Queensland grains research

2019-20

Regional agronomy (research)

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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).

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Foreword

Welcome to the fifth edition of *Queensland grains research*, an annual update of the Department of Agriculture and Fisheries' Regional agronomy (research) team's research, development and extension (RDE) across the grain growing regions of Queensland. The team is an important part of the Queensland Government's strategic investments to support more productive, profitable and sustainable farming systems, and was established with the ongoing support of the Grains Research and Development Corporation (GRDC). Indeed, every project reported here has co-funding from GRDC in their pivotal role of investing in RDE to create enduring profitability for, and on behalf of, Australian grain growers.

The Regional agronomy (research) team has over 15 research agronomists, extension officers and technical support staff based in Goondiwindi, Emerald and Toowoomba. This enables them 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* is a result of this work, providing 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. As such, this edition reports the Regional Agronomy (research) team's contribution to improved farming systems and practices with experimental work; the data, analysis and insights across five themes: Cereals, Pulses, Nutrition, Soils, and Farming systems research. Many articles report on individual experiments with valuable quantitative data on the likely responses and economic returns for those locations. However, this edition also includes analyses of nutrition and farming system research across the northern grains region to understand major effects and their implications for all growers.

Of course, none of the RDE reported here would be possible without the support of all 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 ongoing support.

Finally, we trust that the RDE reported here will help the grains industry and the wider Queensland community in the economic recovery that is needed in the post COVID-19 era, and would value any feedback on work contained in this publication.

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Biometry support

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 papers 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.

Cereal research

Cereal research conducted by the Regional agronomy (research) team and their collaborators has remained focused on wheat and sorghum. This edition of *Queensland grains research* concludes the optimising winter cereal phenology research with two articles on the final year of Queensland trials as part of the work to map the development of 32 genotypes across the northern grains region. There is also an article on progress of research on early (winter) planted sorghum from Central Queensland.

Our wheat physiology research led by Darren Aisthorpe has been conducted with our lead partners in the New South Wales Department of Primary Industries through the 'Optimising grain yield potential of winter cereals in the northern grains region' (BLG104) project. This work 'honed-in' on when each of the varieties hits key growth stages of the plant, the respective biomass produced at those stages, and ultimately yield and grain quality. In Queensland, these trials were conducted at Emerald and Wellcamp (near Toowoomba), two locations with very diverse growing conditions and challenges. The data shows that targeting an optimum flowering date, not sowing date, is the key to yield performance. For example, at Emerald, up to 40% yield increases are possible when management gets the flowering date x genetic decisions correct. Further research to acquire more detailed data on development and performance of different genotypes across Queensland would greatly increase growers and their agronomist's ability to maximise yield potential into the future.

The 'Optimising Sorghum Agronomy' (UOQ1808-001RTX) project run in collaboration with Daniel Rodriguez and his team from Queensland Alliance for Agriculture and Food Innovation is testing the ability of sorghum to germinate and withstand cold temperatures during early growth stages in order to reduce heat-stress during flowering and grain fill. If successful, early sowing will allow more reliable production and possible additional cropping opportunities in our farming systems. This edition of *Queensland grains research* provides an update of last year's research in Emerald in which the late July sowing out-performed mid-August sowings with higher yield, better grain quality and reduced lodging. This will be an interesting project to watch over the coming years.

In addition to these projects, the Regional agronomy team is part of the National Variety Testing (NVT) program and the University of Queensland led Innovation in Plant Variety Testing Australia (INVITA) in Central Queensland, which is not reported here.

Wheat: Phenology and yield response to sowing time—Emerald

Darren Aisthorpe and Ellie McCosker
Department of Agriculture and Fisheries

Research Question: *How does time of sowing influence the phenology and grain yield of wheat genotypes?*

Key findings

1. Quick higher-yielding genotypes offered highest yields for three of the four sowing dates, reinforcing findings from previous years.
2. Crops planted from late May onwards were at a significant yield disadvantage, no matter what genotype maturity was used.
3. Even early-sown winter wheats are not viable in Central Queensland conditions.

Background

In 2019, field experiments were conducted across eight sites in the northern grains region to determine the influence of phenology on grain yield responses for a diverse set of wheat genotypes. This article presents results from the Emerald site in Central Queensland (CQ) and discusses the influence of sowing date on the phenology and grain yield responses of a core set of 32 wheat genotypes.

Table 1. Expected speed to maturity of genotypes used in 2019.

Phenology type	Genotypes
Winter (W)	Longswordᶲ, LongReach Kittyhawkᶲ
Very slow (VS)	EGA Eaglehawkᶲ, Sunlambᶲ, RGT Zanzibarᶲ, LongReach Nighthawkᶲ, Sunmaxᶲ
Slow (S)	Coolahᶲ, EGA Gregoryᶲ, Cutlassᶲ DS Pascalᶲ, LongReach Reliantᶲ, LongReach Lancerᶲ
Mid (M)	Mitchᶲ, LongReach Trojanᶲ, Catapultᶲ, Sunvaleᶲ
Mid-fast (MF)	Scepterᶲ, Suntopᶲ, Maceᶲ, Janz, Beckomᶲ
Fast (F)	Corackᶲ, LongReach Spitfireᶲ, LongReach Hellfireᶲ, Condoᶲ, Vixenᶲ, LongReach Mustangᶲ
Very fast (VF)	Sunprimeᶲ, LongReach Dartᶲ, H45ᶲ, TenFourᶲ

New releases are highlighted in colour.

What was done

The 2019 trial was located at the Emerald Research Facility, on the former Emerald agricultural college. The trial targeted an optimum establishment of 100 plant/m^2, sown in 2 m wide plots with a 50 cm row spacing. The trial was planted using Boss TX45 parallelograms fitted with double disc shanks over four sowing dates (SDs) (Table 2).

Table 2. Treatment sowing and harvest dates, 2019.

SD	Sowing	Harvest
1	8 April	20 September
2	18 April	23 September
3	3 May	4-16 October (due to maturity differences across genotypes)
4	20 May	

Results

Crop development

When considering variety options at sowing, growers should aim to synchronise crop development with seasonal patterns so that flowering occurs at an optimal time, typically a trade-off between increasing heat threat and frost risk. Generally, highest yields are achieved at Emerald when genotype and SD combinations flower from early June to mid-July.

In 2019, the flowering window of all genotypes planted spanned 8 June to 4 September. This was directly influenced by significant early rain at or just before planting, significant heat stress from late August onwards and four mild frost events.

Highest yields were achieved when flowering occurred from late June to late July, which was later than observations in the 2015 to 2018 experiments (detailed in previous *Queensland grains research* publications). Yields then consistently declined when flowering occurred after the end of July (Figure 1).

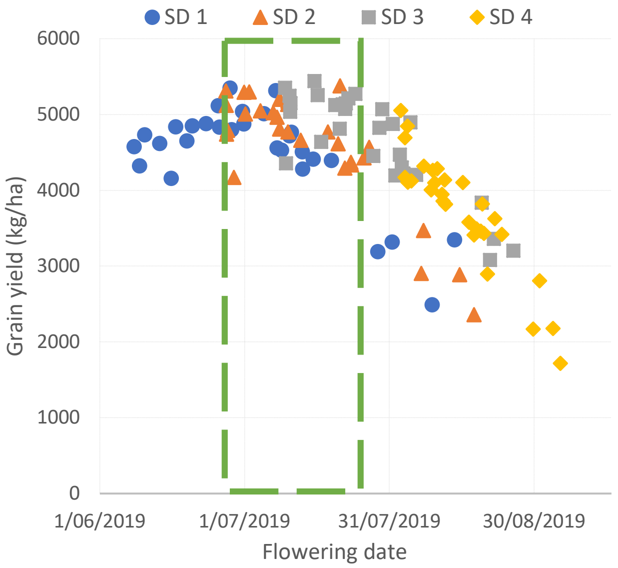

Figure 1. Flowering date for all sowing dates and genotypes used in the trial.
Optimum flowering period for 2019 (green dotted box) was from late June to late July, with average yields falling away for flowering dates after the end of July.

There was variation in the genotypes' development responses to vernalisation and photoperiod, which resulted in crop development varying significantly due to sowing time (Figure 2). This variation influenced the flowering and grain yield responses (Figure 1). Faster-developing spring types, with little to no response to vernalisation, developed quickly when sown early (SD 1); a period characterised by warmer temperatures and longer days. They subsequently flowered earlier than the optimum flowering period (OFP) for 2019.

In contrast, the slower developing winter types had a prolonged vegetative phase due to their vernalisation requirement, but were unable to effectively move past the reproductive stage to produce viable yield in CQ conditions.

For SD 1, mid-maturing spring wheats like Corack$^{\phi}$ and Mitch$^{\phi}$ were able to maximise yields by flowering in late June and early July. However, for SD 2, SD 3 and SD 4, it

