sequences that make better use of this limiting resource, to enable growers to tailor management (e.g. fertiliser applications or variety choices) based on previous crop history, or to avoid situations where low soil water could increase the risk of crop failure.

Results

Crop differences in residual soil water

Grain legumes often leave more residual soil water at harvest

Across a range of experimental comparisons, we have found that grain legumes such as chickpea, faba bean and field pea often leave higher residual soil water at harvest than winter cereals and canola (Table 1). However, these differences are not always consistent and vary significantly across different seasons.

It seems in dry winters with limited spring rainfall (e.g. Pampas 2015) these differences were smaller, reflecting that these crops can extract very similar amounts of soil water under water-limited conditions. However, in wetter seasons or with higher spring rainfall (e.g. Narrabri 2016, Spring Ridge 2016 and Pampas 2017), larger differences between the grain legumes and winter cereals and canola were evident. We believe this occurred because the legumes were beginning to senesce and hence reducing their water demand earlier in the spring and

Table 1 Comparisons of residual soil water post-harvest of winter crops grown in the same seasons and the subsequent impacts on plant available water at sowing and yield of following crops in the sequence.

Site – year	Crop	Residual PAW (mm)	PAW prior to next crop (mm)	Following crop (and year)	Grain yield (t/ha)
Narrabri, 2016	Chickpea	65b	140	Wheat, 2016	2.7
	Faba bean	75b	145		2.5
	Canola	70b	155		2.6
	Field pea	130a	150	-	-
Spring Ridge, 2016	Chickpea	100b	160	Wheat, 2016	3.4
	Faba bean	150a	150		3.6
	Field pea	135a	155		3.7
Trangie (Red soil), 2017	Chickpea	50	35	Barley, 2016	1.6
	Wheat	15	25		1.7
Pampas, 2015	Faba bean	75	110	Durum wheat, 2016	8.3
	Canola	65	120		8.4
Pampas, 2017	Wheat	-10	140	Wheat, 2020	3.4
	Chickpea	95	160		4.3
	Field pea	100	170		4.2
Pampas, 2015	Wheat	70	200	Sorghum, 2016	7.2
	Canola	85	220		7.3
	Chickpea	60	200		7.5
	Faba bean	75	200		7.7
	Field pea	80	185		7.6

not utilising soil water during this period to the same extent. For example, in one comparison on the Pampas site in 2017, the legumes (faba bean and chickpea) had around 100 mm more soil water after harvest than wheat.

Legumes don't always provide more water in subsequent crops

While we regularly found more soil water left after grain legumes compared to wheat or canola, this rarely translated into significantly higher soil water prior to planting the next crops, nor significant crop yield benefits (Table 1). Across our experiments, up to 50 mm more soil water was left after grain legumes. However, the lower efficiencies of water accumulation during the subsequent fallow meant that differences in soil water diminished. This occurred because drier soil profiles were less prone to evaporative losses of this water, and because better residue cover enhanced rainfall infiltration following winter cereals compared to the lower and shorter-lived ground cover left after grain legumes.

Amongst six experimental comparisons here, we have only once seen higher residual soil water at harvest translate into significantly more soil water available in the subsequent crop (Table 1). In this case (Pampas 2017), grain legumes had over 100 mm more soil water after harvest, but by the sowing of the subsequent wheat crop, this difference was reduced to only 20-30 mm. Nonetheless, in this case this additional soil water translated into a yield benefit of 0.8-0.9 t/ha. In all other cases, there were no significant yield differences in subsequent crops that could be attributed to soil water at sowing.

Summer crop comparisons

The research also highlighted some differences in the impact of summer crops on their residual soil water at harvest and the available water at planting of the subsequent crops (Table 2). Two direct comparisons between cotton and a summer cereal (maize or grain sorghum) showed cotton leaving the soil around 20-30 mm drier. Because of the lower ground cover after cotton, this difference has been preserved until the sowing of the subsequent crop; in both short and long fallows. This resulted in significant yield differences of 0.7 and 1.2 t/ha in the subsequent sorghum crops. Our data also suggests that mungbean can leave additional soil water compared to sorghum, though this can depend on the relative timings of the crops. As with the winter grain legumes, this rarely translated into significantly more soil water prior to planting a subsequent crop.

Long-term predictions of residual water (crop comparisons)

While our experimental results provide a diverse range of seasonal and production environments, it is likely that the residual water left by different crops will be highly influenced by seasonal conditions and timing of rainfall. Hence, we have used APSIM to predict over 100 different seasons (1915-2015) how wheat, canola and chickpea compare in terms of residual soil water at Goondiwindi (Figure 1). These predictions support our observed experimental data, with chickpea leaving 20-30 mm more soil water at harvest than wheat and canola in 3 out of 5 years. These differences are smaller under the wettest 20% of seasons where large rainfall events at harvest replenish soil water in the profile in all crops. Differences are also small in the driest 20% of seasons when crops use most of the water available.

Table 2 Comparisons of residual soil water post-harvest of summer crops grown in the same seasons and the subsequent impacts on plant available water at sowing and yield of following crops in the sequence.

Site – year	Crop	Residual PAW (mm)	PAW prior to next crop (mm)	Following crop and year	Grain yield (t/ha)
Pampas, 2016	Maize	150	150	Sorghum, 2017	5.5
	Cotton	120	120		4.8
Pampas, 2018	Sorghum	-6	130	Sorghum, 2020	3.7
	Cotton	-21	100		2.5
Pampas, 2017	Sorghum	20	100	Mungbean, 2019	1.6
	Mungbean	30	100		1.1
Pampas, 2018	Sorghum	-20	20	Mungbean, 2019	0.58
	Mungbean	0	30		0.60

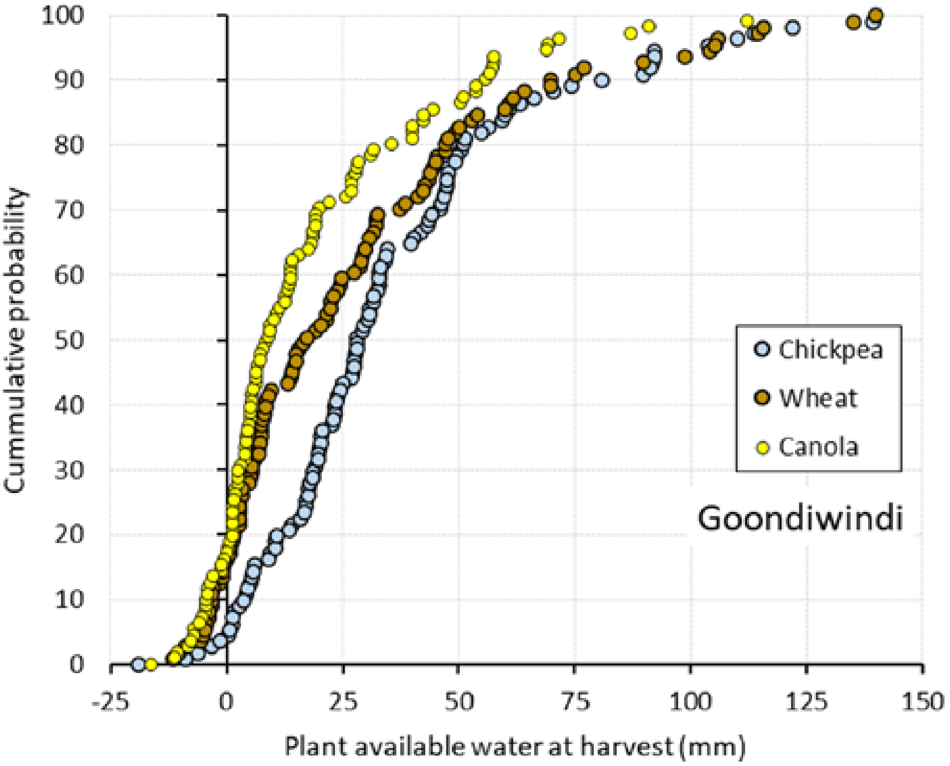

Figure 1. APSIM estimated plant available water at harvest of wheat, chickpea and canola at Goondiwindi over 100 years from 1915 to 2015.

Implications for growers

This analysis has shown the differences in soil water left at harvest of different crop types, which should be accounted for when calculating water use efficiency of these crops.

However, this work has also shown that we should not assume that extra water is still available at planting of the next crop. The effect of stubble loads left by the different crops will have an influence on how efficiently the fallow rainfall is captured for use in the subsequent crop. The cereals typically leave more stubble cover for longer and so capture and store more soil water over the fallow.

Tools such as CliMate or SoilWaterApp give good estimates of these soil water differences at the end of the fallow, providing the cover levels are set appropriately; validation (i.e. with a push probe) is also advisable, especially after long fallows.

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 Grains Research and Development Corporation (CSA00050, DAQ00192, DAQ0007-002RTX), the authors 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.

Water use efficiency is improved by storing more water before planting

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Research question: *How does plant available soil water impact on water use efficiency (WUE) and crop performance?*

Key findings

1. Growing biomass before crops produce grain has a 'water cost' that should be deducted from crop water use to calculate water-use-efficiency (WUE). In the farming systems trials to date, this has been at least 50 mm for chickpea, 100 mm for wheat and 150 mm for sorghum.
2. The WUE was lowest for chickpeas (10 kg/mm); sorghum and wheat returned the same WUE (17 kg/mm).
3. Crops produced a better than average WUE when planted with at least 60 mm PAW in a high in-crop rainfall season, or 120 mm of PAW with low in-crop rainfall.

Background

Soil water accumulation in fallow periods and the efficient use of plant available water (PAW) by crops are key drivers of productivity and profitability in northern farming systems. Stored fallow water provides a buffer for more reliable grain production with our highly variable rainfall. Indeed, crops yields in Queensland and northern New South Wales have typical fallow dependency (i.e. proportion of transpired water from fallowed PAW) of 26% to 82%, so increasing stored water will normally increase crop yields proportionally.

In March 2015, a series of seven experiments were established by the Queensland Department of Agriculture and Fisheries (DAF), CSIRO, the New South Wales Department of Primary Industries (NSW DPI) and the Grains Research and Development Corporation (GRDC) to compare farming systems and crop sequences at Pampas, Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie. A common set of farming system strategies was employed to examine how changes in the farming system (to address the challenges of our ageing system), would impact on overall farming system performance and the factors that drive it.

These sites cover a range of climatic conditions, soil types, nutritional status and paddock history, and compare the best commercial practices (*Baseline*) for each location to alternative systems with higher or lower crop intensity, higher crop diversity, higher legume frequency, higher nutrient supply and higher fertility through the addition of organic matter. The rules around each of these systems have driven crop sequences with a range of different crops and planting and growing conditions at each site. Of particular interest here, is the comparison of systems with different cropping intensities based on the amount of PAW accumulated before crops are planted, which changes the contribution of stored PAW to crop water use and yields. Key comparisons include; the *Baseline* (moderate intensity) planted on 60% plant available water capacity (PAWC), *Higher crop intensity* planted on 30% PAWC and *Lower crop intensity* planted on 80% PAWC.

What was done

These farming systems projects include assessments of the 'overall system water use efficiency' for each crop sequence, which is driven by the efficiency of fallows (i.e. the proportion of rain falling during the fallow that accumulates in the soil to be available for the next crop) and how efficiently the subsequent crops can convert the accumulated soil water and in-crop rainfall into grain or product.

Soil sampling at the sites was conducted prior to planting each crop, and after harvest to measure soil water, nitrogen and pathogens (PREDICTA® B). This soil sampling process allowed soil water accumulation in fallows and use by the subsequent crop to be tracked over five years. With crop data (biomass and grain yield) and on-site weather data fallow efficiency (FE; = ΔSoil water / Rainfall), crop water use (WU; = ΔSoil water + in-crop rainfall), and crop water use efficiency (WUE; = grain yield / Crop water use) was calculated for individual crops and therefore their impact on the farming system. Ultimately, the crop water use, water use efficiency and subsequent fallow water accumulation has been calculated for over 300 different crops over the life of the project to explore how soil water accumulates and is used over different crop sequences.

The relationships between biomass and grain yield to PAW at planting, WU and WUE were analysed for wheat (67 crops), sorghum (56 crops) and chickpea (45 crops). Minor crops were excluded from the analyses. Biomass and grain yield was plotted against crop water use and fitted with a linear regression; the slope being the average WUE. Similarly, grain WUE was calculated for individual crops and the 25% of crops with the highest WUE were fitted with a linear regression to calculate the potential WUE.

Results

Crop biomass WUE

The relationship between biomass (total above-ground dry matter at physiological maturity) and crop water use (i.e. $PAW_{planting} - PAW_{harvest} + Rainfall_{incrop}$) shows all three crops have an intercept around zero and the slope of these linear relationships gives us their WUE_{DM} (Figure 1). The most efficient was wheat with a WUE_{DM} of 29.3 kg/mm, followed by sorghum with a WUE_{DM} of 23.3 kg/mm. Physiological differences between C3 and C4 grasses (i.e. temperate wheat and tropical sorghum) suggest C4 grasses should be more efficient with a higher WUE of transpired water than C3 grasses. However, our data is for the whole farming system and includes all crop water use (both transpiration and evaporation), and so the lower WUE of sorghum is likely due to greater evaporative losses and/or evaporative cooling by the sorghum in the hotter growing conditions of summer. The chickpea crops had the lowest WUE_{DM} of 18.0 kg/mm, as expected of legumes compared to grasses.

Grain water use efficiency

In contrast to biomass, the relationship between grain yield and crop water use for each crop showed a critical water requirement before grain yield accumulated. These shifts

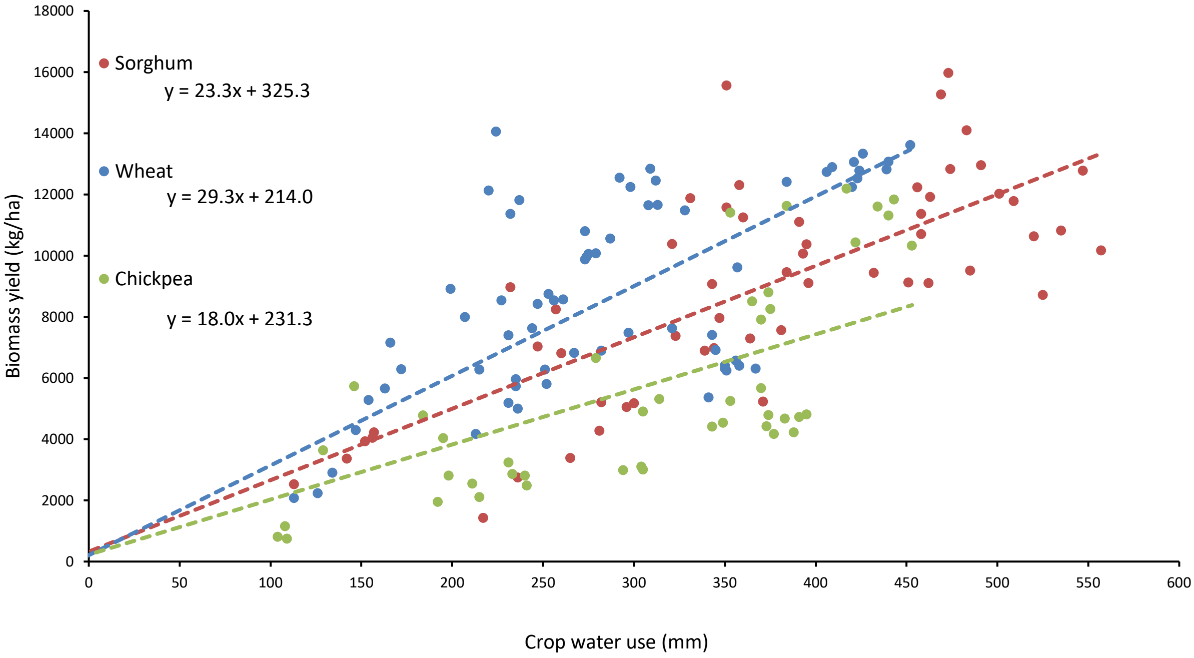

Figure 1. Predicted WUE_{DM} using maturity biomass yield of sorghum, wheat and chickpea crops against the amount of water used (PAW + rainfall).