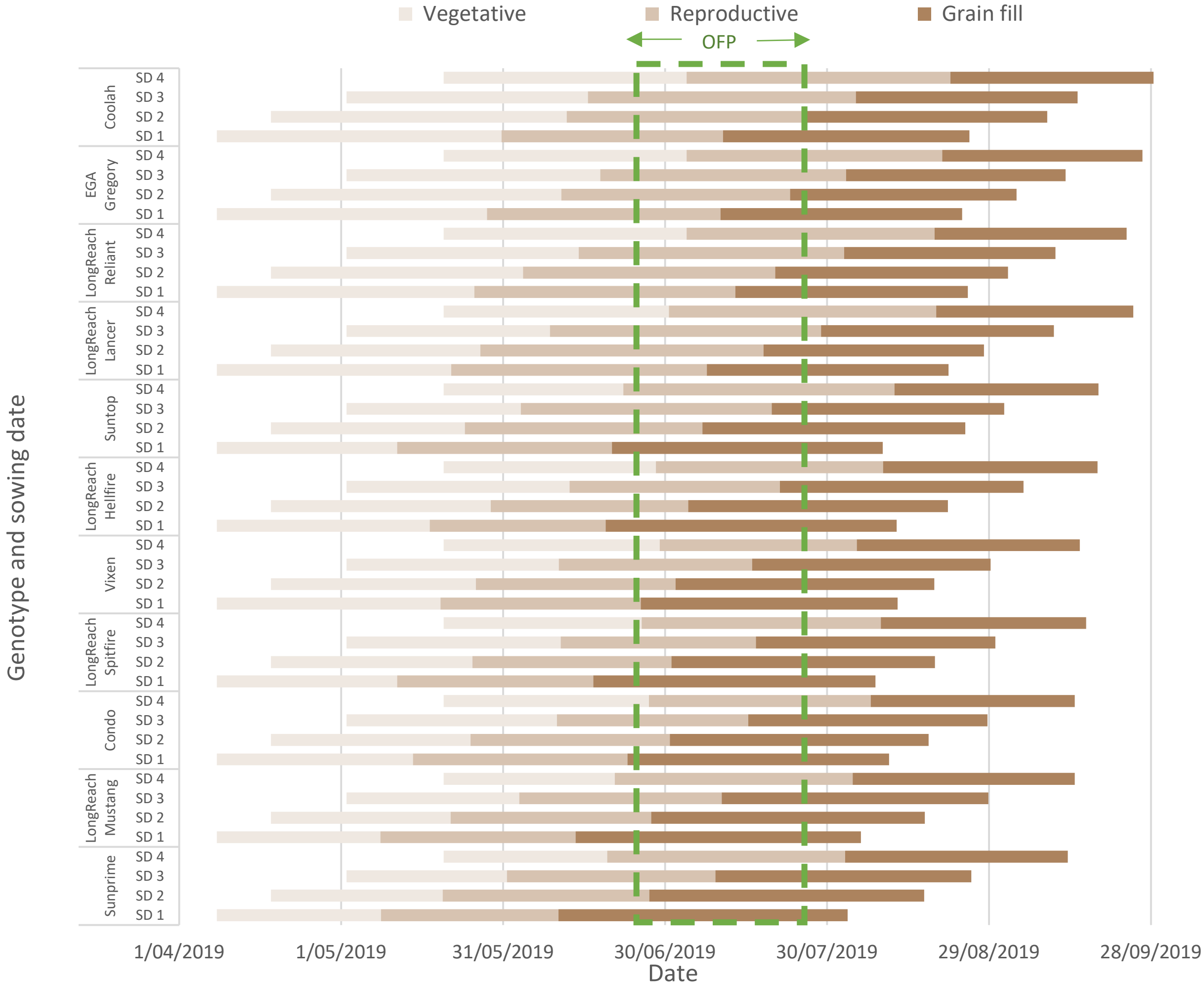

Figure 2. Crop development of 10 of the 32 genotypes used in the trial. All spring wheats had a spread of maturities from Coolah$^{\phi}$ (average 95 days to flowering) to Sunprime$^{\phi}$ (average 69 days to flowering) across the four sowing dates. The colour transition from reproductive to grain fill indicates when 50% flowering was achieved (GS65).

was typically a selection of quick-flowering spring wheats like Vixen⌽, Condo⌽, Sunprime⌽ and LongReach Mustang⌽ that were able to maximise yields. The only stand-out among the longer season varieties was the new mid-season variety, Catapult⌽, which had the highest yield in SD 2. Flowering from SD 4 did not begin until early August and was unable to match the higher yields of the earlier SD yields, regardless of maturity of the genotype.

Yields and quality

Grain yield and genotype rankings varied significantly across sowing dates (Table 3), highlighting the importance of varietal maturity when seeking to optimise yield across a broad planting window, like that observed in Central Queensland.

Table 3. Grain yields (kg/ha).

Genotypes	SD 1 8/04/19	SD 2 18/04/19	SD 3 2/05/19	SD 4 20/05/19
Beckom⌽	4875	4965	5273	4007
Catapult⌽	4529	5378	4876	3490
Condo⌽	4879	5296	5442	4319
Coolah⌽	4766	4427	4897	3626
Corack⌽	5349	4809	4814	4287
Cutlass⌽	4396	4570	4205	3420
DS Pascal⌽	4511	4370	4221	3432
EGA Eaglehawk⌽	3346	2361	3204	2178
EGA Gregory⌽	4718	4337	4301	2897
H45⌽	4578	5121	5249	4693
Janz	4836	5202	5148	3860
LongReach Dart⌽	4159	4173	4356	4108
LongReach Hellfire⌽	4653	5048	5134	4100
LongReach Lancer⌽	4560	4771	4826	3821
LongReach Mustang⌽	4620	4793	5150	4845
LongReach Nighthawk⌽	3319	3472	3836	2809
LongReach Reliant⌽	4282	4615	4472	3464
LongReach Spitfire⌽	4837	5005	4638	4266
Mace⌽	4799	4772	5075	3946
Mitch⌽	5317	5174	5072	4105
RGT Zanzibar⌽	3193	2904	3083	1720
Scepter⌽	5042	5132	5214	3815
Sunmax⌽	2490	2888	3361	2172
Sunprime⌽	4731	5310	5355	5052
Suntop⌽	4850	5025	5126	4137
Sunvale⌽	5013	4662	4455	3580
TenFour⌽	4324	4740	5038	4173
Trojan⌽	4412	4294	4197	3410
Vixen⌽	5115	5297	5258	4124
lsd within SDs	**689**			
lsd bewteen SDs	**725**			
SD average	**4482 a**	**4585 a**	**4665 a**	**3730 b**

The highest grain yield was achieved by a fast-developing spring type sown in early May (Condo⌽ with 5442 kg/ha in SD 3).

However, there was no significant statistical difference between the average yields of the top 10 varieties in 2019 (Table 4). There was only one mid-maturity variety in this list, and no slow or very slow maturities. This has been a consistent trend across the research project for the CQ site.

Table 4. Top ten yielding varieties across all four sowing dates in 2019.

Genotype	Maturity	Avg. yield (kg/ha)
Sunprime⌽	Very fast	5112
Condo⌽	Fast	4984
Vixen⌽	Fast	4948
Mitch⌽	Mid	4917
H45⌽	Very fast	4910
LongReach Mustang⌽	Fast	4852
Corack⌽	Fast	4815
Scepter⌽	Mid-fast	4801
Suntop⌽	Mid-fast	4790
Beckom⌽	Mid-fast	4780

Grain quality was also significantly affected by sowing date and maturity (Table 5). Grain protein for SD 1, SD 2 and SD 3 averaged 12.3%, but rose to average 13.8% for SD 4, which would be an expected trade-off as yield declined under stress conditions and screenings began to increase.

Grain screenings were not significantly different for SD 1 and SD 2 (2.45% average). However, SD 3 was significantly higher (4.2%), and SD 4 was significantly higher again (7.9%). The grain screenings data almost mirrored the yield response to flowering date (Figure 3). Any genotypes that flowered later than the OFP saw screenings rise. Quick maturity genotypes generally fared better, but all were significantly affected, especially the later the flowering date drifted beyond the OFP.

The maximum daily temperatures in August (Figure 4), neatly correlate with the spike in screenings (Figure 3). Temperatures spiked up to 30 °C in the first week in August, and then fluctuated between 25 °C and 30 °C for the rest of the month. In association with no rainfall, high evaporative pressure and low relative humidity over the period, this meant any genotype flowering in August was constantly under stress conditions during flowering and grain fill. This was reflected in the yield and grain quality responses, for SD 4 in particular. (Tables 4 and 5).

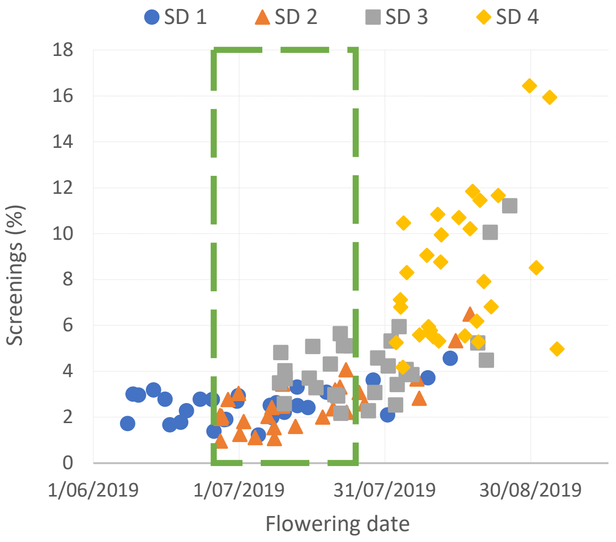

Figure 3. Grain screenings response to flowering date for all sowing dates for the 2019 trial.

Consistent with the drop in yield, screenings spike quickly in genotypes flowering after the end of July. The green dotted box shows the estimated optimum flowering period for 2019.

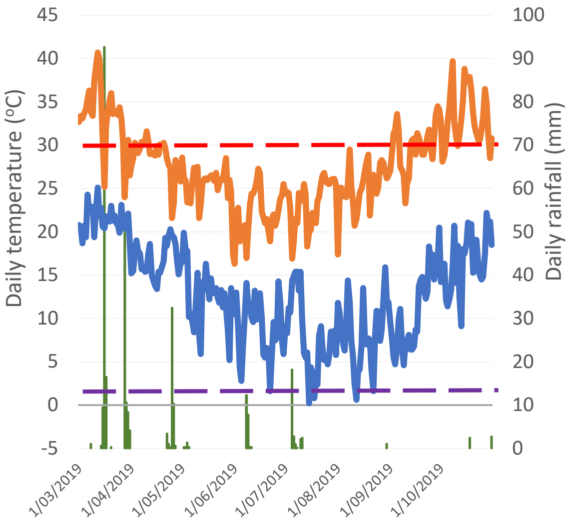

Figure 4. Daily temperatures and rainfall for Emerald over the duration of this trial.

The orange and blue lines show daily maximum and minimum temperatures respectively. Observations above the red dotted line (30 °C) indicate risk of experiencing heat stress, periods below purple dotted line (2 °C) indicate potential frost risk, depending on the crop's susceptibility at the time. Rainfall is indicated by green bars.

Table 5. Grain qualities.

Genotype	1000 grain wt. (g)				Test weight (kg/hl)				Screenings (%)				Protein (%)			
	SD 1	SD 2	SD 3	SD 4	SD 1	SD 2	SD 3	SD 4	SD 1	SD 2	SD 3	SD 4	SD 1	SD 2	SD 3	SD 4
Beckom$^{\phi}$	36.4	35.8	33.8	29.2	84.6	83.4	82.9	80.0	2.9	2.4	5.1	9.1	11.3	11.7	11.8	13.2
Catapult$^{\phi}$	39.1	38.6	37.1	28.6	83.8	82.8	81.5	76.7	2.6	3.2	4.2	11.8	12.4	11.8	12.2	14.5
Condo$^{\phi}$	45.0	45.0	41.3	32.4	85.4	86.0	85.3	81.8	2.8	3.0	3.7	5.6	11.2	11.6	11.2	12.8
Coolah$^{\phi}$	37.1	35.9	34.1	28.9	83.4	82.9	82.8	79.7	2.5	3.1	4.1	6.8	12.3	12.6	12.3	14.1
Corack$^{\phi}$	46.6	46.3	40.8	33.6	84.8	83.4	83.7	79.6	1.9	1.5	3.0	5.5	11.2	11.7	11.8	12.2
Cutlass$^{\phi}$	34.8	35.6	34.2	27.2	81.4	81.5	81.1	75.8	3.1	2.6	3.9	11.7	13.0	13.1	13.2	15.3
DS Pascal$^{\phi}$	32.7	31.5	31.4	26.3	81.6	81.6	80.8	77.0	3.3	4.1	5.9	11.5	12.8	12.7	12.5	14.6
EGA Eaglehawk$^{\phi}$	30.2	29.4	28.4	27.7	81.8	79.2	79.0	78.3	4.6	6.5	11.2	15.9	14.8	15.2	15.5	16.6
EGA Gregory$^{\phi}$	39.3	37.7	35.9	28.7	85.1	84.0	83.9	78.9	2.2	2.2	3.4	7.9	11.9	12.2	12.6	15.0
H45$^{\phi}$	40.6	40.8	36.8	32.2	85.8	85.2	85.6	83.2	1.7	1.0	2.6	6.8	11.1	11.4	10.7	11.4
Janz	39.8	39.0	37.4	30.3	85.1	84.5	84.5	82.0	1.4	1.1	2.2	5.3	11.7	11.7	11.7	13.5
LongReach Dart$^{\phi}$	40.1	38.8	36.3	32.3	83.3	83.2	83.4	80.5	2.8	2.8	4.8	10.5	12.5	12.1	12.3	12.6
LongReach Hellfire$^{\phi}$	47.1	45.6	40.7	34.2	84.8	83.8	84.0	80.8	1.8	1.1	2.9	5.8	13.0	13.0	12.6	14.4
LongReach Lancer$^{\phi}$	38.6	37.2	38.7	29.2	85.4	83.9	84.9	81.0	2.0	2.0	3.1	5.3	12.5	12.8	12.2	14.7
LongReach Mustang$^{\phi}$	42.8	42.7	41.0	34.8	84.8	85.5	86.2	83.8	3.2	2.0	3.7	4.2	10.9	10.5	10.5	11.2
LongReach Nighthawk$^{\phi}$	35.0	31.5	31.0	28.4	83.8	83.1	81.5	80.1	2.1	2.8	5.2	8.5	14.2	14.0	14.7	15.9
LongReach Reliant$^{\phi}$	42.5	41.9	38.6	30.7	85.1	83.5	83.7	80.3	2.5	2.4	2.5	6.2	12.2	11.9	12.3	13.7
LongReach Spitfire$^{\phi}$	46.4	44.5	39.4	34.2	85.5	84.8	83.8	81.9	1.7	1.3	3.3	5.9	13.1	13.0	13.0	14.1
Mace$^{\phi}$	40.8	40.2	37.4	32.1	83.0	82.5	81.6	78.3	1.9	2.5	5.6	10.8	11.1	11.4	11.3	12.6
Mitch$^{\phi}$	39.2	38.9	38.0	30.3	82.4	81.7	81.4	77.3	2.5	3.4	4.6	10.7	11.2	11.2	11.7	13.0
RGT Zanzibar$^{\phi}$	39.2	36.9	34.2	34.2	81.7	81.9	78.9	78.1	3.6	3.7	4.5	5.0	13.4	13.7	14.2	16.4
Scepter$^{\phi}$	44.1	41.6	40.7	32.6	84.2	83.0	82.9	77.8	2.7	2.5	5.1	9.9	10.9	11.1	11.1	13.2
Sunmax$^{\phi}$	32.1	30.2	28.1	27.2	82.1	80.3	78.3	77.2	3.7	5.3	10.1	16.4	15.3	15.6	15.7	17.5
Sunprime$^{\phi}$	42.7	43.1	41.1	37.7	83.8	85.3	84.5	82.4	3.0	2.1	3.5	5.2	11.6	11.3	11.3	11.9
Suntop$^{\phi}$	42.3	43.1	41.1	35.6	82.8	83.8	84.3	81.5	2.3	2.0	4.3	8.8	11.5	11.4	11.2	12.8
Sunvale$^{\phi}$	34.8	34.2	33.3	27.8	86.0	84.7	85.2	81.7	1.2	1.6	2.3	5.5	12.6	12.5	12.8	14.7
TenFour$^{\phi}$	40.3	40.3	37.7	32.1	83.4	83.9	82.9	80.0	3.0	1.9	4.0	7.1	11.8	11.4	11.6	12.5
Trojan$^{\phi}$	37.1	36.2	34.8	29.7	85.2	82.5	82.7	80.9	2.4	3.3	5.3	10.2	12.6	12.8	12.3	14.1
Vixen$^{\phi}$	44.2	43.3	38.1	31.9	84.2	82.9	81.9	78.2	2.8	1.8	5.1	8.3	11.0	11.2	11.4	12.4
lsd within SDs	2.2				1.5				0.26				0.6			
lsd between SDs	2.3				1.6				0.28				0.7			
SD average	**39.6** a	**38.8** a	**36.6** b	**31.0** c	**83.9** a	**83.3** ab	**82.9** b	**79.8** c	**2.5** c	**2.4** c	**4.2** b	**7.9** a	**12.2** b	**12.3** b	12.3 b	**13.8** a

Table 6 shows the effect of sowing date on yield and water use efficiency (WUE) in kg/ha/mm that was monitored for one standard genotype (EGA Gregory$^{\text{⏀}}$) across all trial sites. Yield and the conversion of plant available water into grain was reduced by nearly 30% in SD 4.

Table 6. Water use efficiency difference between sowing dates for EGA Gregory$^{\text{⏀}}$.

SD	WUE kg/mm	Yield (kg/ha)
1	17.2	4587
2	16.8	4312
3	18.7	4180
4	12.4	2816

Implications for growers

Seasonal conditions significantly influenced phenology, yield and grain quality responses to sowing time in 2019. Despite an excellent start to the season with almost full profiles of plant available water (PAW), there was little to no rainfall at the back-end of the season. Low relative humidity and rapidly increasing daily maximum temperatures increased plant stress, resulting in lower yields and grain quality as the flowering date got away from the optimal flowering window.

The threat of frost remains in the CQ region. Crops less than 50 km north and south from the trial site received significant damage during the cold events in hollows and lower lying areas in 2019. Chickpea next to the trial site also received significant flower drop and pod damage in the cold events in July, yet the wheat trial seemed unaffected.

Embracing this research is as much about balancing risk with reward. Our research has conclusively shown over the past three to five years, that flowering earlier within the optimum flowering period, to avoid heat stress during grain fill can provide some significant yield and grain quality uplift. Despite this, frost risk must be assessed on a case by case situation and managed accordingly so as not to forfeit any gains achieved from an earlier sowing date or change of genotype maturity. The missing link in this work is a definitive way to accurately estimate flowering date for a given genotype within a given environment.

After five years of trials, we can predict how quickly one of the trial varieties will flower at the Emerald trial site for a given sowing date, with some degree of confidence. This confidence falls away quickly with changes in the environment, plant available water and the effects of temperature or water stress events. Future research must continue to identify the optimum flowering period for a wider range of environments in Queensland, and assess the ever-changing array of varieties being released onto the market.

Acknowledgements

This trial was part of the 'Optimising grain yield potential of winter cereals in the northern grains region' project (BLG 104) led by Dr. Felicity Harris; a joint investment by the Grains Research and Development Corporation (GRDC) and New South Wales Department of Primary Industries (NSW DPI), under the Grains Agronomy and Pathology Partnership. The Queensland Department of Agriculture and Fisheries co-invested with GRDC and NSW DPI for the Queensland trial components.

I would also like to acknowledge Jane Auer and the other Regional Research Agronomy technicians based in Emerald for their assistance with observations and sample processing over the season.

Trial details

Location:	Emerald Research Facility
Crop:	Wheat
Soil type:	Grey Vertosol with pH of 7.2 (0–10 cm) and 7.1 (10-30 cm). The site had an average PAW at planting of 198 mm and 146 kg N/ha at planting.
Fertiliser:	35 kg/ha monoammonium phosphate (MAP) at sowing with 46 kg N/ha as urea offset from the planting row by 25 cm.
Climate:	In-crop rainfall (April–October) for SDs 1 & 2 was 98 mm and for SDs 3 & 4 was 49 mm. Minimum daily temperatures dropped close to or below the frost risk threshold five times (Figure 4) without any frost damage observed.

Wheat: Phenology and yield response to sowing time—Pampas

Darren Aisthorpe, John Lehane and Ellie McCosker
Department of Agriculture and Fisheries

Research Question: *How does time of sowing influence the phenology and grain yield of wheat genotypes?*

Key findings

1. Identifying and targeting the optimum flowering period will help maximise potential wheat yields.
2. In high yielding (low water stress) scenarios, varietal selection within a similar maturity type can become an important selection criteria. However, targeting the optimum flowering period remains the primary objective, no matter which variety is selected.

Background

In 2019, field experiments were conducted across ten sites in the northern grains region to determine the influence of phenology on grain yield responses for a diverse set of wheat genotypes. This paper presents results from Pampas in Southern Queensland (SQ) and discusses the influence of sowing date on the phenology and grain yield responses of a core set of 30 wheat genotypes.

Table 1. Expected speed to maturity of genotypes used in 2019.