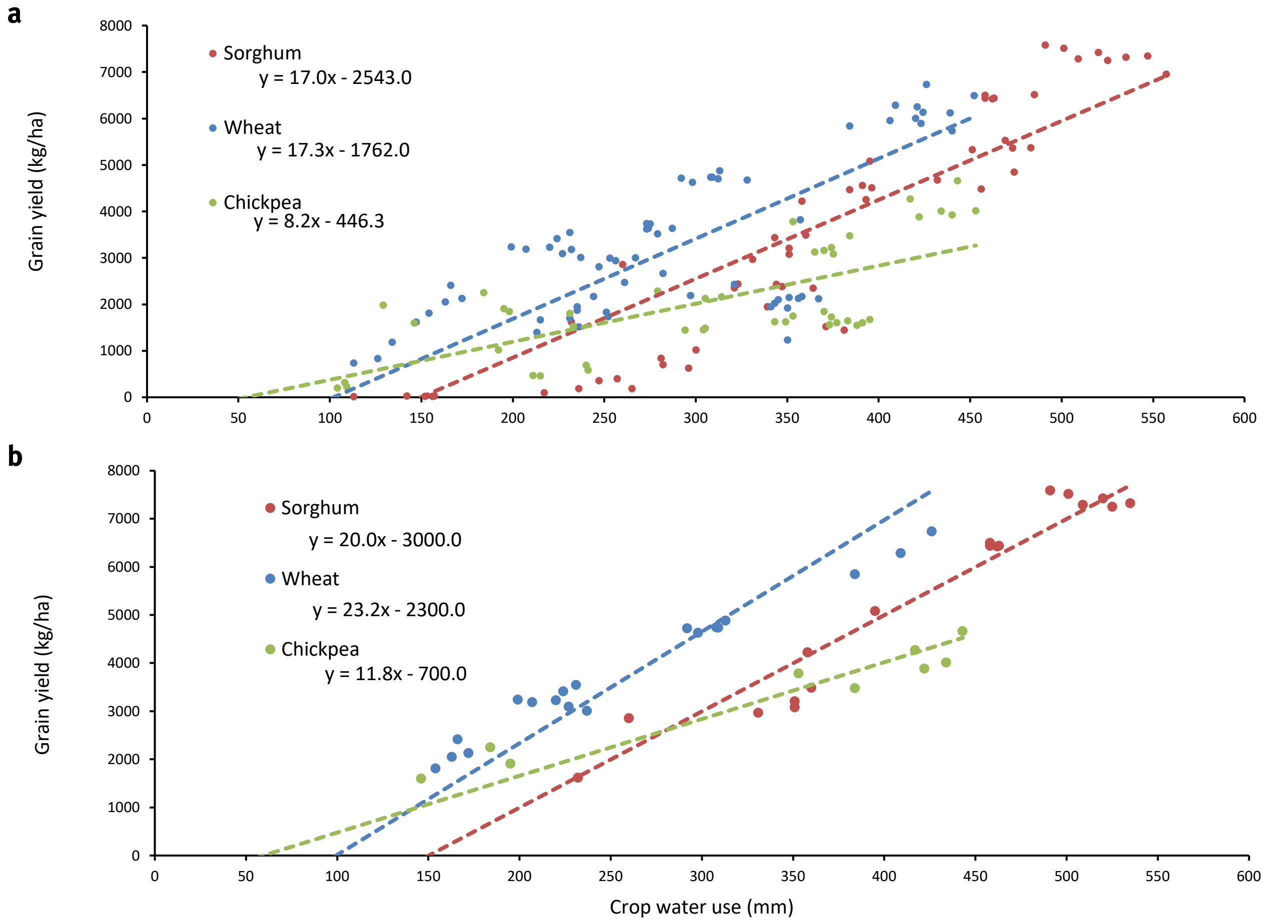

Figure 2. Grain yield of sorghum, wheat and chickpea crops with different amounts of crop water use. Figure 2a includes all crops and Figure 2b is the top 25% for WUE ('best'). The slope of the trendlines represents the WUE.

in the intercepts on the X-axis of ~50 mm for chickpea, ~100 mm for wheat and ~150 mm for sorghum (Figure 2) show how much crop water use was needed before grain was produced. The slope of the resulting trendlines provide each crop's subsequent water use efficiency (WUE_{grain}), calculated by first deducting the intercept (50 mm, 100 mm or 150 mm) from the total crop water use.

Despite the 50 mm difference in initial water demand, wheat and sorghum then had a similar average WUE_{grain} (17.3 and 17.0 kg/mm, Figure 2a). This suggests that once the initial demand is met, these winter and summer cereals were able to produce grain yield with similar water use efficiency.

Chickpea had a lower initial water demand to start producing grain and a lower subsequent WUE_{grain}. The indeterminate reproduction of chickpea that continually produces flowers and pods as it accumulates biomass explains its lower demand prior to grain-fill, compared to cereals that invest resources to build biomass before converting to grain yield. Chickpea's lower WUE_{grain} may result from its need to support the symbiotic relationships with rhizobia to produce nitrogen and the higher concentration of nitrogen in the legume grain. In fact, the relationship between grain N removal (kg N/ha) and crop water use is very similar for wheat and chickpea (data not shown).

WUE of the best crops (Figure 2b) compared to average WUE of all crops (Figure 2a), suggests potential to improve the grain WUE of sorghum by 3 kg/mm, wheat by 5.9 kg/mm and chickpea by 3.6 kg/mm. Importantly, the range of performance occurred across the full range of seasonal grain yields. This suggests other factors, such as disease, nutrients, agronomy, heat/cold stress, are reducing the yield potential of many crops.

Soil water at planting is a driver of crop WUE

WUE is an accepted indicator of the link between grain yield and crop water use. The value of stored PAW at planting is also well recognised across the northern grains region as a management tool to influence crop selection, reliability and grain yield. As such we looked at the relationship between PAW at planting and WUE of each crop (Figure 3). Each crop has been plotted in relation to a proposed 'best' WUE.

Crops with low PAW at planting have a much higher reliance on quantity and timeliness of in-crop rainfall. In this data all crops with less than 60 mm PAW at planting demonstrated lower WUE. When planted with 60 to 120 mm PAW there was an even spread of high and low WUE across all three crop types, suggesting this is sufficient buffer to support the crops between in-crop rainfall events. However, these crops had a greater chance of failure, with low WUE and low grain yields when in-crop rainfall was low.

The optimum PAW at planting for each of the three crops was slightly different. Chickpea crops with the best WUE had 70 mm to 170 mm of PAW at planting, while the best wheat crops were planted with 110 mm to 160 mm PAW. The best sorghum crops were planted with more than 120^+ mm PAW and had no downside when there was more PAW at planting; more PAW as better!

Implications for growers

The first five years of the Northern Farming Systems project show clear trends in the capacity of crops to convert available water into biomass and grain. In all crops there was a crop water use cost in converting crop biomass into grain yield, suggesting it is appropriate to subtract this value from the crop water use prior to calculating water use efficiency.

Chickpea had the lowest water cost for biomass as it accumulates yield and biomass simultaneously. In contrast, cereals may use all the available water on biomass and fail to produce any grain in very dry seasons. The resulting WUE of grain yield was similar for sorghum and wheat, and lower for chickpea. However, gross margins were not considered, so growers still need to consider the underlying return for their total rainfall ($/mm)

Ultimately, the research highlights the advantage of storing at least 60 mm of PAW prior to planting chickpeas, 110 mm for wheat and 120 mm for sorghum. In dryer environments or seasons with less in-crop rainfall, PAW provides a greater contribution to total crop water use, so delaying planting until there is more than 120 mm of PAW will further reduce the risk of crop failure.

Acknowledgements

This research (CSA00050, DAQ00192, DAQ2007-002RTX) was made possible by the significant contributions of trial cooperators, farm and field staff and the Grains Research and Development Corporation.

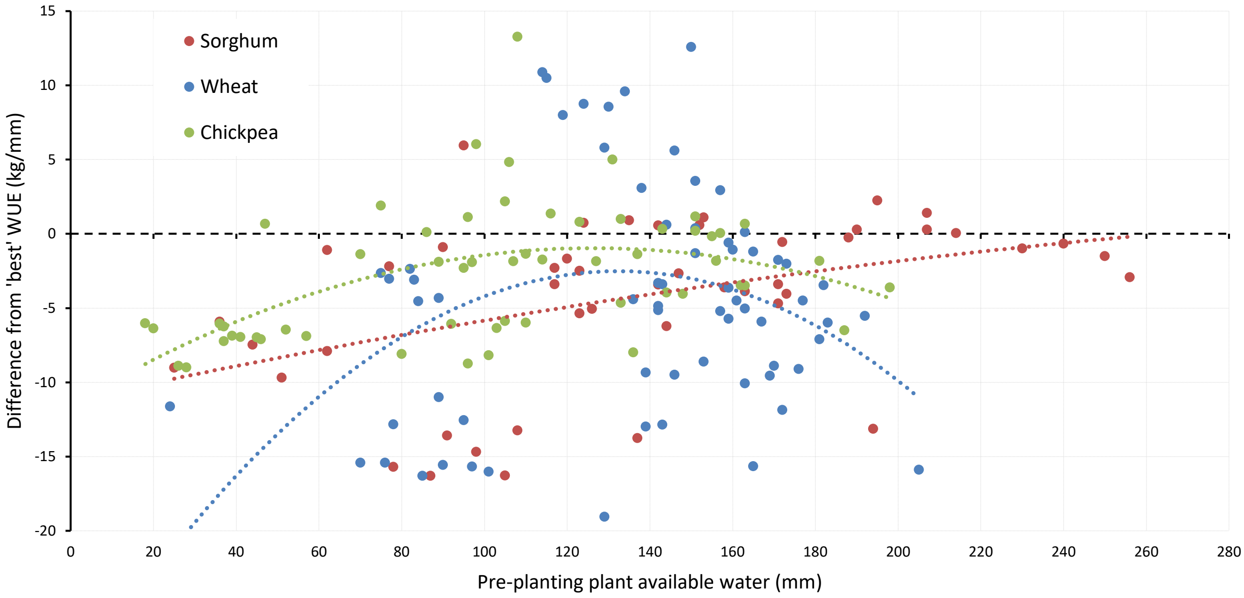

Figure 3. Difference from 'best' WUE (determined in Figure 2b) of sorghum, wheat and chickpea crops with different amounts of PAW at planting.

Pathogen monitoring is important for farming systems—Pampas, Darling Downs

Nikki Seymour
Queensland Department of Agriculture and Fisheries

Research question: *How have different farming systems impacted pathogen and arbuscular mycorrhizal fungi (AMF) levels in soil over a five-year trial period at the Farming Systems trial site at Pampas?*

Key findings

1. Pathogen presence shows the potential risk of developing a disease, but a suitable host and environment are required to complete the disease triangle for disease expression.
2. Enforced fallow can be your friend by lowering soil and stubble-borne pathogens. However, growth of susceptible hosts in following seasons with favourable conditions can quickly build pathogen loads up to damaging levels.
3. Of the pastures grown, snail medic/burgundy bean increased root-lesion nematode populations by 1.5 times, whereas grass pastures of Bambatsi/Rhodes mix decreased these nematodes by approximately one-third over the four years.
4. Arbuscular mycorrhizal fungi (AMF) levels following cropping were high with AMFa dominating at this site. However, levels reduced by 50% following just one season of fallow (8–10 months).
5. PREDICTA® B DNA-based soil test is an effective method to monitor pathogen build-up and select appropriate crop species and varieties.

Background

Farming systems trials have been conducted since 2015 at one core site (Pampas) and six regional sites from Central Queensland to central New South Wales. This research aims to explore the changes in farming systems that enable further increases in system efficiency and examine key issues where current systems may be underperforming. This report focuses on the Pampas site.

Pathogens are a constraint to productive systems and therefore require monitoring and careful management to minimise their impacts. Tolerant and/or resistant crops and varieties can be used to manage pathogens, and it should be noted that presence of the pathogen does not necessarily mean the disease will be expressed and cause production losses. All three aspects of the disease triangle (pathogen, host and the right environment) need to be present for disease to be expressed.

Arbuscular mycorrhizal fungi (AMF) are common in cropping soils as they colonise the roots of most plant species and aid in the uptake of nutrients, particular phosphorus (P) and zinc (Zn). AMF require a host plant to complete their life cycle and propagate. Consequently, fungi levels decline during fallow periods and can lead to a crop condition called 'Long Fallow Disorder', where root colonisation by the fungi is reduced due to depleted levels in soil. The plants become P or Zn deficient.

What was done

The Farming Systems trial site at Pampas has 38 systems across summer, winter and mixed systems. These were established in 2015 with first crops sown in winter across all plots. PREDICTA® B DNA-based soil test samples were collected from 0-30 cm for all plots to give a starting level of soil pathogens and AMF, and subsequent samples were collected at the start and finish of each crop (pre-plant and post-harvest) to assess stubble and soil-borne pathogen dynamics. Pre-determined protocols for the trial dictated crop and variety choice to reflect best practice for each situation/system (Table 1).

Table 1. Crop sequences for various systems imposed at the Pampas Farming Systems site.

System		Summer 14/15	Winter 15	Summer 15/16	Winter 16	Summer 16/17	Winter 17	Summer 17/18	Winter 18
Baseline	summer	x	wheat	x	x	maize	x	sorghum	x
(Baseline) High crop competition		x	wheat	x	x	maize	x	sorghum (high pop)	x
+ nutrient supply		x	wheat	x	x	maize	x	sorghum	x
+ legume		x	faba bean	x	x	maize	x	mungbean	x
+ crop diversity		x	wheat	x	x	cotton	x	sorghum	x
+ crop diversity + nutrient		x	wheat	x	x	cotton	x	sorghum	x
+ crop diversity + legume		x	faba bean	x	x	cotton	x	mungbean	x
+ cover crop		x	chickpea	x	oat CC	sorghum	oat/vetch CC	sorghum	x
- crop intensity		x	x	maize	x	mung	x	x	x
Baseline	mixed	x	wheat	x	x	sorghum	chickpea	x	x
Baseline B		x	wheat	x	x	sorghum	chickpea	x	x
+ nutrient supply		x	wheat	x	x	sorghum	chickpea	x	x
+ legume		x	faba bean	x	x	sorghum	chickpea	x	x
+ crop diversity		x	canola	x	x	sorghum	chickpea	x	x
+ crop diversity + nutrient		x	canola	x	x	sorghum	chickpea	x	x
+ crop diversity + legume		x	field pea	x	x	sorghum	chickpea	x	x
+ crop intensity		x	wheat	mungbean	x	sorghum	chickpea	sorghum	x
+ crop intensity + nutrient		x	wheat	mungbean	x	sorghum	chickpea	sorghum	x
+ crop intensity + legume		x	faba bean	mungbean	x	sorghum	chickpea	sorghum	x
+ crop intensity + crop diversity		x	canola	mungbean	x	sorghum	durum	sunflower	x
+ crop intensity + crop diversity + nutrient		x	canola	mungbean	x	sorghum	durum	sunflower	x
+ crop intensity + crop diversity + legume		x	field pea	mungbean	x	sorghum	chickpea	sunflower	x
+ cover crop		x	chickpea	x	x	sorghum	wheat	x	x
- crop intensity		x	wheat	x	x	cotton	wheat	x	x
Baseline A	winter	x	wheat	x	chickpea	x	wheat	x	x
Baseline B		x	wheat	x	chickpea	x	wheat	x	x
+ nutrient supply		x	wheat	x	chickpea	x	wheat	x	x
+ legume		x	faba bean	x	wheat	x	chickpea	x	x
+ crop diversity		x	canola	x	durum	x	chickpea	x	x
+ crop diversity + nutrient		x	canola	x	durum	x	wheat	x	x
+ crop diversity + legume		x	faba bean	x	durum	x	field pea	x	x
+ cover crop		x	wheat	x	chickpea	x	wheat	x	x
- crop intensity		x	wheat	x	x	x	chickpea	millet CC	x
+ grass ley	pasture	Bambatsi/Rhodes					x	x	
+ grass ley + nutrient		Bambatsi/Rhodes + N fertiliser				x	x		
+ grass ley pasture + legume		Bambatsi/Rhodes + burgundy bean/snail medic			x	x			
+ legume pasture		snail medic/ burgundy bean				x	x		
fallow		x	x	x	x	x	x		

Results

The significant pathogens detected at the Pampas site were *Pratylenchus thornei*, *Macrophomina phaseolina*, *Pyrenophora tritici-repentis, Fusarium pseudograminearum* and multiple other *Fusarium* sp. Arbuscular mycorrhizal fungi (AMF) levels in soil were also assessed to follow changes due to particular systems, crop species and fallow periods.

Root-lesion nematodes (RLN)

Root-lesion nematodes(RLN; *Pratylenchus thornei*) are present at the site at Pampas. No *Pratylenchus neglectus* have been found there. Populations at the start of the trial were mostly at moderate levels (between 4-8 nematodes per gram of soil), where there is a medium risk of damage/yield loss to susceptible and intolerant crops.

Summer systems

All systems (except *Summer dominant - lower intensity* system) were planted to a winter crop in 2015, which built numbers of RLN in the soil. However, nematodes in all systems were reduced by 2018 to near or equal those in the permanent fallow. Growing sorghum and cotton (non-hosts) in the summer rotations kept *Pratylenchus thornei* numbers relatively low (Figure 1). Mungbean are hosts of *P. thornei*, so systems where they were grown, (e.g. the *Summer dominant + higher diversity + higher legume* system shown below) are approximately double the level of the completely fallow treatment or where sorghum was grown; they remained higher than others even after almost two years of fallow. Mungbean grown in 2019–20 increased the RLN numbers from a low to medium risk level in most cases.

Winter systems

The winter system of wheat-chickpea-wheat used in the *Baseline* systems are certainly the ones to watch for building RLN numbers. They have a high level of nematode risk (Figure 2). Chickpea (HatTrick$^{\text{⟨D⟩}}$) after wheat did not build numbers of nematode as much as the wheat (LRPB Gauntlet$^{\text{⟨D⟩}}$) after chickpea or faba bean. Diversity in cropping with some non-hosts including canola and durum clearly reduced *P. thornei* numbers. However, just one wheat crop then doubled populations again. The lack of planting in winter 2018 onwards reduced levels for all treatments but those with previous wheat and chickpea still remained slightly higher than others.

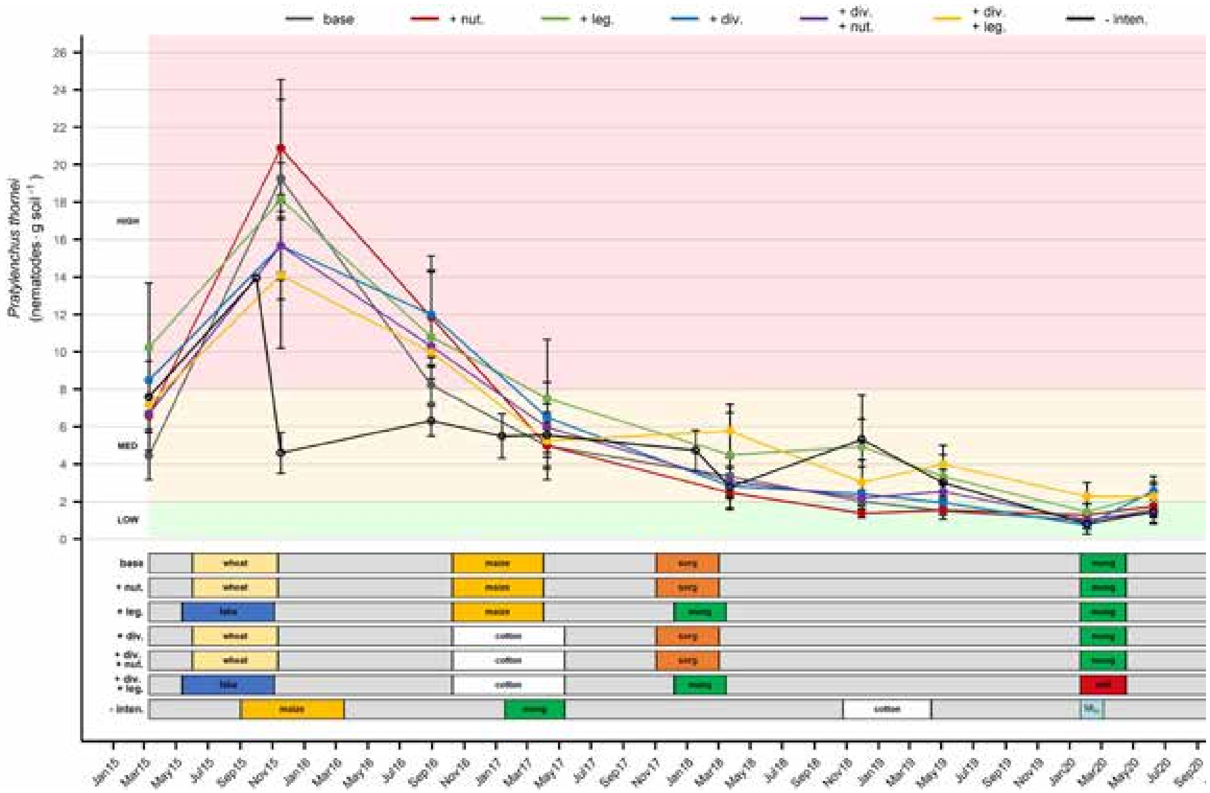

Figure 1. ***Pratylenchus thornei*** **(nematodes/g soil) in summer systems 2015-2020.**
Error bars represent standard errors for four replicates.

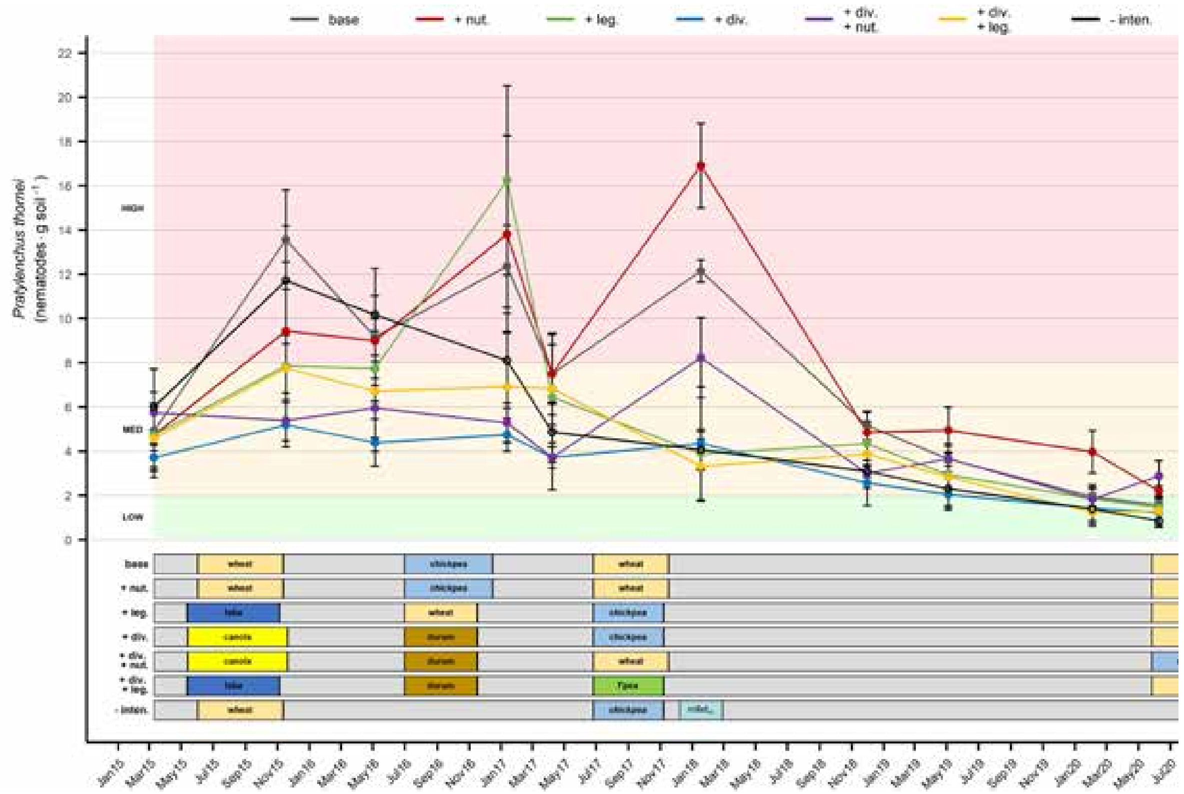

Figure 2. ***Pratylenchus thornei*** **(nematodes/g soil) in selected winter systems 2015-2020.**
Error bars represent standard errors for four replicates.

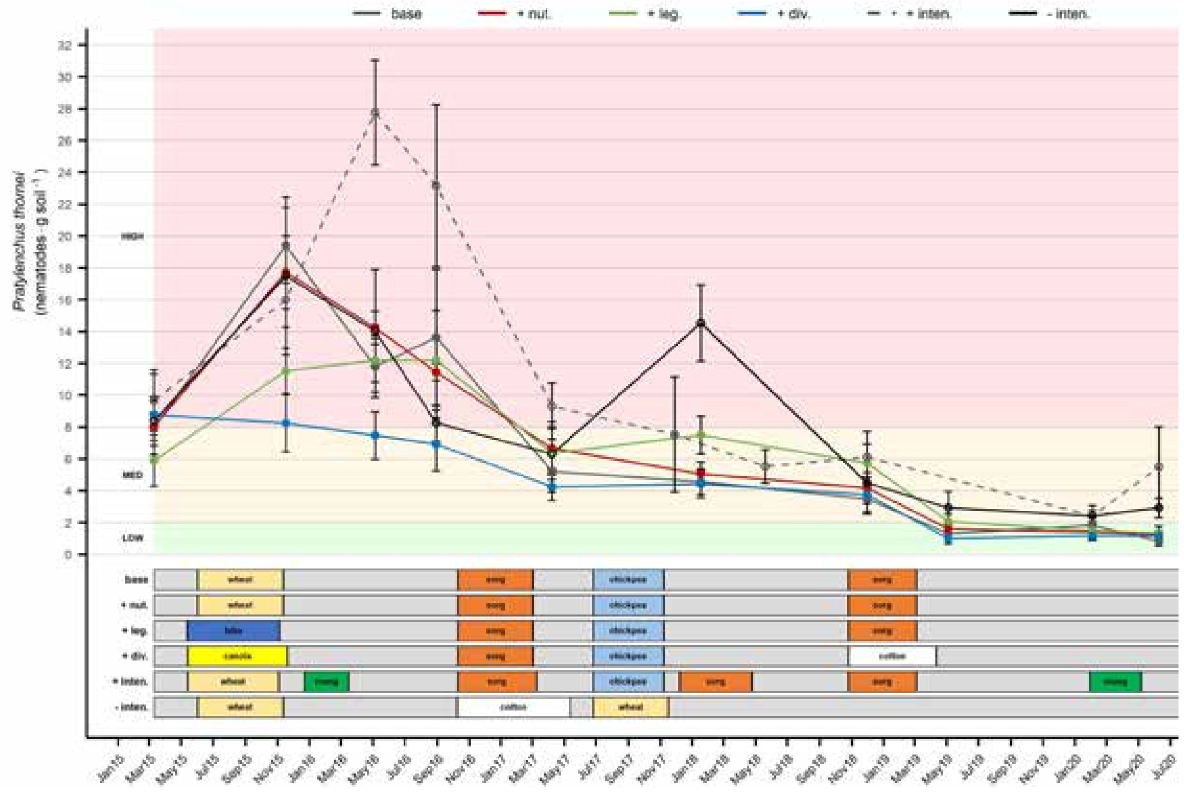

Figure 3. ***Pratylenchus thornei*** **(nematodes/g soil) in selected mixed systems 2015-2020.**
Error bars represent standard errors for four replicates.

Mixed systems

The levels of RLN peaked in the mixed systems that contained their strong hosts; wheat (Figure 3) and mungbean. However, these RLN populations declined in all mixed systems with extended fallows, or when sorghum was grown.

The permanent fallow treatment in the trial also reduced numbers from medium levels at the start to low over the full five years; the systems with no recent wheat declined to near that permanent fallow level.