Phenology type	Genotypes
Winter (W)	Longsword$^{\phi}$
Very slow (VS)	EGA Eaglehawk$^{\phi}$, Sunlamb$^{\phi}$, LongReach Nighthawk$^{\phi}$, Sunmax$^{\phi}$
Slow (S)	Coolah$^{\phi}$, EGA Gregory$^{\phi}$, Cutlass$^{\phi}$, DS Pascal$^{\phi}$, LongReach Reliant$^{\phi}$, LongReach Lancer$^{\phi}$
Mid (M)	Mitch$^{\phi}$, LongReach Trojan$^{\phi}$, Catapult$^{\phi}$, Sunvale$^{\phi}$
Mid-fast (MF)	Scepter$^{\phi}$, Suntop$^{\phi}$, Mace$^{\phi}$, Janz, Beckom$^{\phi}$
Fast (F)	Corack$^{\phi}$, LongReach Spitfire$^{\phi}$, LongReach Hellfire$^{\phi}$, Condo$^{\phi}$, Vixen$^{\phi}$
Very fast (VF)	Sunprime$^{\phi}$, LongReach Dart$^{\phi}$, H45$^{\phi}$, LongReach Mustang$^{\phi}$, TenFour$^{\phi}$

New releases are highlighted in colour.

What was done

The 2019 trial in SQ was conducted at 'Tosari', the new grains research facility near Pampas, south-west of Toowoomba. An above average yield potential was targeted in the flood-irrigated trial. The target population was 100 plants/m^2, planted on 25 cm row spacing with 7 rows planted per 2 m bed.

The three sowing dates (SDs) for 2019 were: 24 April, 6 May and 20 May. Irrigation water was applied to the site on four occasions prior to and during the growing period; a pre-plant irrigation in mid-April, post-plant of SD3 in mid-May, mid-tillering in late July, and during flowering and grain fill in early September. All treatments were harvested on 11 November 2019.

Results

Crop development

When considering variety options at sowing, growers should aim to synchronise crop development with seasonal patterns so that flowering occurs at an optimal time, typically a trade-off between increasing heat threat and declining frost risk.

In this trial, the combined flowering window for the 3 SDs spanned from 4 August to 6 October. Highest yields were achieved when flowering occurred from late August to mid-September. Yields then consistently declined once flowering occurred after 20 September (Figure 1).

There was variation in the genotypes' development responses to vernalisation and photoperiod, which resulted in phasic development of the crops varying significantly with respect to sowing time (Figure 2). This variation influenced the flowering and grain yield responses (Figure 1). Faster-developing spring types, with little to no response to vernalisation, developed quickly when sown early (SD 1); a period characterised by warmer temperatures and longer days.

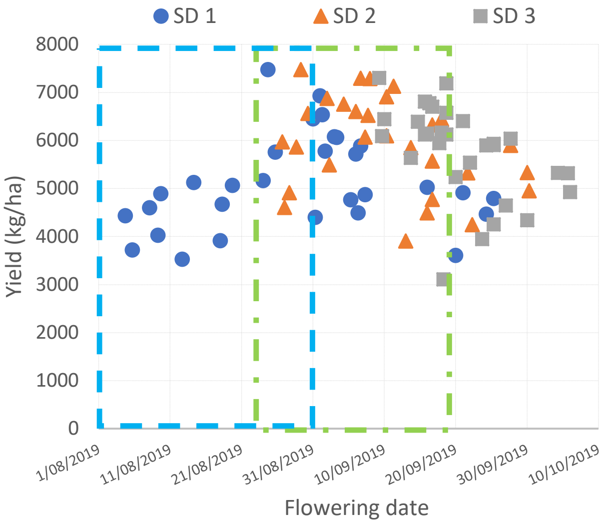

Figure 1. Flowering date for all sowing dates (SDs) and genotypes used in the trial.

Optimum flowering period for 2019 (marked in the green dotted box) was from late August to mid-September, with average yields noticeably falling away for any flowering dates after mid-September. The blue dotted box was the period of frosts for the year.

They subsequently flowered earlier than the optimum flowering period (OFP) for 2019, and frost compromised their yields. The long spring types and the winter types with their vernalisation requirement, had a prolonged vegetative phase that extended beyond the OFP. This also compromised yields as temperatures increased during the grain fill period.

For SD 1, it was the mid-maturing spring wheats like Beckom$^{\phi}$, DS Pascal$^{\phi}$ and Catapult$^{\phi}$ that maximised yields by flowering early in the OFP window of late August/early September. Quick spring wheats like LongReach Mustang$^{\phi}$ and Sunprime$^{\phi}$ performed poorly with reduced yields, as expected given they flowered during the peak frost periods (Figure 2). Equally, the long spring type varieties like Sunmax$^{\phi}$, Sunlamb$^{\phi}$ and the quickest winter wheats like Longsword$^{\phi}$ were still too long for the OFP (Figure 2) and again failed to yield to potential in the earliest SD.

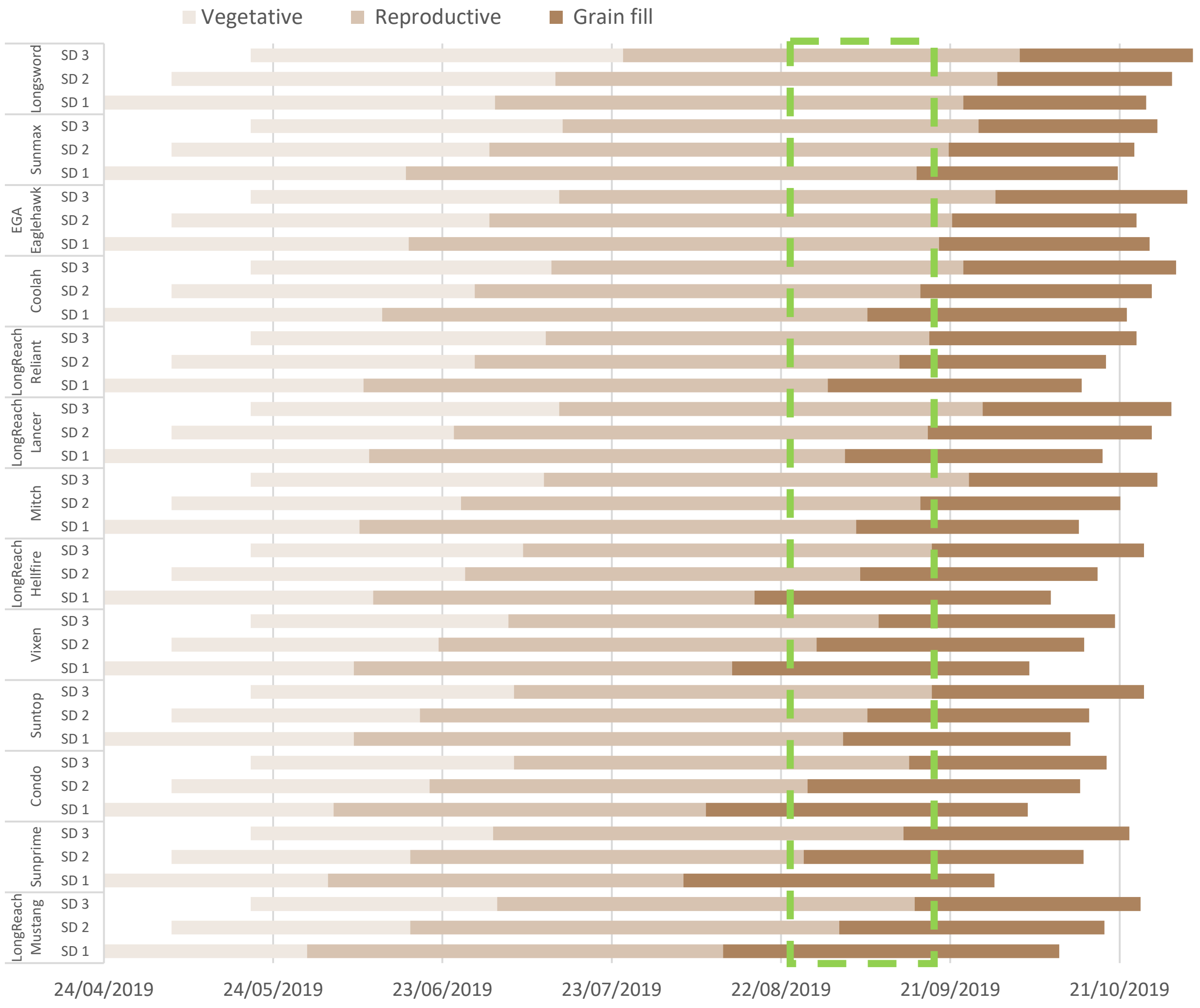

Figure 2. Phasic development of 13 of the 30 genotypes used in the trial. The transition from reproductive to grain fill indicates when 50% flowering was achieved (GS65). The green rectangle represents the optimum flowering period identified in Figure 1. All varieties listed are covered by $^{\phi}$.

For SD 2 and SD 3, Beckomᶲ continued to perform well. However, quicker maturity spring wheats like Vixenᶲ and Scepterᶲ were able to match or outperform it as they were not compromised by the frost damage that was experienced in SD 1.

Yields and quality

Grain yields and genotype rankings varied significantly across sowing dates from late April to late May. This highlighted the importance of varietal maturity when seeking to optimise yield across the broad planting window, which is catered for by the current selection of varieties suitable for Southern Queensland.

Table 2. Top ten yielding varieties across all three sowing dates.

Genotype	Maturity	Avg yield (kg/ha)
Beckomᶲ	Mid	7314
Catapultᶲ	Mid	6774
Vixenᶲ	Fast	6636
Trojanᶲ	Mid	6508
Scepterᶲ	Mid-fast	6415
Maceᶲ	Mid-fast	6407
Suntopᶲ	Mid-fast	6243
LongReach Lancerᶲ	Slow	6179
TenFourᶲ	Very fast	6097
Cutlass ᶲ	Slow	6081

The top-10 average yielding varieties across all three SDs are listed in Table 2, and a list of genotypes is in Table 3. The highest grain yield was achieved by planting either a mid-maturity spring type in late April (Beckomᶲ), or a quick-maturity variety in early May (Vixenᶲ).