Pastures and fallow

The grass only (Bambatsi and Rhodes grass mix) and grass + legume (Bambatsi/Rhodes + burgundy bean/snail medic) plots that became grass dominated over the three years they were grown, followed a similar decline in RLN levels to the fallow plots (Figure 4); neither of the grass species used in this ley were hosts of *P. thornei*. However, there was a 50% increase in numbers under the legume only (burgundy bean/snail medic) plots as both are *P. thornei* hosts.

Charcoal rot (*Macrophomina phaseolina*)

Testing for charcoal rot (*Macrophomina phaseolina*) demonstrated that mungbean are a strong host of the pathogen. The levels of *Macrophomina* in the soil went from low to high risk in just one mungbean crop in selected mixed systems (Figure 5). Care will be needed to ensure the next crop after the mungbeans is not also susceptible. For example, high levels were recorded in summer systems when sorghum after maize, or mungbean after maize/cotton were grown. These high levels dropped rapidly during the fallow that followed.

Yellow leaf spot (*Pyrenophora tritici-repentis*)

Significant levels of *Pyrenophora tritici-repentis*, the pathogen that causes yellow leaf spot (YLS) built up under the diverse winter systems that included durum wheat (Figure 6). The system with durum in 2016 followed by wheat in 2017 remained higher than systems with chickpea in 2016 and wheat in 2017. The highest levels recorded (between 2 and 2.5) were in the 2016 winter and are considered medium. These systems would certainly be ones to watch if winter cereals are grown in the wetter years when YLS is most commonly expressed. In contrast, the levels of *Pyrenophora* dropped right off in the *Winter dominant + higher legume* system when the wheat in winter 2016 was followed by chickpea in the following winter.

Arbuscular mycorrhizal fungi (AMF)

High levels of AMF fungi are desirable in cropping systems; AMF helps crops take up P and Zn, particularly if soil P and Zn levels are low. At the Pampas site, P and Zn were both very high and so the importance of AMF in the systems is less significant. However, AMF levels did increase during cropping with hosts and then declined by approximately 50% in extended fallow periods (Figures 7 and 8). AMF require a living host to reproduce hence the longer the fallow the greater the decline.

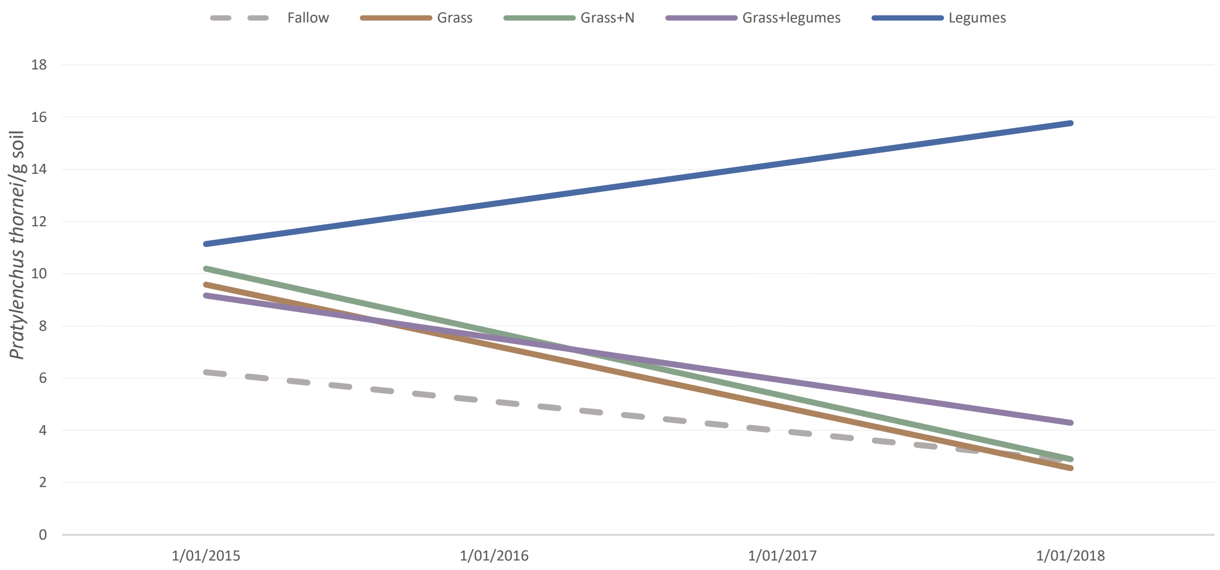

Figure 4. *Pratylenchus thornei* (nematodes/g soil) in pasture systems 2015-2018.

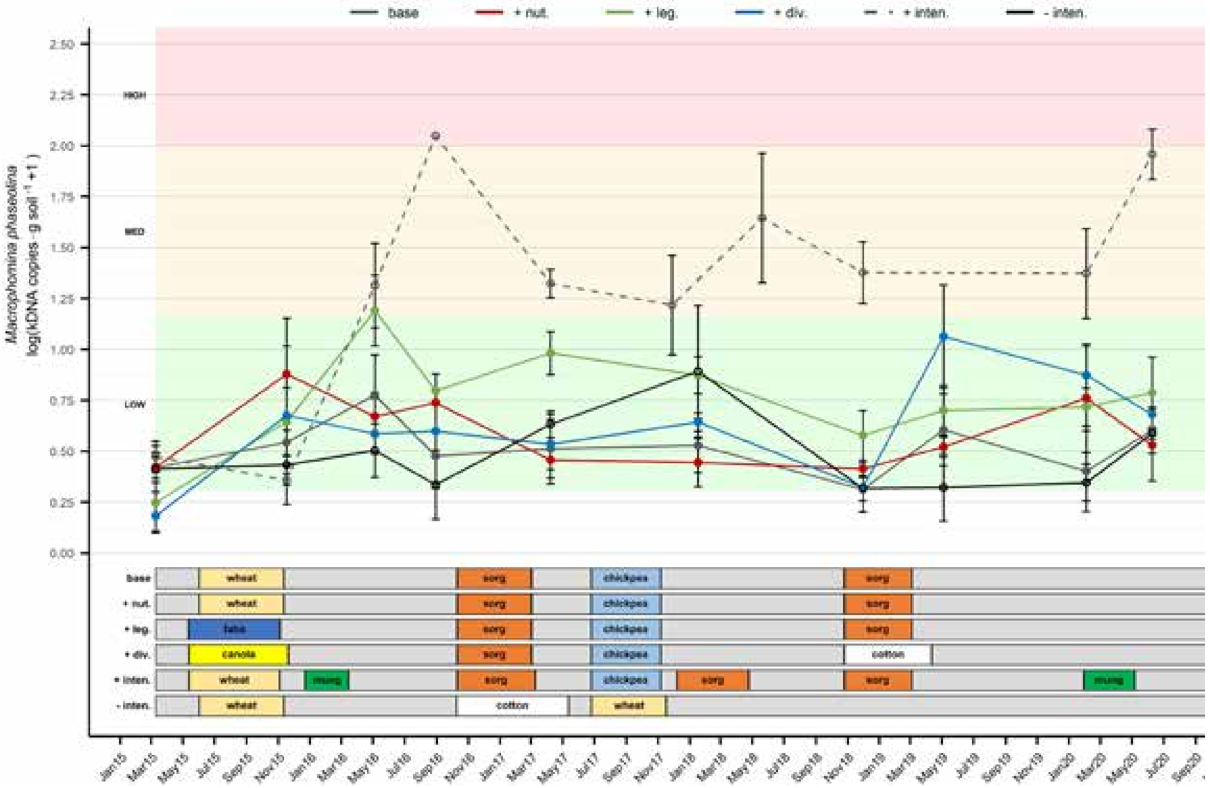

Figure 5. Levels of *Macrophomina phaseolina* (causing charcoal rot) in selected treatments from the mixed systems 2015-2020.

Error bars represent standard errors for four replicates.

Figure 6. Levels of *Pyrenophora tritici-repentis* (causing yellow leaf spot) in the winter cropping systems.

Error bars represent standard errors for four replicates.

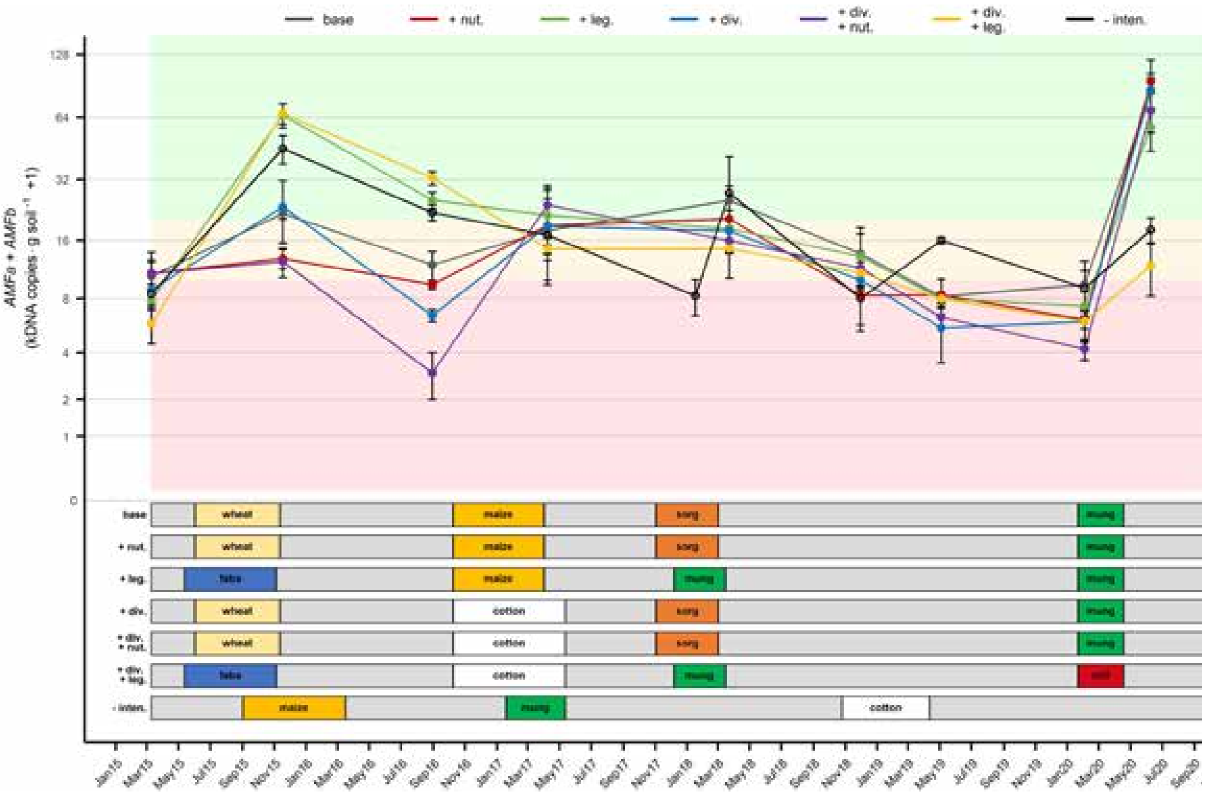

Figure 7. Total levels of AMFa and AMFb found in selected summer farming systems.
Error bars represent standard errors for four replicates.

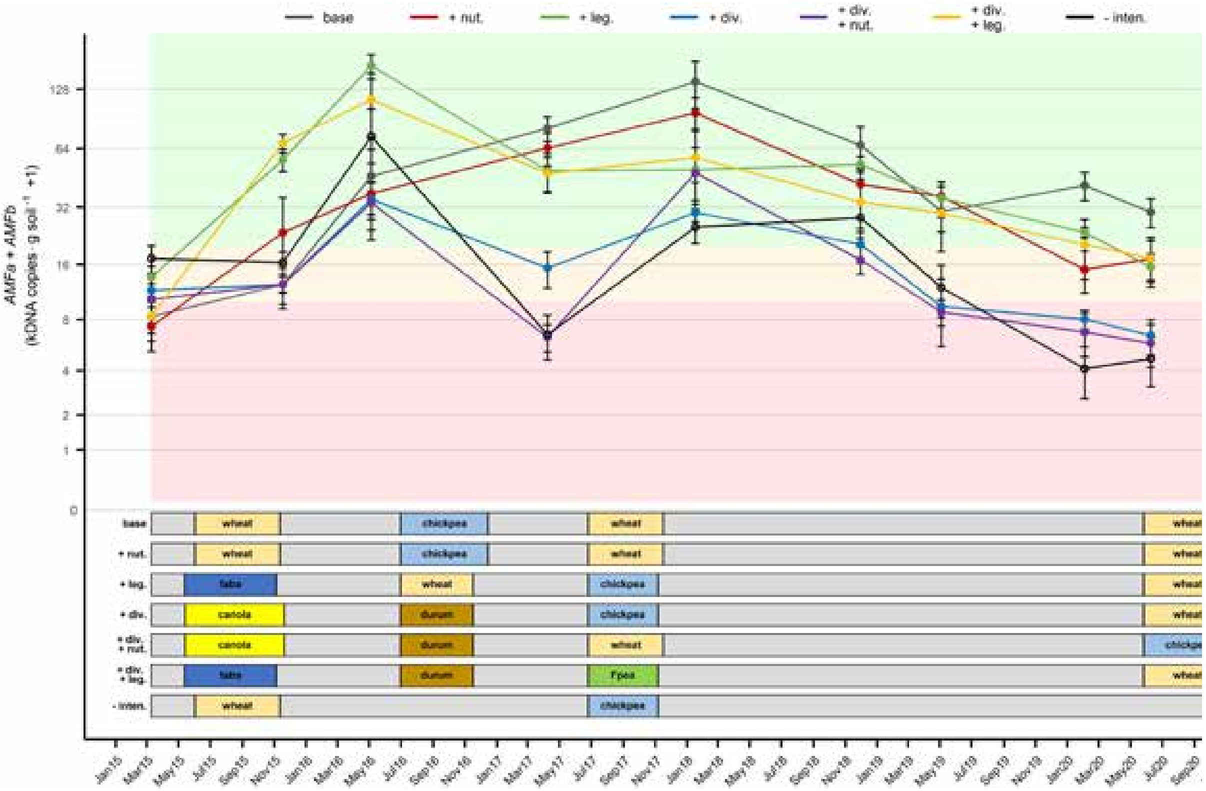

Figure 8. Total levels of AMFa and AMFb found in selected winter farming systems.
Error bars represent standard errors for four replicates.

Figure 9. Total levels of AMFa and AMFb found in the mixed farming systems. Error bars represent standard errors for four replicates.

Summer crops in mixed and summer systems generally maintained high levels of AMF (Figure 9). Mungbean showed a good capacity to build AMF levels quickly. The lower cropping intensity systems were the worst for AMF levels.