Grain quality was also significantly affected by sowing date and maturity (Table 4). Grain protein for the first sowing date was 13%, dropping to 12.3% and 12.4% for SD2 and SD 3 respectively. Grain screenings were not significantly different for SD 1 and SD 2 (1.5% average). However, screenings were higher in SD 3 (2.5% average) with individual genotypes like Sunmaxᶲ, Longswordᶲ and Eaglehawkᶲ, well above the 5% delivery standard threshold. Most genotypes that flowered later than the OFP had higher screenings. Quick maturity genotypes generally fared better, but all suffered higher screenings as flowering dates became later (Figure 3).

Table 3. Grain yield (kg/ha).

Genotypes	SD 1 24/04/19	SD 2 6/05/19	SD 3 20/05/19	Trial avg across SDs	
Beckomᶲ	7476	7292	7190	7314	a
Catapultᶲ	6540	7129	6408	6774	b
Condoᶲ	4895	4911	6395	5286	ijkl
Coolahᶲ	4876	5571	5899	5449	hijk
Corackᶲ	3918	6568	6146	5544	hij
Cutlassᶲ	5888	6446	5909	6081	defg
DS Pascalᶲ	6931	5853	5241	6008	efg
EGA Eaglehawkᶲ	3609	4247	4343	4012	op
EGA Gregoryᶲ	4494	4496	3952	4314	no
H45ᶲ	4438	5970	6095	5501	hij
Janz	5782	6102	5537	5807	fgh
LongReach Dartᶲ	4031	5868	6443	5447	hijk
LongReach Hellfireᶲ	4676	6603	6125	5801	fgh
LongReach Lancerᶲ	6068	6429	6039	6179	def
LongReach Mustangᶲ	3529	5491	6127	5049	klm
LongReach Nighthawkᶲ	4911	5902	4929	5247	ijkl
LongReach Reliantᶲ	4399	3910	3111	3807	p
LongReach Spitfireᶲ	5070	6523	5947	5847	fgh
Longswordᶲ	4465	4951	5328	4915	lm
Maceᶲ	5757	6759	6706	6407	bcde
Mitchᶲ	4769	6328	5930	5676	ghi
Scepterᶲ	5170	7297	6777	6415	bcde
Sunlambᶲ	4796	5333	5318	5149	jkl
Sunmaxᶲ	5027	5325	4649	5001	lm
Sunprimeᶲ	3720	4605	5638	4654	mn
Suntopᶲ	6079	6071	6579	6243	cdef
Sunvaleᶲ	5722	4774	4254	4916	lm
TenFourᶲ	4604	6875	6812	6097	defg
Trojanᶲ	6449	6911	6163	6508	bcd
Vixenᶲ	5128	7476	7305	6636	bc
lsd within SDs		776			
lsd bewteen SDs		828			
SD average	**5116** b	**5917** a	**5777** a		

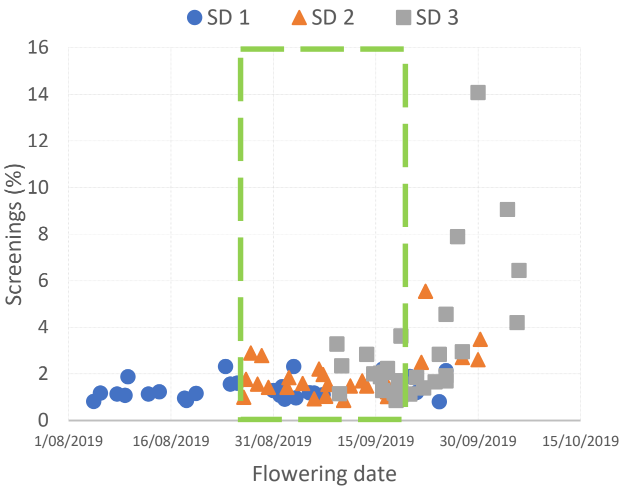

Figure 3. Effect of flowering date of grain screenings. Sowing date (SD) 1 and SD 2 screening levels were not significantly different on average. SD 3 had statistically higher average grain screenings than the first two sowing dates, with individual genotypes exceeding the 5 % delivery threshold.

Table 4. Grain quality measures of all genotypes and each sowing date.

Genotype	1000 grain wt. (g)			Test weight (kg/hl)			Screenings (%)			Protein (%)		
	SD 1	SD 2	SD 3	SD 1	SD 2	SD 3	SD 1	SD 2	SD 3	SD 1	SD 2	SD 3
Beckomᶲ	37.6	37.2	36.8	80.5	80.9	80.9	1.6	1.6	1.6	12.2	12.1	12.4
Catapultᶲ	46.1	45.0	41.3	81.0	80.8	80.0	1.4	1.5	1.9	11.6	11.4	11.9
Condoᶲ	48.9	46.7	41.1	83.1	83.4	83.1	1.9	2.9	2.0	13.3	12.6	11.8
Coolahᶲ	43.0	40.7	35.7	83.2	83.4	79.4	1.1	1.5	2.8	12.1	11.6	11.7
Corackᶲ	51.9	48.9	47.1	81.5	81.7	81.6	1.0	1.4	1.3	13.2	11.6	12.0
Cutlassᶲ	47.6	44.6	36.9	81.3	82.6	79.3	1.1	1.1	1.7	12.7	12.1	12.3
DS Pascalᶲ	40.9	37.9	35.6	81.8	81.3	82.2	1.1	1.5	1.1	11.6	11.8	11.9
EGA Eaglehawkᶲ	37.1	32.0	28.7	80.9	79.2	71.4	1.9	5.5	14.1	13.5	13.2	12.9
EGA Gregoryᶲ	42.7	42.3	40.1	82.9	83.8	81.7	1.1	1.5	1.7	12.6	11.5	12.8
H45ᶲ	39.2	40.8	38.0	82.2	84.0	84.4	0.8	1.0	1.2	14.0	11.8	11.8
Janz	42.0	41.3	36.7	82.8	83.5	81.9	0.9	0.9	1.4	12.7	12.4	12.9
LongReach Dartᶲ	44.1	41.1	37.3	81.2	81.3	77.7	1.1	1.6	2.4	15.2	13.3	12.4
LongReach Hellfireᶲ	50.7	46.8	45.2	82.9	82.5	83.2	0.9	0.9	1.1	14.0	13.5	13.4
LongReach Lancerᶲ	43.0	41.0	35.8	83.1	83.5	80.8	1.0	1.4	2.9	13.1	12.7	13.4
LongReach Mustangᶲ	47.6	44.8	41.9	82.2	84.6	83.3	1.1	1.8	1.9	13.5	11.6	11.2
LongReach Nighthawkᶲ	39.7	36.2	30.0	81.9	81.4	77.1	1.2	2.7	6.4	12.9	12.4	13.8
LongReach Reliantᶲ	45.3	43.3	42.4	81.8	84.0	83.2	1.3	1.7	1.7	12.6	11.4	12.0
LongReach Spitfireᶲ	49.2	46.4	45.1	82.8	82.4	82.6	1.2	1.0	1.2	14.6	13.6	13.7
Longswordᶲ	37.3	32.1	29.2	79.8	75.7	72.9	0.8	3.5	9.1	14.1	14.2	13.7
Maceᶲ	44.3	43.6	40.8	78.9	80.1	78.8	1.6	1.6	2.2	12.3	11.9	11.6
Mitchᶲ	48.0	43.1	34.9	80.9	80.9	75.1	1.2	1.2	4.6	13.0	11.6	11.7
Scepterᶲ	44.2	46.8	45.2	78.0	79.8	80.3	2.3	2.2	2.1	12.3	11.5	11.7
Sunlambᶲ	33.8	32.9	30.9	78.0	78.7	73.4	2.1	2.6	4.2	13.6	13.7	13.5
Sunmaxᶲ	39.7	39.3	30.1	81.3	78.4	72.2	2.2	2.5	7.9	13.2	12.5	13.3
Sunprimeᶲ	45.6	44.0	40.9	80.8	82.3	81.7	1.2	1.8	2.8	13.7	12.4	11.8
Suntopᶲ	43.6	41.0	38.4	81.7	82.7	80.8	2.3	2.0	3.6	12.1	11.7	11.4
Sunvaleᶲ	38.2	38.7	35.6	82.6	83.5	81.7	1.2	1.0	1.9	13.4	12.9	13.3
TenFourᶲ	47.4	45.8	41.8	79.5	82.1	82.5	1.1	1.4	2.0	13.7	12.5	12.0
Trojanᶲ	40.8	43.0	45.9	82.3	82.2	82.6	1.3	0.9	0.9	11.3	11.6	11.7
Vixenᶲ	46.9	43.7	39.7	80.5	79.1	78.7	1.2	2.8	3.3	13.1	11.9	11.8
lsd within SDs		2.7			1.8			0.19			0.6	
lsd between SDs		3.1			2.1			0.23			0.7	
SD average	43.5	41.7	38.3	81.4	81.7	79.8	1.3	1.7	2.5	13.0	12.3	12.4

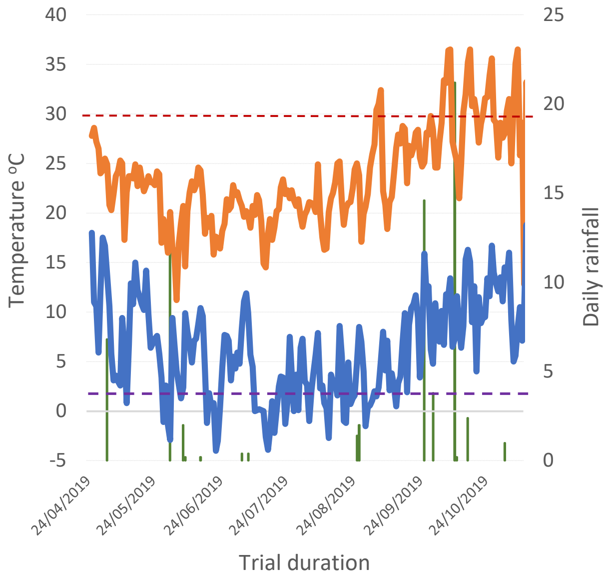

Figure 4. Daily temperatures and rainfall for Pampas in 2019 during the trial.

The orange and blue lines show daily maximum and minimum temperatures respectively. Observations above the red dotted line (30 °C) indicate risk of experiencing heat stress, periods below purple dotted line (2 °C) indicate potential frost risk, depending on the crop's susceptibility at the time. Rainfall is indicated by green bars.

Maximum daily temperatures in late October (Figure 4), neatly correlate with the spike in screenings. Any genotype flowering in the second half of October was constantly under heat stress conditions during flowering and grain fill, which was reflected in their yield and grain quality responses.

Flood irrigation and the inability to accurately assess how much water was applied made water use efficiency calculations impossible in this trial. However, Table 5 shows the difference (Delta) between starting plant available water (PAW) and finishing soil PAW to a depth of 180 cm over the period of the trial. The differences in residual water of 20% may be significant for future crop options.

Table 5. Soil water measurements taken before and after the trial at Pampas. The coloured columns indicate how much of the original plant available starting water was still available post-harvest.

	EGA Gregory$^{\phi}$				Suntop$^{\phi}$			
	Starting PAW (mm)	Harvest PAW (mm)	Delta PAW (mm)	% of starting PAW (mm)	Starting PAW (mm)	Harvest PAW (mm)	Delta PAW (mm)	% of starting PAW (mm)
SD 1	398	275	123	71%	377	268	109	71%
SD 2	372	229	143	61%	353	229	124	64%
SD 3	406	227	179	56%	448	228	220	51%

Implications for growers

Seasonal conditions significantly influenced phenology, yield and grain quality responses to sowing time in 2019. Despite an almost unlimited water profile, there was a prolonged frost period that lasted well into late August, followed by a relatively quick transition to hot dry days from late September onwards; both of which are typical conditions for the region.

Varietal variation played a more significant role in optimising yields in this trial than the sister experiment in Central Queensland. The OFP still played a very important role in maximising yields (Figure 2). The spread of yields within the OFP for varieties of very similar maturity was as high as 3 t/ha. However, this was in a low water stress environment, so such big differences would be less likely in a more typical dryland scenario. Importantly, the low water stress environment means the days to flowering observed in this trial may also be longer than what would typically be expected under traditional dryland conditions.

The targeted optimum flowering period for a location should stay relatively consistent to minimise the risk of stress on the flowering/early grain fill plants. The challenge is in selecting the correct maturity, which will flower within this period from year to year when variables like plant available water, sowing date and environment can vary significantly. Those agronomic influences will also influence plant stress, which in turn can significantly speed up or (in this trial's case) slow down the duration of time from sowing date to flowering.

While we can estimate an approximate days to flowering for the varieties trialled over the longer term at some locations, this confidence will diminish for locations with a different climate or soil type, or with brand new genotypes. This will be particularly evident in Queensland where there are significant differences between trial locations (Toowoomba and Emerald), and the subsequent phenology of the crops over the life of the project.

Acknowledgements

This trial was part of the 'Optimising grain yield potential of winter cereals in the northern grains region' project (BLG 104) lead by Dr. Felicity Harris; a joint investment by the Grains Research and Development Corporation (GRDC) and New South Wales Department of Primary Industries (NSW DPI), under the Grains Agronomy and Pathology Partnership. The Queensland Department of Agriculture and Fisheries co-invested with GRDC and NSW DPI for the Queensland trial components. We'd also like to acknowledge Duncan Weir as the SQ trial site lead before his departure from the Department in mid-2019.

Trial details

Location:	Pampas, southern QLD
Crop:	Wheat
Soil:	Light Grey Vertosol with a pH of 6.1 (0-10 cm) and 6.4 (10-30 cm). Plant available water (PAW) averaged 392 mm at planting and the site had 321 kg of nitrogen available down to 1.8 m.
In-crop rainfall:	(April-October) for each sowing date was SD 1-70 mm; SD 2-63 mm; SD 3-63 mm.
Fertiliser applied:	135 kg/ha monoammonium phosphate (MAP) and 100 kg N/ha as urea, offset from planting rows to ensure no nutritional limitations.

Sorghum: Winter sown sorghum in Central Queensland—Emerald

Darren Aisthorpe and Jane Auer
Department of Agriculture and Fisheries

Research Question: *Can sowing sorghum in winter avoid heat and water stress in Central Queensland cropping systems?*

Key findings

1. The late-July sowing date outperformed the mid-August sowing date with higher yield, better grain quality and reduced lodging.
2. A mid-August sowing date did not give sorghum sufficient time (less than 50 days) to achieve head emergence, flowering and commence grain fill before daily maximum temperatures begin to exceed the 35 °C threshold.
3. Exposure to temperatures above 35 °C during the flowering and grain fill period had a significant effect on the performance of the August sowing date.

Background

Water stress and extreme heat at flowering are common stresses limiting yield in cereal crop production across the northern grains region. Traditionally, most sorghum in Central Queensland (CQ) has been planted in summer to avoid flowering in the periods with the highest risk of heat stress. Spring-sown sorghum crops have also been planted once the risk of frost is gone and soil temperatures rise above 16 °C, but this period is considered very high risk as water/heat stress at flowering is very common. However, recent research has suggested that winter-sown sorghum may tolerate cold conditions and help target a less risky flowering period.

The Queensland Alliance for Agriculture and Food Innovation (QAAFI) leads a Grains Research and Development Corporation (GRDC) research project in partnership with the Queensland Department of Agriculture and Fisheries (DAF) and NSW Department of Primary Industries (NSW DPI) that is challenging perceptions of how early sorghum can be planted. This 'Optimising sorghum agronomy' project (UOQ 1808-001RTX) is testing the ability of sorghum to germinate and withstand cold temperatures during early growth stages, and so target flowering dates with lower temperatures during flowering and grain fill to minimise heat stress.

The early sowing dates were selected using CliMate to target a suitable flowering window with maximum (<35 °C to minimise heat stress) and minimum (>10 °C to reduce the chance of ergot infection) temperatures. Planting dates were determined so that head emergence began mid-September (Figure 1).

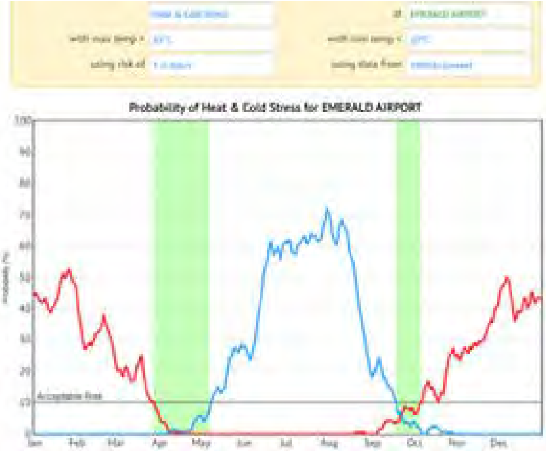

Figure 1. CliMate data since 1990 showing the likelihood of a temperature 'sweet spot' for flowering and grain fill. The green bars on the graph indicate there was a less than 1 in 10 year chance of receiving temperatures below 10 °C and above 35 °C in those periods.

What was done

The trial was planted at the Emerald Research Facility on a 1 m solid row spacing using a tyned parallelogram with V-Set precision seeding system. Eight hybrids with a range of maturities were planted across three times of sowing (TOS) at four populations ranging from 3 to 12 plants/m^2 (Table 1). The July and August-planted treatments were harvested on 11 December 2018. The traditional sowing date treatment (January 2019; TOS 3) suffered extremely dry conditions and consequent extreme bird pressure, and was not harvested.

Table 1. Treatments and sowing dates for the three times of sowing in the 2018/19 trial.

Hybrids used	Target populations per hectare	Time of sowing (TOS) dates
MR Apollo	30,000	TOS 1: 25 July 2018
MR Buster	60,000	TOS 2: 16 August 2018
MR Taurus	90,000	TOS 3: 17 January 2019
Cracka	120,000	
HGS114		
G33		
A66		
Agitator		

Results

Establishment

Soil temperatures at TOS 1 (17.8 °C) and TOS 2 (17.3 °C) were already above the industry-recommend minimum planting temperature of 16 °C. As a result, good establishment was achieved (Figure 2) with minimal post-emergent mortalities, despite minimum air temperatures between 25 July and 24 August regularly dropping below 5 °C.

Conversely, establishment was challenging for the January sowing (Figure 2). The field received 25 mm of rain on 22 December 2018 and an additional 60 mm of overhead irrigation prior to planting, however soil temperatures often exceeded 40 °C in the first 10 days post plant.

Flowering

Days to 50% flowering varied across the TOS dates. Despite less than one month's difference between TOS 1 and TOS 2, average days to 50% flowering were 84 days and 73 days respectively, with TOS 3 only taking 53 days (Figure 3). The target window to commence flowering for TOS 1 and TOS 2 was 17 September to 5 October. This was missed in TOS 1 by 10–15 days (50% flowering achieved on 5/10/18) and in TOS 2 by more than 20 days (the first variety achieved 50% flowering on 23/10/2018).

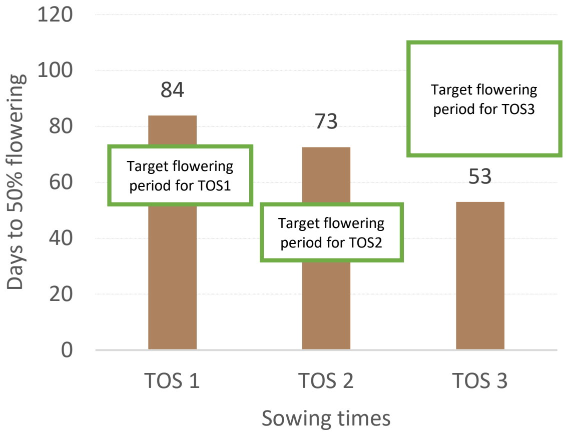

Figure 3. Average days to flowering for the three sowing dates. The target flowering period for each sowing date (based on Figure 1) is indicated by the green boxes.