In winter systems, durum did not help AMF levels and again the lower intensity cropping of two winter crops in five years was worst for AMF levels. Winter systems with canola at the start of the five years were never able to reach the high levels of AMF seen in other winter systems. The systems with canola dropped to low AMF levels in the fallows, whereas other winter crops systems were able to stay at medium levels.

Implications for growers

Summer systems are generally better to keep *P. thornei* at low levels, especially if non-hosts such as sorghum and cotton are grown. However, mungbean will host and increase *P. thornei* and should be used carefully in mixed systems where subsequent crops may be susceptible. Tolerant wheat varieties are available that reduce the impact on yield.

Extended fallows from the trial's extended dry periods generally reduced soil-borne pathogens to similar levels to those of complete fallow (especially root-lesion nematodes); a positive for subsequent crops. The extended fallows also saw declines in AMF propagules as no hosts were present.

Extra phosphorus (P) and zinc (Zn) fertiliser may be required post-fallows, particularly if fallows are extensive (>18 months) and the soil P and Zn status are marginal or low.

Care in variety choice is always critical and good information on crop and variety tolerances and resistance levels to various pathogens can be found on the GRDC National Variety Trials website (nvt.grdc.com.au).

Acknowledgements

Particular thanks to Lyn Brazil for the large area under trial. Also thanks to all CSIRO and Department of Agriculture and Fisheries staff that have worked on this trial over the years and have collected and processed the hundreds of soil samples that have contributed to the data shown here; and to Brook Anderson at CSIRO for constructing the graphs.

Trial details

Location:	Pampas
Crop:	Summer and winter cereals and pulses, oilseeds, grass and legume pasture
Soil type:	Black Vertosol

Summer crop choice in northern farming systems – impacts on root-lesion nematode, charcoal rot, arbuscular mycorrhizae fungi and winter cereal crop pathogen levels

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Research question: *What is impact of different summer crop choices on root-lesion nematode, charcoal rot, arbuscular mycorrhizae fungi and winter cereal crop pathogen levels?*

Key findings

1. Summer crop choices are complex and should include relative impact on pathogens and also beneficial soil biota such as arbuscular mycorrhizae fungi (AMF).
2. Mungbean resulted in the greatest increase in AMF populations but also elevated disease risk for charcoal rot and root-lesion nematode (*Pratylenchus thornei*) compared with sorghum, cotton, maize, sunflower and millet.
3. Summer crops generally reduced Fusarium crown rot risk for following winter cereal crops, but relative effectiveness was variable.
4. Maize, cotton, sorghum and mungbean appear to be potential alternate hosts for common root rot (*Bipolaris sorokiniana*), while sunflower does not appear to be a host.

Background

Crop choice decisions often involve trade-offs between different aspects of farming systems. In particular, crop choice should consider the need to maintain residue cover, soil water and nutrient availability, and managing pathogen inoculum loads using non-host crops to avoid or reduce risk of problematic diseases (e.g. Fusarium crown rot). This is increasingly challenging as many cropping systems face evolving diseases and weed threats. Hence, understanding how different crops impact on these aspects is critical.

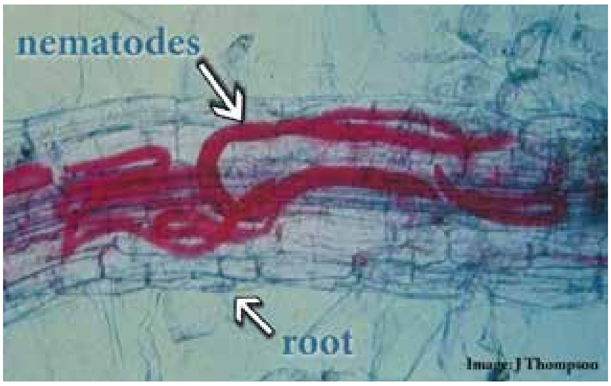
With limited winter rotation crop options in the northern grains' region, summer crops offer advantages as break crops within cropping sequences. Incorporating a mix of summer and winter crops allows variation in herbicide and weed management options, often also serving as disease breaks within the system. For example, sorghum is known to be resistant to the root-lesion nematode *Pratylenchus thornei* (*Pt*), allowing soil populations to decline. However, the increasing use of summer crops in many regions, has seen an increase in the frequency of other diseases (e.g. charcoal rot caused by the fungus *Macrophomina phaseolina*). Similarly, using long fallows to transition from summer to winter crop phases can induce low levels of beneficial arbuscular mycorrhizae fungi (AMF) populations associated with long-fallow disorder. In this report, we interrogate the data collected from Northern Farming Systems research sites over the past six years to examine how different summer crop options impact on levels of both pathogen and AMF populations within farming systems.

PREDICTA® B sampling.

What was done

Seven research sites were established in 2015 to test a range of different farming systems in different environments across northern NSW, southern and central Queensland. Over the life of the project, the team has sampled and analysed soil (0-30 cm) using the Northern-PREDICTA® B quantitative PCR (qPCR) DNA analysis to examine how pathogens and other soil biology have varied over a range of crop sequences. Here we have looked specifically at the impact of summer crops grown in these crop sequences to calculate the extent of change in DNA populations of pathogens and AMF associated with crop choices. It should be noted that populations are what have naturally developed within each system at the various sites and were not artificially inoculated.

Data from site-crop combinations where a particular pathogen or AMF was not present or below testing detection limits was excluded, as this does not provide a useful indication of the propensity of a crop choice to impact a particular pathogen or AMF population. PREDICTA® B data from soil samples collected at sowing and after harvest of each summer crop were used to calculate relative changes or multiplication factor for populations over their growing season for the various summer crop rotation options. This multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0) in pathogen levels following growth of different summer crops.



Stained nematodes within a wheat root.

Results

Root-lesion nematodes

Root-lesion nematodes (RLN, *Pratylenchus* spp.) are microscopic plant parasites that feed on crop roots. Two important species are known to infect crops in eastern Australia: *Pratylenchus thornei* (*Pt*) and *P. neglectus* (*Pn*). *Pn* generally feeds and causes root damage in the top 15 cm of soil whilst *Pt* can feed and damage roots down the entire soil profile. Root damage restricts water and nutrient uptake from the soil causing yield loss in intolerant winter cereal and chickpea varieties. Only *Pt* densities were prevalent at high enough densities across northern farming system sites to examine the effect of summer crop options on soil *Pt* populations.

Summer crops are known to vary in their susceptibility to *Pt* with sorghum, cotton, millet and sunflower considered moderately resistant to resistant (MR-R). Maize is considered susceptible to moderately resistant (S-MR) whilst mungbean is susceptible (S). The range in resistance ratings can relate to differences between varieties. Our results support these general findings. Mungbean resulted in the highest average increase in *Pt* populations, whilst sorghum favoured the lowest population increases (Table 1).

Table 1. Effect of summer crop choice on *Pratylenchus thornei* soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	1.4	8.3	3.2	2.0	3.4	5.0
Range	0.2 - 6.6	4.0 - 21.3	0.8 - 13.7	1.4 - 2.8	3.2 - 3.7	4.0 - 6.0
No. observations	31	20	10	5	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Table 2. Effect of summer crop choice on *Macrophomina phaseolina* (charcoal rot) soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	9.5	150.0	20.8	7.2	28.9	3.9
Range	1 - 27	5 - 1191	1 - 117	4 - 11	6 - 50	2 - 6
No. observations	23	23	9	4	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Cross-section of internal crown showing charcoal rot.

Charcoal rot (*Macrophomina phaseolina*)

All six of the summer crops grown increased average *M. phaseolina* populations by between 3.9 to 150 times, demonstrating the known wide host range of this fungal pathogen (Table 2). However, considerable differences were evident between the various summer crop options with mungbean elevating populations 5 to 40 times more than the other crops (Table 2).

Arbuscular mycorrhizae fungi (AMF)

AMF colonise roots of host plants and develop a hyphal network in soil which reputedly assists the plant to access phosphorus and zinc. Low levels of AMF have been associated with long fallow disorder in dependent summer (cotton, sunflower, mungbean and maize) and winter crops (linseed, chickpea and faba beans). Although wheat and barley are low and very low AMF dependent crops respectively, they are hosts and are generally recommended as crops to grow prior to sowing more AMF dependent crop species, in order to elevate AMF populations.

There are two PREDICTA® B qPCR DNA assays for AMF with combined results from both assays presented. It is important to remember that in contrast to all the other pathogen assays outlined, AMF is a beneficial fungus, so higher multiplication factors are good within a farming system context.

Mungbean resulted in the highest average increase in AMF populations, whilst sorghum was the lowest (Table 3). Interestingly, even though millet was grown as a short cover crop twice within these farming systems, it resulted in around a 7-fold increase in AMF populations. Hence, millet may be a good option for restoring ground cover over summer and AMF populations which both decline following extended dry conditions.

Fusarium crown rot (*Fusarium* spp.)

Two PREDICTA® B qPCR DNA assays detect genetic variants of *Fusarium pseudograminearum* with a separate third combined test detecting *F. culmorum* or *F. graminearum*. All three *Fusarium* species cause basal infection of winter cereal stems resulting in Fusarium crown rot and the expression of whiteheads when heat and/or moisture stress occurs during grain filling. Fusarium crown rot has increased in northern farming systems with the adoption of conservation cropping practices which include the retention of standing winter cereal stubble.

Table 3. Effect of summer crop choice on arbuscular mycorrhizae fungi (AMF) soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	3.5	26.8	10.7	5.7	12.0	7.2
Range	0.4 - 12.4	2.2 - 61.5	1.8 - 32.0	3.4 - 8.0	6.3 - 17.6	6.5 - 7.9
No. observations	41	22	10	4	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Table 4. Effect of summer crop choice on *Fusarium* spp. (Fusarium crown rot) soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	1.7	2.9	0.4	0.5	-	-
Range	0.03 - 10.3	0.4 - 9.7	0.1 - 1.0	0.2 - 0.8	-	-
No. observations	19	8	3	2	-	-

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Table 5. Effect of summer crop choice on *Bipolaris sorokiniana* (common root rot) soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	3.9	2.6	6.8	7.4	0.04	-
Range	0.5 - 9.6	0.3 - 9.3	0.3 - 12.0	na	na	-
No. observations	12	6	3	1	1	-

*** multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)**

Yield impacts however are sometimes offset by the higher levels of plant available water often available to the plant during grain fill in zero tillage systems when compared to tilled systems. The *Fusarium* spp. causing this disease can survive 3-4 years within winter cereal stubble depending on the rate of decomposition of these residues.

Limited observations were available to support conclusions on the relative effect of summer crops on *Fusarium* spp. associated with Fusarium crown rot. However, cotton and maize appeared most effective at reducing inoculum loads (Table 4). Results were more variable with sorghum and mungbean, but both generally reduced or only moderately increased Fusarium crown rot inoculum levels. Inoculum dynamics associated with saprophytic growth of *Fusarium* spp., potential redistribution during harvest of summer and winter break crops and the role of grass weed hosts appears worthy of further investigation to improve management of this disease across farming systems.

Common root rot (*Bipolaris sorokiniana*)

Bipolaris primarily infects the sub-crown internode of winter cereal crops causing dark brown to black discolouration of this tissue referred to as the disease ‘common root rot’. Common root rot reduces the efficiency of the primary root system in susceptible wheat and barley varieties resulting in reduced tillering and general ill-thrift in infected crops. This disease has increased in prevalence across the northern region over the last decade with the increased adoption of earlier and deeper sowing of winter cereals which exacerbates infection.

Although limited observations were available to support conclusions on the relative effect of summer crops on *B. sorokiniana* populations, the data appears to support the only previous study of host range from Pakistan (Iftikhar et al. 2009*). Mungbean, sorghum and maize appeared to generally increase populations, whilst sunflower considerably decreased levels of this pathogen (Table 5). Cotton, which was not included in the Pakistan study, also appears to generally increase *B. sorokiniana* soil populations (Table 5). These results indicate that the role of summer crops need to be considered when managing common root rot in northern farming systems. Further research is required to confirm the relative host range of this increasingly important pathogen.

Implications for growers

Summer crop choice remains a complex balancing act and should include the relative impact on pathogens and beneficial soil biota such as arbuscular mycorrhizae fungi (AMF).

For example, mungbean had the largest increase in beneficial AMF levels but had the negatives of elevating charcoal rot and *Pt* risk compared with sorghum, cotton, maize, sunflower and millet. Mungbean also did not appear to be as effective at reducing Fusarium crown rot risk for subsequent winter cereal crops compared with other summer crop options where data was available. Maize, cotton, sorghum and mungbean appear to be potential alternate hosts for the winter cereal pathogen *Bipolaris sorokiniana* (common root rot), while sunflower does not appear to be a host.

Quantification of individual summer crop choices on pathogen levels has highlighted potential areas requiring further detailed investigation to improve management of these biotic constraints across northern farming systems.

Acknowledgements

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*Iftikhar et. al. (2009). Hosts of Bipolaris sorokiniana, the major pathogen of spot blotch of wheat in Pakistan. Pakistan Journal of Botany. 41.

Growing cover crops for improved fallow efficiency—what have we learnt from three years of research?

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Research questions: *Can cover crops increase the net fallow accumulation of plant available water in grain and cotton systems with low ground cover (<30%) in the northern region? | Can cover crops improve fallow efficiency and accumulate 20 mm more plant available water?*

Key findings

1. Cover crops can improve fallow efficiency and provide a 'net' water benefit when grown in low cover fallows.
2. Increased ground cover at planting can improve crop establishment (and thus yields) by maintaining a moist seed bed for longer.
3. Cover crop species and spray-out timing should consider 'what' and 'when' the next cash crop will be planted.

Background

In a Queensland farming system plant available water (PAW) is 'king', but in dryland crops only 15-30% of fallow rainfall is captured for use. Around 5-20% of rainfall is lost in runoff and deep drainage, and up to 75% is lost to evaporation. Recent farming systems research has measured lower fallow efficiency (FE; the proportion of fallow rainfall captured in the soil) after crops that have low stubble loads or that break-down quickly (e.g. chickpea) than those with higher stubble loads (e.g. wheat).

Cover crops are not new. They offer an opportunity to increase ground cover that can protect the soil from erosion, suppress weeds, boost nitrogen levels (when legume species are included), maintain soil organic matter and improve FE. However, growing crops that do not produce grain or fibre is typically considered 'wasteful' of both rainfall and irrigation. Previous on-farm research has supported grower experience that cover crops may provide benefits with little or no loss of soil water.

Consequently, Queensland's Department of Agriculture and Fisheries (DAF), the New South Wales Department of Primary Industries (NSW DPI) and CSIRO recently joined forces with funding from the Grains (GRDC) and Cotton (CRDC) Research and Development Corporations to assess the impact of cover crops on the net soil water accumulation of fallows for grain and fibre crops. This research went beyond the previous limited on-farm research, and focused on the following research questions using rigorous soil water measurement across cover crops in low-cover fallows and the subsequent 'cash' crops:

1. Can cover crops increase net fallow accumulation of plant available water in grain and cotton systems with low ground cover (<30%) in the northern region?
    - What is the net water cost to grow cover crops?
    - What is the net water gain to subsequent grain/cotton crops (fallow and early crop growth)?
    - What is the impact on the yield of the subsequent grain/cotton crops?
2. Can cover crops improve fallow efficiency and accumulate 20 mm more plant available water?