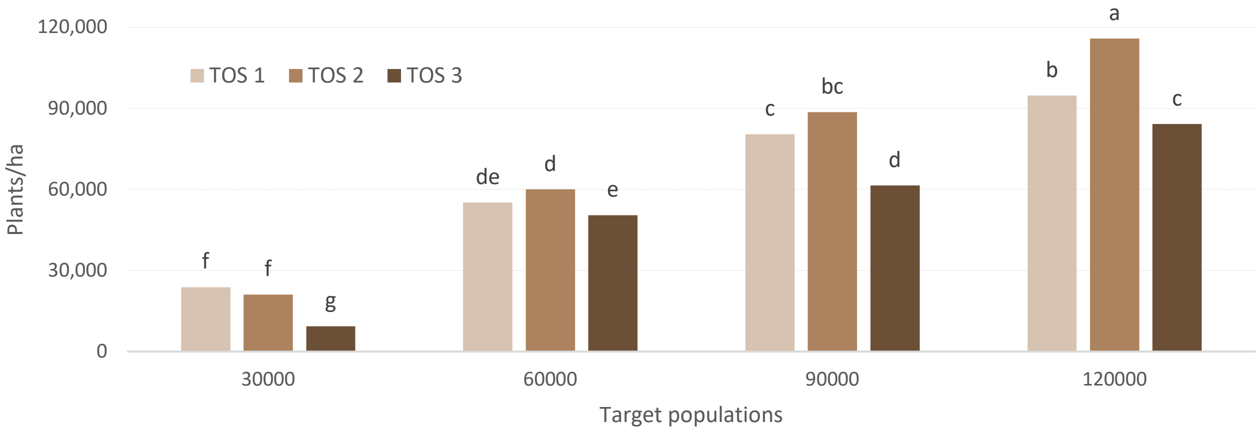

Figure 2. Average emergence across the three times of sowing for the four target populations. Minimal difference between TOS 1 and TOS 2 was observed on average, but TOS 3 had noticeably lower emergence that may have been linked to high temperatures during emergence (lsd 5%).

Grain yield

Grain yield was significantly different (P<0.01) between TOS 1 and TOS 2. TOS 1 had an average machine harvested yield of 3.8 t/ha while TOS 2 had an average yield of 2.4 t/ha across all varieties. Crop yield was affected by both bird damage and lodging. TOS 2 had particularly bad lodging. Charcoal rot (*Macrophomina phaseolina*) was observed in a number of treatments during biomass cuts. Other stems showed no sign of infection yet appeared quite fibrous and weak despite the size of the plant (Figure 4).

Figure 4. Four cut stems from TOS 2. One healthy (left) while the second and fourth stems are clearly affected by charcoal rot (*Macrophomina phaseolina*). The third stem from the left had no visible infection but was highly porous and weak.

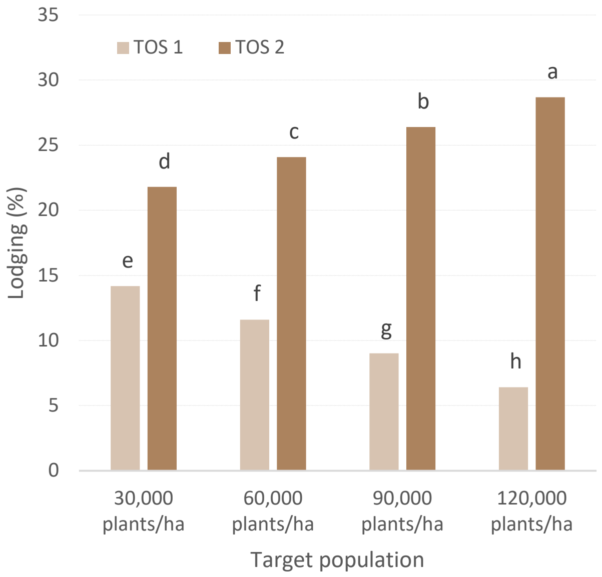

Figure 5. Lodging response to population and sowing date. For TOS 1, lodging decreased as population increased. Conversely for TOS 2, lodging increased as target population increased.

Screenings for both early TOS dates were above grain delivery specifications. However, TOS 1 had significantly lower screenings than TOS 2 (P=0.003), except at the lowest target population (Figure 7). Screenings generally decreased in TOS 1 as populations increased, with the highest population treatments (and the most heads/m^2) having lower average screenings than low population treatments in both TOS 1 and TOS 2. TOS 2 displayed a more typical response to population, with screenings increasing as population and viable heads per m^2 increased.

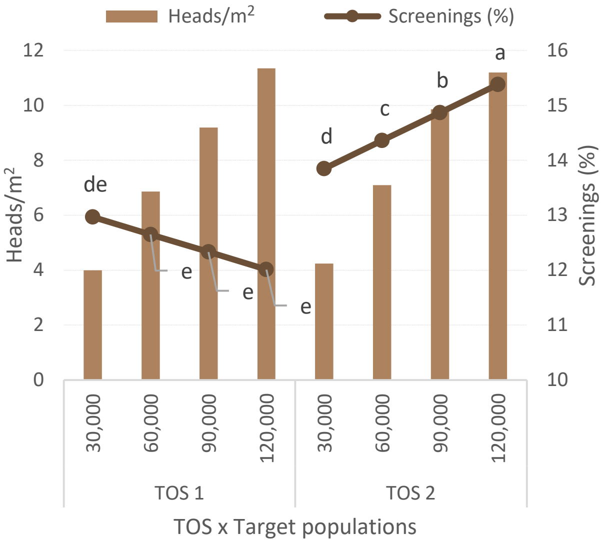

Figure 6. Relationship between heads per m^2 and screenings across the four populations for the first two sowing dates.

There was no significant difference in screenings between the populations in TOS 1; however, there was a significant difference in TOS 2 (P=0.002; lsd = 0.81%). There was no significant difference in head number/m^2 between the times of sowing for each population, however there was a population difference (P<0.001).

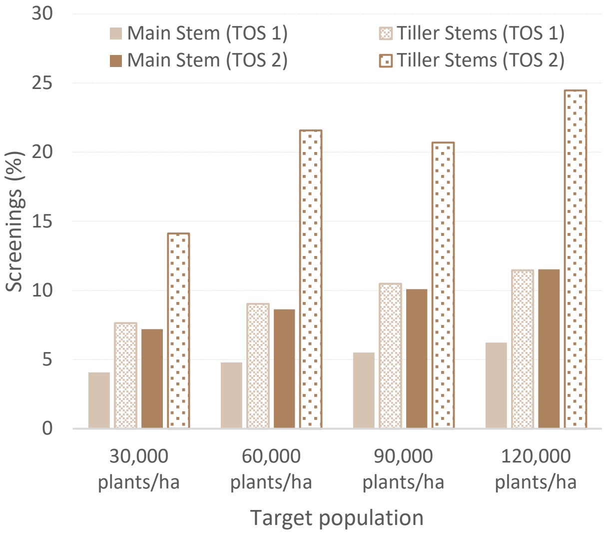

Figure 7. Average screening levels of grain samples collected from the main stem and tiller stems from all plots (avg. lsd = 2.26). TOS 1 screenings were significantly lower than those of TOS 2 for both main and tiller stems.

Grain size on 'tiller heads' are generally smaller than those on the main tillers, and this was very apparent for both of the early sowing dates. The July planted TOS 1 clearly had the lowest screenings for both main stem and tiller stems. However, what was quite remarkable was the significant 'blowout' in tiller stem screenings for TOS 2 (August), which was much higher than TOS 1 (July).

Implications for growers

Spring-planted sorghum has always been considered a high-risk proposition in CQ, and for very good reason. Daily maximum temperatures tend to rise rapidly from approximately 25 °C in mid-August up to 35 °C and higher in early October.

The premise of this project was less about soil temperatures at planting as the frost risk is lower in CQ than for southern areas. The focus was on targeting a relatively tight flowering 'window' of only three weeks, before average maximum temperatures exceed sorghum's estimated heat stress threshold of approximately 35 °C. The project was unable to achieve this in its first year. The target of having flowering for TOS 1 done in less than 70 days was missed by 14 days. However, the research still provided excellent insight into the potential benefits of avoiding the heat until later during the grain fill period.

TOS 2 was quicker and taller than TOS 1, but had no further advantages. TOS 1 out-yielded TOS 2 significantly and had better grain quality with similar in-crop rainfall. The benefits of the TOS 1 (July) plant over TOS 2 (mid-August) plant was apparent during the final period of crop development. TOS 2 had smaller grain, tighter heads and the plants simply looked more stressed that those of TOS 1.

Post spray-out lodging was significant across a range of hybrids. However, it was much worse in TOS 2 than TOS 1, in-line with observations that this lodging is strongly linked to stress during the flowering and grain fill period.

Possibly the greatest challenge for this type of out-of-season cropping is pest management. Birds were very attracted to this sorghum; it was the only crop on the Emerald Research Facility due to very dry conditions. Despite significant efforts to move the birds away (they were keen to share in this new learning experience), there was enough damage to make the TOS 3 yield data unusable.

Acknowledgements

Thanks to Queensland Alliance for Agriculture and Food Innovation (QAAFI) Toowoomba (Joseph Eyre & Daniel Rodriguez), New South Wales Department of Primary Industries (Loretta Serafin), the Department of Agriculture and Fisheries and the Grains Research Development Corporation for funding the project 'Optimising sorghum agronomy' (UOQ 1808-001RTX).

Thank you to Sam Lee from Cotton Seed Distributors for access to their FastStart™ Soil Temperature Network data set from 'Tandawanna' Emerald, while on-site logging equipment was established.

Trial details

Location: Emerald Research Facility

Crop: Sorghum

Soil type: A cracking, self-mulching, Grey Vertosol over 1.5 m deep with a plant available water holding capacity to 1.5 m of ~240 mm. Plant available water (PAW) at sowing was 195 mm. Post-harvest PAW was 140 mm to 1.5 m, with more than 70 mm of that sitting below 1 m depth.

In-crop rainfall:

- TOS 1 & 2: 141.8 mm.
- Between 11/12/2018 (harvest TOS 1 & 2) and 17/01/2019 (planting TOS 3): 58 mm rain + 60 mm irrigation pre-plant.
- 17/01/2019–15/03/2019 (57 days after sowing and past 50% flowering): 12 mm.
- 16/03/2019–01/05/2019 (TOS 3 written off due to damage from birds): 242 mm.

Pulse research

The 2018/19 season has seen a focus on nutrition management in mungbeans with the first trials harvested under the new 'Mungbean agronomy' project (DAQ1805-003RTX). The first season of trials in this project were structured around getting a response to applied nitrogen (N) fertiliser either in the presence or absence of rhizobia inoculation. The 2018/19 season will also be remembered as a particularly dry and hot summer season that made mungbean production more difficult.