What was done

Seven sites were established by DAF in April 2017: preceding overhead irrigated cotton near Yelarbon, Goondiwindi and Croppa Creek; in a long fallow after skip-row sorghum near Bungunya and Yagaburne; in a short fallow with low cover after chickpea near Billa Billa, and wheat stubble near Lundavra that was manually reduced to different stubble levels.

Unfortunately, this research was done over three very dry seasons. One of the seven sites was too dry to plant a cover crop (Lundavra in 2019); Goondiwindi and Croppa Creek didn't have enough water to grow cotton (irrigated or dryland) so didn't get the following 'cash crop' planted, and two sites relied on irrigation to establish the 'cash crop' (Yagaburne and Billa Billa). Yelarbon grew irrigated cotton in 2017-18; leaving only Bungunya to grow wheat solely on rainfall in 2018.

Cover crops were sprayed out with glyphosate; their use of soil water and its subsequent recharge was monitored regularly over the fallow, along with the yields of the following 'cash crops' as another estimate of the (water) benefit of the cover crops.

The aim was to increase resilient ground cover for water capture, or fallow efficiency, so cereal crops were selected as the primary species and sprayed out at different times to create a range of biomass volumes and resilience at each site. These cereal cover crops (barley or wheat in winter and millet or sorghum in spring/summer) were sprayed-out: 'early', at first node when the plants start producing stem; 'mid', at flag leaf emergence when reproduction begins; or 'late', at anthesis when peak biomass is produced.

At some sites other cover crop species were also included; vetch, lablab (legumes) and tillage radish, either alone, with cereals, or in multi-species mixtures. Sorghum was included as an easy to establish comparison when millet was the primary cereal. These additional species options were sprayed-out at the 'mid' termination time.

This report summarises the learnings from three years of trials; detailed individual trial reports are available in past editions of *Queensland grains research* (2017-2020).

Results

Cover crop biomass and ground cover

All experiments successfully increased ground cover levels from ~10% in the existing 'low cover' fallows (control treatments) to over 50% at the 'droughted' sites, and between 60-95% in the other locations (Figure 1). The cereal cover crops were most effective in generating and maintaining ground cover. They produced more dry matter and ground cover than the legume treatments that were slower to grow cover and faster to break down. Brassicas grew cover fastest, but again were quick to break down.

Between 2,500-4,000 kg/ha of dry matter (DM) was established by the cereals in the mid-termination treatments typically used in commercial plantings. The late terminations produced between 4,000-5,000 kg/ha, and the 'very late' crops and those grown through to harvest produced up to 10,000 kg DM/ha (Figure 2). The exceptions were two severely 'droughted' experiments, such as the Yagaburne experiment that only grew between 100-500 kg DM/ha for the winter cover crops and 500-2,500 kg DM/ha for the summer cover crops.

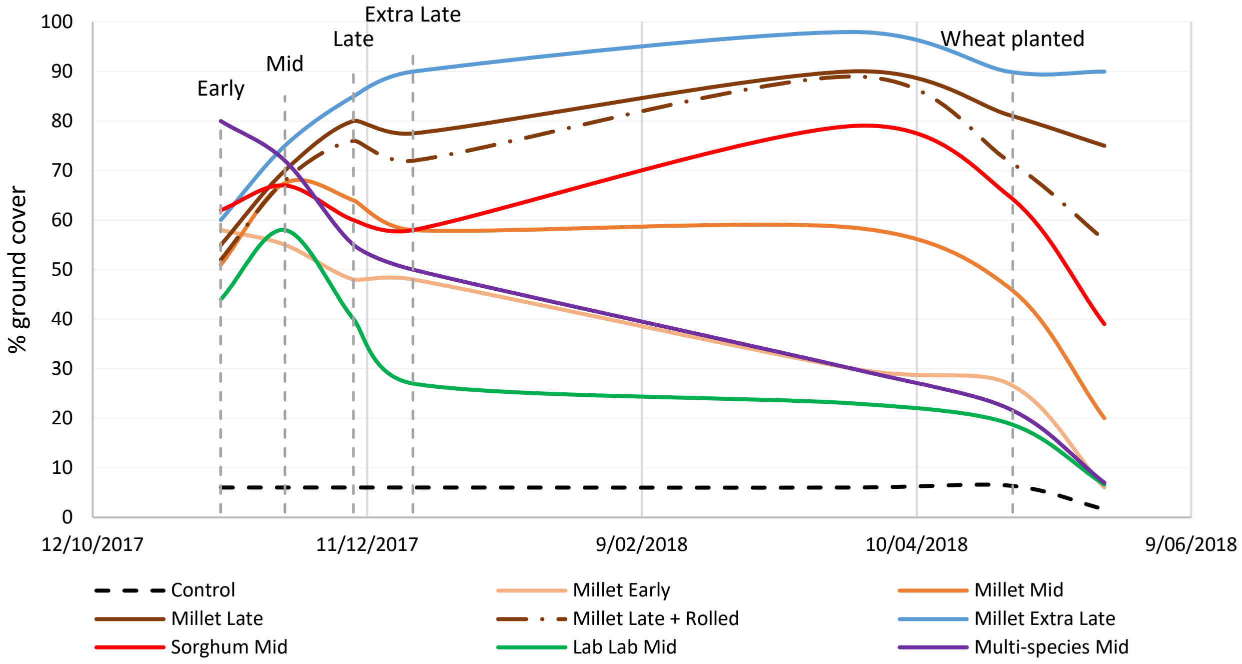

Figure 1. Visual assessment of % ground cover at Bungunya.
Note, sorghum cover increasing after termination is a result of the crop collapsing across the plant rows.

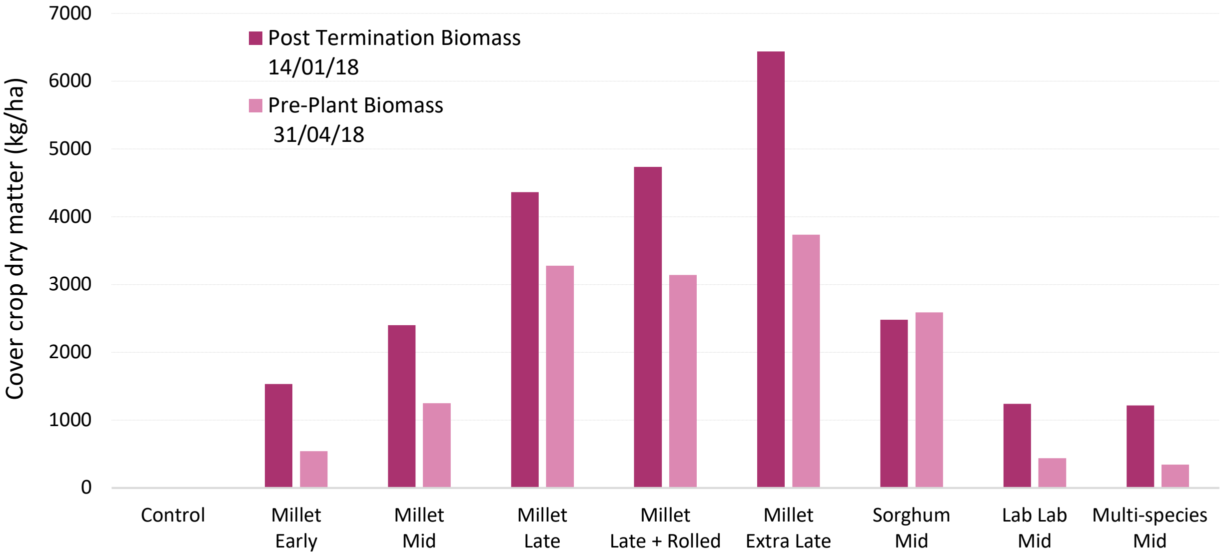

Figure 2. An example of cover crop biomass for a range of crop types and termination timings, measured post-termination and at the end of the fallow at Bungunya. Lablab and Multi-species had significant biomass reduction between termination and first assessment.

Fallow water dynamics

The best cover crop treatments at each site typically recouped their water deficits at termination to finish the fallows with similar, or better soil water levels than the Control treatments (Table 1). However, extreme treatments included in the research (e.g. very late termination, harvested cereals, terminations without subsequent fallow rain, some tillage radish and/or legume treatments) either used more water or did not maintain cover and finished the fallows with significantly less stored soil water P(0.05).

Table 1. Summary of fallow water storage for 'Control' (~10% cover) and the cover crop treatments.

Cover crop experimental sites	Fallow water storage by Control	Fallow water balance compared to the Control	
		Best	Worst
Yelarbon	56 mm	+38 mm	-4 mm
Bungunya	42 mm	+31 mm	-5 mm
Goondiwindi	30 mm	+10 mm	-8 mm
Yagaburne	14 mm	+6 mm	-19 mm
Croppa Creek	11 mm	+20 mm	0 mm
Billa Billa	28 mm	-37 mm	-55 mm

The natural variation in soil water made it difficult to confidently measure differences, something commonly seen in soil water studies. The differences for the key commercially-relevant treatments were at the limit of significance P(0.10). Despite this, the trends in the results were very consistent across sites and treatments; best illustrated for summer cover crops at Bungunya (Figure 3), and reflected expectations from theories of soil water storage and use. These results also matched simulation/modelling case studies.

Net fallow water storage at each site was reflected in almost all yield comparison of the 'cash crops', building confidence that observed treatment effects were real. Current commercial cover crop treatments across sites showed:

- a net loss of stored soil water at one site (Billa Billa summer cover crops in a short fallow)
- recovery to similar net water storage at three sites (Yagaburne, Goondiwindi, Croppa Creek)
- net water gains at two sites (Bungunya, Yelarbon).

Lundavra was established to compare management of traditional wheat stubble loads, but the cover crops were not planted due to drought. The wheat stubble treatments stored just 23 mm from harvest until the end of February and 1 mm net fallow accumulation until the monitoring concluded in June.

Not surprisingly, the water deficit (cost) at termination of the cover crops varied with cover crop species, growth stage at termination and the amount and timing of rain (Figure 3, Table 2). Typical net-water-deficits to grow the cover crops were ~20 mm (range 0-50 mm) for early termination, ~30 mm (range 15-70 mm) for mid-termination and ~50 mm (range 0-90 mm) for late termination. When cover crops were left to grow beyond anthesis (late termination) this deficit could be in excess of 100 mm with no additional biomass. Timely removal was critical to avoid dramatic water losses.

Table 2. Deficit (mm) of cereal cover crops at different termination timings.

	Early	Mid	Late
Yelarbon	-39	-67	-86
Bungunya	-31	-44	-58
Goondiwindi summer*	-1	-32	-36
Goondiwindi winter*		-19	-33
Yagaburne winter*	5	-13	2
Yagaburne spring*	-16	-47	-62
Billa Billa	-31	-29	-68
Croppa Creek	-15	-43	-59
Average	-18	-37	-50

*Goondiwindi and Yagaburne had both winter and spring/summer cover crops at the same site.

The ability to recover from these deficits was then impacted by the amount and resilience of cover grown and the amount of rain that fell in the subsequent fallow (fallow length) to potentially refill the profile.

The recovery of soil water from these deficits after termination was equally dramatic and consistent across the project. The drier soil profiles and extra cover boosted the infiltration and storage of water for the rest of the fallows in-line with theory. The millet cover crop at Bungunya (Figure 3), was planted on ~120 mm of plant available water, used 50-60 mm more water than the control fallow through to late termination, but had an overall fallow efficiency of 17% compared to 14% for the bare fallow. This was due to its very high fallow efficiency (>80%) in the short period after the cover crop was sprayed out.

Similar results across sites saw most treatments recover the deficits on the next major rain event and then finish with similar levels of soil water by the end of the fallow. Cover crops with less water than the Bare fallow were the late terminations, which didn't provide sufficient fallow time to recover their larger deficits, and some legume and brassica cover crops where the stover broke down too quickly to maintain cover for the whole fallow.

At the Yelarbon site, higher ground cover persisted after planting the cotton crop and continued to increase water capture and support early crop growth up to canopy closure.

Table 3. Difference in planting PAW to the bare fallow (Control) from cereal cover crops at different termination timings for each of the sites.

	Early	Mid	Late
Yelarbon	15	-1	-15
Bungunya	50	40	69
Goondiwindi cotton*	2	-23	-31
Goondiwindi wheat*	5	-3	-7
Yagaburne winter cover crop	-10	-7	-11
Yagaburne spring cover crop	-14	-7	-19
Billa Billa	-44	-42	-43
Croppa Creek cotton*	1	-20	-93
Croppa Creek wheat*	0	18	1
Average	1	-5	-16

*Goondiwindi and Croppa Creek were not planted, so values are for nominal planting dates of cotton or wheat.

Ultimately, the most appropriate cover crop treatments (early termination for short fallows; late terminations for long fallows) typically finished with more stored water than the bare

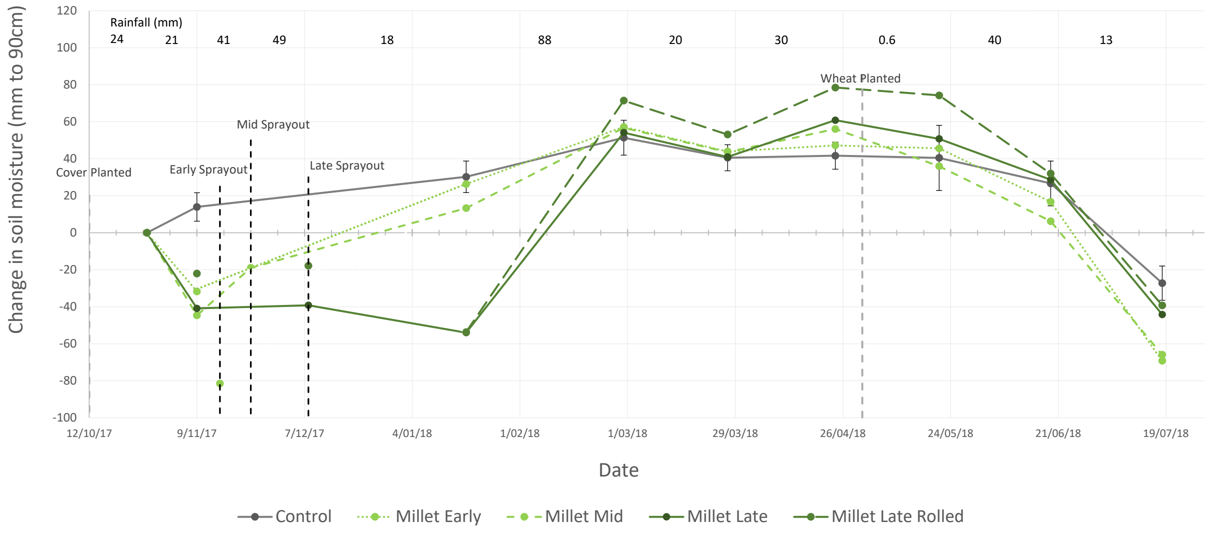

Figure 3. Soil water dynamics at the Bungunya site, showing soil water use by millet cover crops with different termination timings, and recharge over the following fallow.

fallow, presumably as more cover protected the soil from raindrop impacts and soil micro-pores and root channels helped water movement. (Table 1, Table 3)

Planting moisture

Increased ground cover retained surface moisture for longer, which had a marked effect on the capacity to plant the following cash crops. Observations and Theta probe measures at two sites confirmed that increased cover from cover crops had maintained surface moisture sufficiently to allow planting, which was not possible where there was no cover crop sown. At Bungunya, the cover and extra moisture at planting produced a dramatic improvement in the population of wheat established (Figure 4) and its subsequent yield.

At Yagaburne in May 2019, surface moisture was again aligned to the level of ground cover established by cover crops. Treatments with low cover (<30%) were too dry to plant and returned Theta (0-10 cm capacitance probe) readings of 7 to 9. Treatments with moderate cover (30-70%) had Theta readings of 9 to 11, which was likely to produce a patchy establishment, while treatments with high cover (>70%) had Theta readings of 11 to 14, which was suitable for planting (Figure 5). It was decided to wait for another planting opportunity that didn’t eventuate, so the site was irrigated for establishment in June.

Figure 4. Wheat establishment at Bungunya with low or high cover at planting. Left: bare fallow (Control); right: high cover (mid-sprayed millet).

Yield of subsequent ‘cash’ crops

Yields of subsequent grain and cotton cash crops reflected the soil water trends across dryland and irrigated sites; more soil water typically produced more yield.

At Yelarbon, the overhead irrigated cotton yields were all higher with cover crops, but there was no difference between the type of cover crops used or their subsequent soil water differences at planting. This may have been due to better capture of the 650 mm of in-crop irrigation by the later-terminated treatments that had grown more cover, along with the suggestion of greater extraction of soil water in these treatments by the time of cotton defoliation.

The three dryland trials had a much stronger reliance on water stored over the fallow period for grain yield. The wheat after cover crops at these sites had similar water-use-efficiencies within each trial. At Bungunya there were significant differences in grain yield, in-part reflecting stored soil water differences at planting. However, the ‘patchy’ establishment in the bare Control also meant this crop extracted less water at harvest, so used much less than treatments with cover crops.

Figure 5. Yagaburne ground cover at planting assessment. Treatments with low cover (left) were too dry to plant, moderate cover (centre) were marginal, and high cover (right) had good planting moisture.

Very dry conditions in 2019 meant the wheat crops at Yagaburne and Billa Billa needed irrigation for crop establishment. This trickle tape irrigation resulted in an even population of 100 plants/m², so grain yield was much more closely related to planting water. At Yagaburne, grain yields were similar across the trial, reflecting the consistent soil water levels of the treatments at planting. Billa Billa had quite large differences in soil water at planting and as such achieved large yield penalties following cover crops. With an even plant population established, yield was again penalized at a consistent 15 kg grain/mm PAW.

Simulation

Simulation modelling from the Bungunya experiment, using a water deficit of 20 mm/t dry matter produced by the cover crops, showed benefit from cover crops in 45% to 70% of years (Figure 6a). In the wettest 5% of years, all systems were predicted to finish with similar moisture levels. Whereas the driest years saw net water losses in 10% of years for early terminations and up to 50% of years for late terminations with at least 3 t/ha of biomass. This conservative analysis means that early-terminated cover crops that produce 1 t DM/ha can recoup or improve soil water storage in 70% of years (not the 25% driest or the 5% wettest). For later terminations producing 3 t DM/ha, they can recoup or improve soil water storage in 45% of years (not the driest 50% or wettest 5% of years). For years with in-fallow rainfall of 200-500 mm, net soil water accumulation was predicted to increase by 17 mm on average. Assuming 15 kg/mm, this aligns to the grower's experience over the last 10 years of 200-300 kg/ha grain yield increase where cover crops have been grown.

The added benefit of cover crops predicted in this simulation is the reduction in erosion risk during fallows by reducing runoff volumes and sediment concentration in runoff water (Figure 6b). In 99% of years erosion was predicted to be lower with cover crops, with even small stubble levels (1 t/ha) eliminating sediment losses in up to 50% of years. While cover crops may have little benefit for water storage in very wet years, higher levels of stubble are predicted to be effective in preserving soils during years of high erosion risk. Cover crops that produced 1 t/ha dry matter were predicted to reduce long-term erosion by 82%, 2 t/ha of dry matter by 96% and 3 t/ha by 99% at the Bungunya site. This reduction in erosion would deliver savings to growers in reduced earthworks (i.e. contour bank maintenance) and associated nutrient losses.

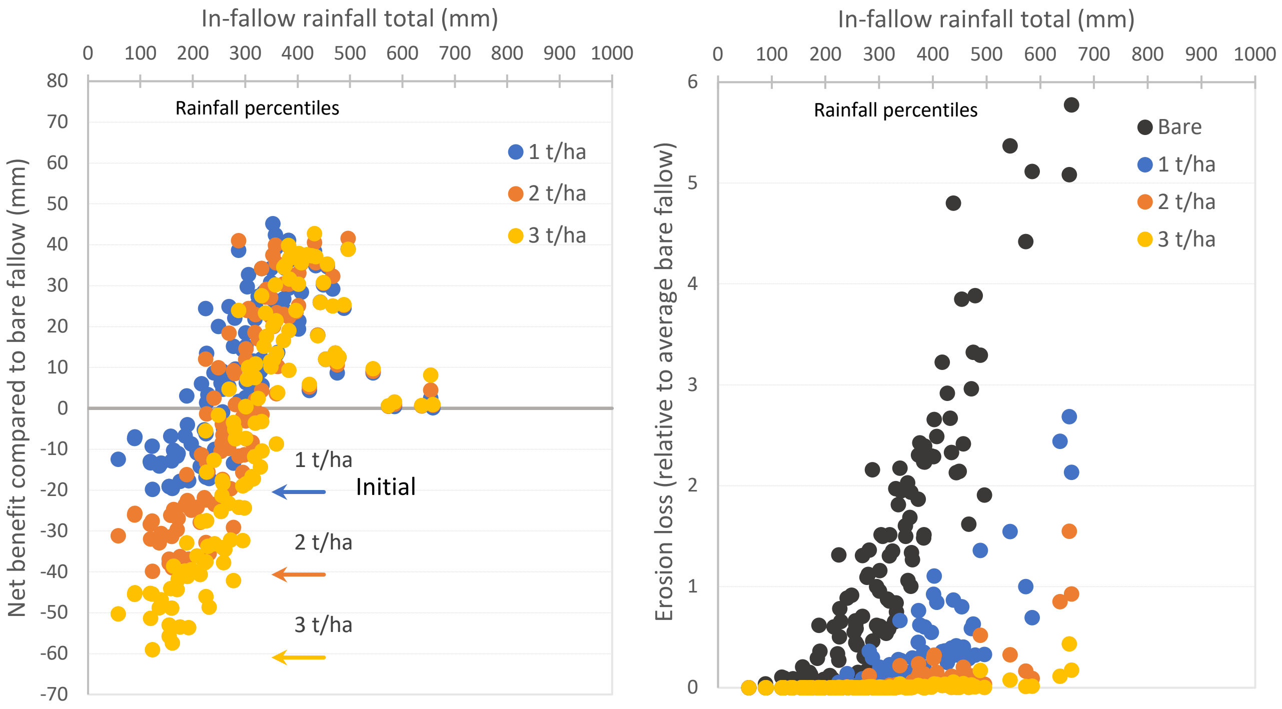

Figure 6. Simulation modelling: a) net benefit of spring cover crops of varying stubble mass on stored moisture compared to bare fallow with 60 mm starting PAW; b) relative erosion losses due to cover crops during the fallow.

Bare soil erosion rates are shown for comparison, as are rainfall percentiles for the fallow, and the initial soil water deficit to grow the cover crops.

Implications for growers

Growing cover crops is a useful strategy for increasing ground cover in low cover fallows. Fallows with high ground cover, such as following cover crops (but not exclusively), will generally have higher fallow efficiency from reduced evaporation and run-off.

A higher fallow efficiency will provide more stored water at planting, improving the yield potential of the crop. Dry cracking clay soils can achieve fallow efficiencies greater than 70% over a short period, so combined with the higher fallow efficiency from increased ground cover, the fallow after a carefully managed cover crop can recover the soil water used to grow the extra ground cover.

Reducing evaporation provides an additional benefit by maintaining moisture near the surface for longer. This can extend the planting window to better match the optimum date for maximum yield potential, and/or planting larger areas of crop without the need for time-critical rainfall.

Soil loss in runoff was a major driver for the shift to zero or minimal till farming systems. Whilst not measured in our field trials, the simulation demonstrated the potential to reduce erosion with cover crops. Preventing erosion will deliver savings in earthworks (contour bank and drain maintenance) and reduce losses of nutrients and pesticides attached to the sediment, delivering economic, agronomic and environmental benefits.

Collecting soil samples from the cover crop sites.

Considerations for a carefully managed cover crop include:

1. What is the current ground cover? Does (or will) the fallow need additional cover?
2. How much soil water is currently available? Can I grow a profitable crop now that will leave stubble cover?
3. What and when is the likely next crop? How long will the fallow be? How long do I want the cover crop to grow for?
    - A longer fallow will need more resilient stubble and have more time to recover water used by a later termination timing.
    - A shorter fallow will benefit from a smaller deficit at termination of the cover crop, and there is less need to wait for resilient stem in the stover.
4. What is the most appropriate crop to plant? Consider planting conditions (date, planting depth, temperature etc.) and disease implications.

Acknowledgements

We very much appreciate the support of the trial co-operators and consultants for their effort and contributions to the project, along with our project team members in CSIRO, David Freebairn, and the DAF Technical officers, Biometry and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments. Thanks also to the Grains Research and Development Corporation, Cotton Research and Development Corporation and the Department of Agriculture and Fisheries for funding the project (DAQ00211).

Many people contributed to the monitoring and management of these sites, including current staff: Rod O'Connor, John Lehane, Makhdum Ashrafi, Christabel Webber, Peter Want, Ian Broad and Cameron Silburn; thanks for the hard work and dedication in some challenging seasons.

Second year impact of cover crops—Yagaburne and Billa Billa

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Research question: *What is the residual impact of a cover crop on the second subsequent grain crop?*

Key findings

1. Differences in yield of the second grain crop were related to the stubble left by the first crop after removing a cover crop.
2. At Yagaburne the first crop following cover crops provided consistent stubble cover, so there were no differences in wheat yield the second year.
3. At Billa Billa the wheat crop produced much less new stubble after cover crops than the fallowed wheat or chickpea stubble, leaving less cover in the second fallow, establishing lower populations and yielding less in the second crop.

Background

Cover crops are typically grown to protect the soil from erosion in low stubble situations, return biomass that helps maintain soil organic matter and biological activity, and to provide additional nitrogen when legumes are used. The extra ground cover also offers an opportunity to increase infiltration and fallow moisture storage and reduce run-off for better and more profitable grain and cotton crops across the northern region of New South Wales (NSW) and Queensland.

Previous trials by GRDC's Eastern Farming Systems project and Northern Growers Alliance suggest that cover crops or increased stubble loads can reduce evaporation, increase infiltration and provide net gains in plant available water over traditional fallow periods. The recent GRDC and CRDC cover crop project (DAQ00211) monitored sites intensively to quantify the impact of different stubble loads on the accumulation of rainfall, the amount of water required to grow cover crops with sufficient stubble loads, the net water gains/losses for the following crops and the impacts on their growth and yield.

These projects only assessed the impact of the fallow and crop directly following the cover crop. However, two sites that grew cover crops in 2018 and grain crops in 2019 were monitored over the following fallow and 2020 grain crop to assess any residual impacts from the cover crops.

What was done

A range of cover crops were planted at Yagaburne and Billa Billa in 2018 (Tables 1 and 2), sprayed out and subsequently planted to wheat crops in 2019. The effect on this initial fallow and wheat crop was reported in *Queensland grains research* 2019-20.

Ground cover in the original plots was assessed during the fallow period until these two sites were planted again in 2020, Yagaburne to wheat and Billa Billa to barley. Soil water was measured with gravimetrics at planting and harvest, along with the established plant population, peak biomass and final header grain yield.

Table 1. Cover crop treatments at Yagaburne (sorghum - cover - wheat - fallow - wheat).

	Previous crop	Cover crop	Cover treatment
1	Sorghum	Nil	Bare (Control)
2	Sorghum	Wheat	Spray-out Early
3	Sorghum	Wheat	Spray-out Mid
4	Sorghum	Wheat	Spray-out Late
5	Sorghum	Wheat	Spray-out Late + Rolled
6	Sorghum	Winter multi	Spray-out Mid
7	Sorghum	Millet	Spray-out Early
8	Sorghum	Millet	Spray-out Mid
9	Sorghum	Millet	Spray-out Late
10	Sorghum	Millet	Spray-out Late + Rolled
11	Sorghum	Sorghum	Spray-out Mid
12	Sorghum	Spring multi	Spray-out Mid

Table 2. Cover crop treatments at Billa Billa (chickpea/wheat - cover/fallow - wheat - fallow - barley).

	Previous crop	Cover crop	Cover treatment
1	Chickpea	Nil	Bare (Control)
2	Chickpea	Sorghum	Spray-out Early
3	Chickpea	Sorghum	Spray-out Mid
4	Chickpea	Sorghum	Spray-out Mid + Rolled
5	Chickpea	Sorghum	Spray-out Late
6	Chickpea	Sorghum	Spray-out Late + Rolled
7	Wheat	Nil	Tall standing stubble
8	Wheat	Nil	Tall stubble rolled
9	Wheat	Nil	Shorter retained stubble
10	Wheat	Nil	Shorter reduced stubble

Results

Yagaburne

There was no difference in grain yield between treatments in the first grain crop (year one) after the cover crops (2019). The stubble from this wheat crop provided ~50% ground cover for all treatments, with only the late sprayed millet and sorghum maintaining additional residual ground cover at planting in May 2020 (Figure 1). Soil coring showed all treatments had similar PAW at planting and harvesting of the 2020 wheat crop (Figure 2). Therefore, it was not surprising that the biomass (average 5 t/ha) and grain yields (average 2.4 t/ha) of this crop were also similar across the treatments.

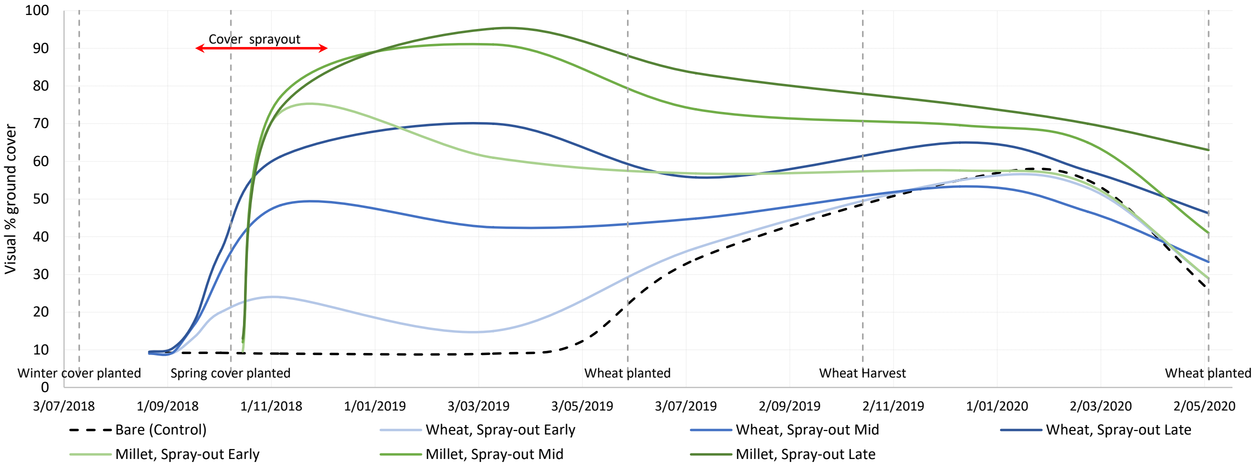

Figure 1. Visual assessment of ground cover (%) of selected treatments at Yagaburne. The treatments shown represent high, medium and low cover at planting of the first wheat crop after cover crops.

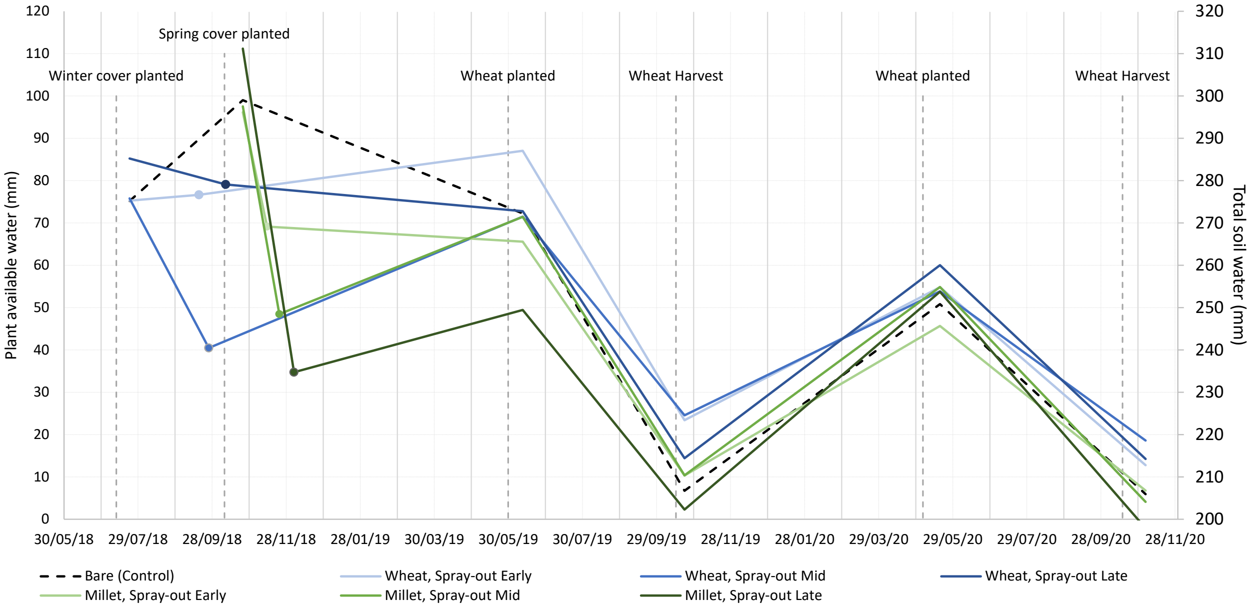

Figure 2. Soil water of select treatments at Yagaburne measured with gravimetric soil cores at key times. This shows the spread of soil waters at spray-out of cover crops and similarities of soil water over the second fallow and wheat crop.

Billa Billa

The Yagaburne site had similar wheat yields in 2019 across all treatments, but the Billa Billa sorghum cover crops reduced PAW at planting and therefore reduced biomass and grain yield of the 2019 wheat crop in these treatments. Consequently, the 2019 wheat produced the most 'new' stubble in the Bare Control, followed by the four wheat stubble treatments and the early sprayed cover crop (Figure 3).

The mid and late sprayed cover crops did not recharge soil water after the cover crops, so had very little wheat stubble after 2019 harvest; ground cover was then reliant on the residual cover crop residue in these treatments. The impact of this was the 2019 wheat stubble persisted over the fallow period, whilst the sorghum cover crop residue decayed to provide the least ground cover at the end of the 2019-20 fallow period.

All treatments had a low, but even population established. The average population was 270,000 plants/ha, but the treatments with better wheat stubble from 2019 (i.e. five fallowed treatments) had 289,000 plants/ha whilst the five cover crop treatments had only 252,000 plants/ha (P=0.1). This trend correlates with the crop water use and biomass and grain yields, that is, the differences in population reduced the crops' ability to dry the soil profile to harvest and reduced yield (Figure 4).

The five cover crop treatments relied heavily on the sorghum residue over the 2019-20 fallow, so had lower fallow efficiency and used on average 15 mm less water in the crop (i.e. planting water – harvest water) (Figure 5).

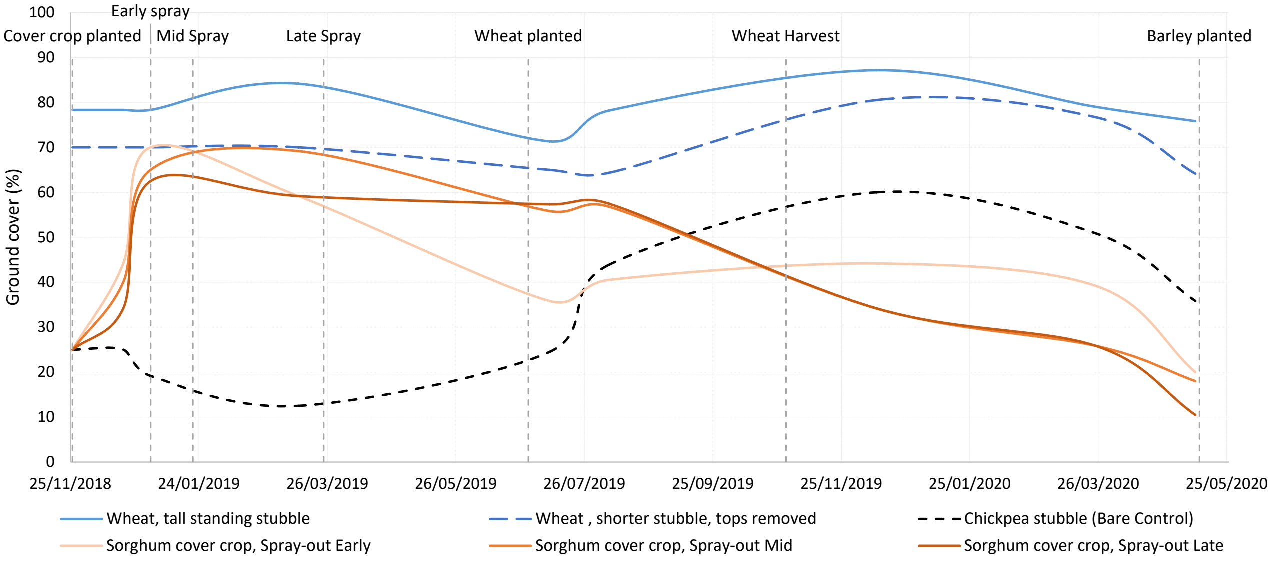

Figure 3. Visual assessment of ground cover (%) in selected treatments at Billa Billa.

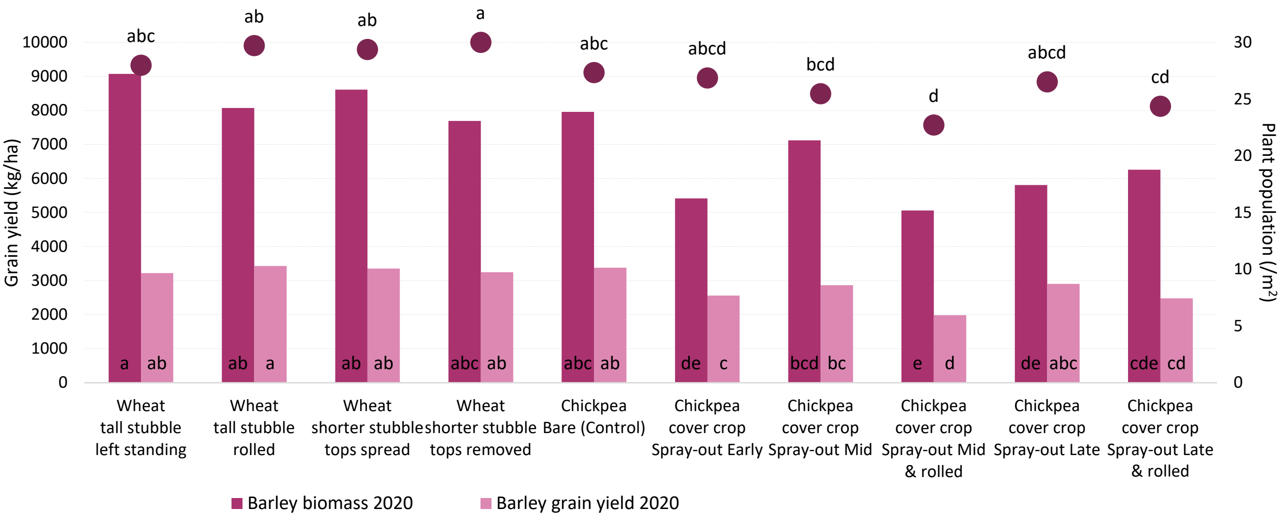

Figure 4. Biomass, grain yield and established population of the 2020 barley crop at Billa Billa.
Letters indicate significant differences P(0.05) for yield and P(0.10) for population).

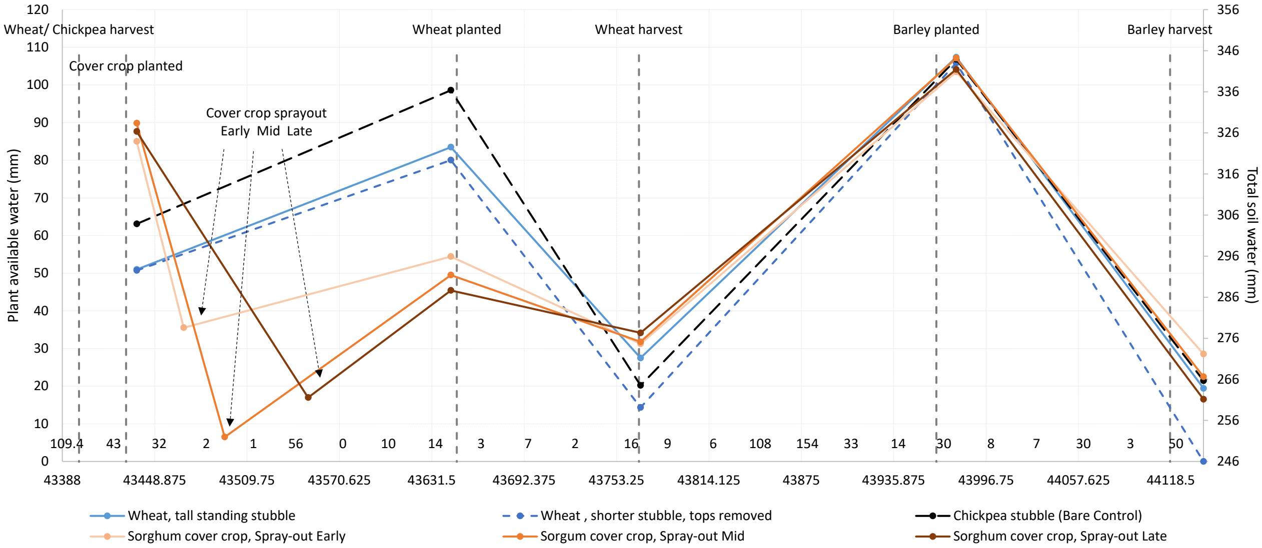

Figure 5. Soil water measured to 120 cm at key points in time at the Billa Billa trial.

Statistical analysis of the barley biomass yield divided the treatments into these same two groups (Figure 4). The higher yielding group (dark pink columns with the letter ‘a’) includes 2018 wheat (treatments 7-10) and Bare Control (treatment 1). The lower yielding group comprised the treatments that grew a sorghum cover crop in 2018 (letters ‘d’ or ‘e’).

Grain yield had similar results to the biomass yield. The wheat stubble and chickpea stubble (bare control) treatments had a higher yield than chickpea followed by a cover crop (lsd letter ‘a’ in Figure 4).

Implications for growers

Continued monitoring for a second crop after the cover crops were removed highlighted potential legacy effects on yield of subsequent crops.

At both sites, differences in PAW present at harvest diminished over the fallow, so PAW was not a factor in the yield of this second crop. The difference in yield was related to the plant population established. Improving ground cover at planting helps maintain moisture in the seedbed (0-10 cm) longer, which helps establish a higher population and more even plant stand and in-turn allows the crop to maximise yield for the resources available.

Poor wheat on the ‘fenceline’ between the cover crop trial (L) and commercial millet stubble (R) at Yagaburne 2020.

Areas of low ground cover can be improved with a cover crop, best illustrated at Bungunya and reported in *Queensland grains research 2018-19*, or by growing a high residue cash crop such as the wheat grown at these two sites. In either case, these areas should be targeted to be planted while seedbed moisture is ideal, and/or greater care taken in planter setup to maximise plant establishment.

Acknowledgements

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Trial details

Location:	Yagaburne and Billa Billa
Crop:	Wheat and barley
Soil type:	Box (Chromosol) and Belah (Duplex)
Rainfall (mm):	204 and 324 (fallow) 62 and 128 (in-crop)

Notes:

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Queensland's Regional agronomy (research) team conducts experiments that support agronomists and grain growers to make the best decisions for their own farms. The research summaries in this publication provide rigorous data for industry-wide solutions and relevant information to refine local practices.

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