Key learnings from trial sites located in Central Queensland (CQ) and Southern Queensland (SQ) were that high nitrate levels in the top 30 cm of the soil profile did not promote better yields than corresponding control treatments, whether the crop was inoculated or not. Natural mineralisation levels at both sites were quite high, with even the control treatments having access to over 100 kg N/ha down to 120 cm of soil depth.

Glasshouse pot trials conducted in the 2019/20 season showed that a background level of 32 kg N/ha in the top 30 cm of soil will reduce rhizobia populations significantly and caused a slight reduction in biomass production. Soil nitrate levels above 32 kg/ha did not significantly increase dry matter yield for either inoculated or uninoculated plants. It appears that high levels of nitrate in the soil does not increase mungbean grain yield or biomass, which is consistent with the initial findings from field trials in 2018/19.

Other glasshouse experiments have tried to quantify the impact of arbuscular mycorrhiza fungi (AMF) on the uptake of phosphorus (P) in the plant at different soil concentration levels. High levels of AMF significantly increased biomass production in mungbeans at low levels of soil P concentration (5–10 mg/kg). Once soil P levels exceeded 20 mg/kg, the AMF effect became negligible on biomass production. It is also worth noting that P concentration in the plant continued to increase as soil P levels increased all the way to 320 mg/kg, even though maximum biomass response was reached at 20 mg/kg. This would indicate that mungbeans have some ability to store luxury amounts of P.

Chilling effects on chickpeas have been widely observed to impact flowering and grain yield. Observations from commercial crops indicate that high stubble loads may exacerbate these chilling effects because of an insulation effect on soil temperatures. An experiment conducted at the Hermitage Research Station showed some impact from cold temperatures in the establishment phase of chickpeas in high stubble loads; however late rainfall proved to be the biggest influencer on yields and the high stubble loads proved to be more beneficial in maximising rainfall efficiency. This in turn meant high stubble load treatments gave a yield increase over the low stubble treatments. It would seem there can be contradictory outcomes to stubble management in chickpeas.

The 2018/19 season has provided some initial data on the nutritional management of mungbeans, particularly around N and P. Further experimentation over the next two years will provide more insight into nutrition of pulses.

Mungbean: Yield response to applied nitrogen—Irvingdale

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Department of Agriculture and Fisheries

Research Question: *Do N application parameters influence mungbean yields more than inoculation?*

Key findings

1. Mungbean may not respond to applied nitrogen fertiliser or inoculation where soil mineral nitrogen concentrations are adequate to achieve yield potential.
2. The soil nitrogen pool is highly dynamic and conditions favouring mineralisation can make significant amounts of mineral nitrogen available to the crop.
3. Effective nitrogen decisions for mungbeans require an understanding of your specific soil type, its ability to mineralise nitrogen and the conditions conducive to mineralisation.
4. The research confirms that mungbean may not nodulate when soils have high mineral nitrogen levels. However, the critical mineral nitrogen level requires further research.

Background

Over the past year the Mungbean agronomy team have been investigating the impact of timing and placement of nitrogen (N) fertiliser on yields of inoculated versus uninoculated mungbeans. Grower consultation identified a gap in knowledge about the nutritional management of mungbeans, 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's easier and more efficient to apply N in order to maximise yield. As mungbeans are a very short duration crop, some 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 mungbeans 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.

This begs the question, what is it about N applied early in the fallow that improves mungbean yield over those with N applied at planting? Does the better distribution of N in the soil profile help mungbean plants that have a small root system and few adventitious roots? Applying N early in the fallow should allow time for subsequent rainfall to redistribute the N more widely through the soil profile. This should increase the roots' efficiency, as root growth will be into N enriched soil and roots won't have to actively search for it. This research aims to clarify industry observations and identify if N application parameters influence mungbean yields more than inoculation.

What was done

A field experiment was conducted on a grower's property at Irvingdale (east of Dalby), selected for its moderate soil mineral nitrogen content at the time of sampling (76 kg N/ha, 0-90 cm, 1/11/2018) to maximise potential N responses. Table 1 lists the treatments.

Table 1. Details of nitrogen treatments.

Treatment*	N rate (kg N/ha)	Inoculated
Nil	0	Yes
Nil	0	No
Planting	100	Yes
Planting	100	No
Fallow $^{1}/_{2}$ + Planting $^{1}/_{2}$	50:50	Yes
Fallow $^{1}/_{2}$ + Planting $^{1}/_{2}$	50:50	No
Fallow Deep	100	Yes
Fallow Deep	100	No
Fallow Shallow	100	Yes
Fallow Shallow	100	No

*Fallow treatments were placed at ~5cm (shallow) and 15-20cm (deep).

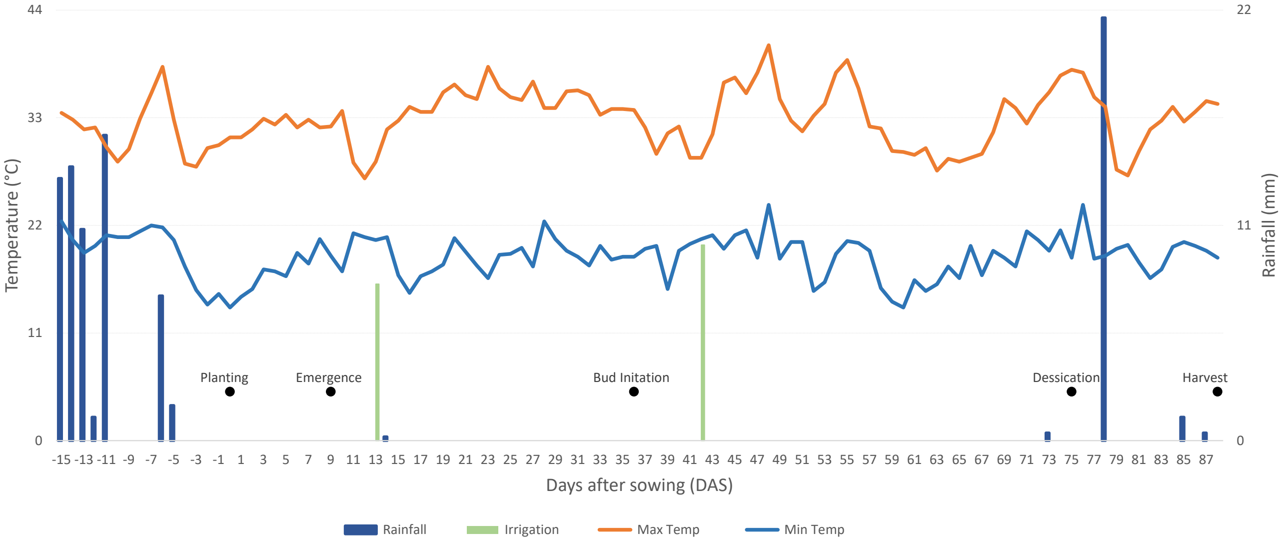


Figure 1. Maximum and minimum daily air temperature, daily total rainfall and crop phenology throughout the mungbean growing period.

Fallow N was applied on 9 November 2018 and planting treatments were applied on 28 December 2018 by banding N fertiliser in between the plant row (Table 1). There was 64 mm of rainfall recorded between fallow N applications and planting.

There were no detected nematodes and arbuscular mycorrhizal fungi (AMF) levels were low. Plots were 16 m x 6 m in a complete randomised block design with four replications per treatment. Jade-AU$^{\text{⌽}}$ was planted at 50 cm row spacings with 25 kg/ha of Supreme Z® applied. Planting was carried out using a disc planter. However, surface moisture was quickly lost and supplementary overhead irrigation equivalent to 8 mm/ha was applied to promote establishment. Due to ongoing dry conditions (Figure 1) a follow-up irrigation of 10 mm/ha rainfall equivalent was applied at flowering via trickle tape.

Results

Acceptable establishment was achieved (15–18 plants/m^2), albeit lower than recommended levels to maximise yield, and unfortunately patchy. There was however, no significant difference in yield between treatments (Figure 2). The lack of rainfall would have also reduced nitrogen movement within the soil profile during the fallow and growing periods. The mungbeans yielded well considering the tough conditions, averaging just over 1 t/ha yield across all treatments, suggesting that the critical maximum temperature for mungbeans to begin aborting flowers may be higher than the currently accepted 33 °C.

Indeed, temperatures throughout the trial were extreme with an average maximum daily temperature of 33 °C. There were 47 days (62%) above the 33 °C currently believed to initiate flower abortion and yield decline.

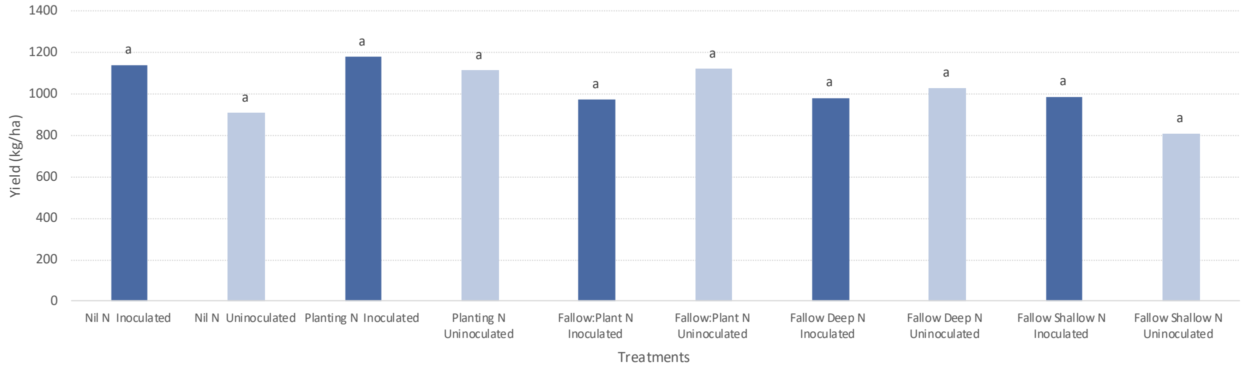


Figure 2. Hand-harvested yield.

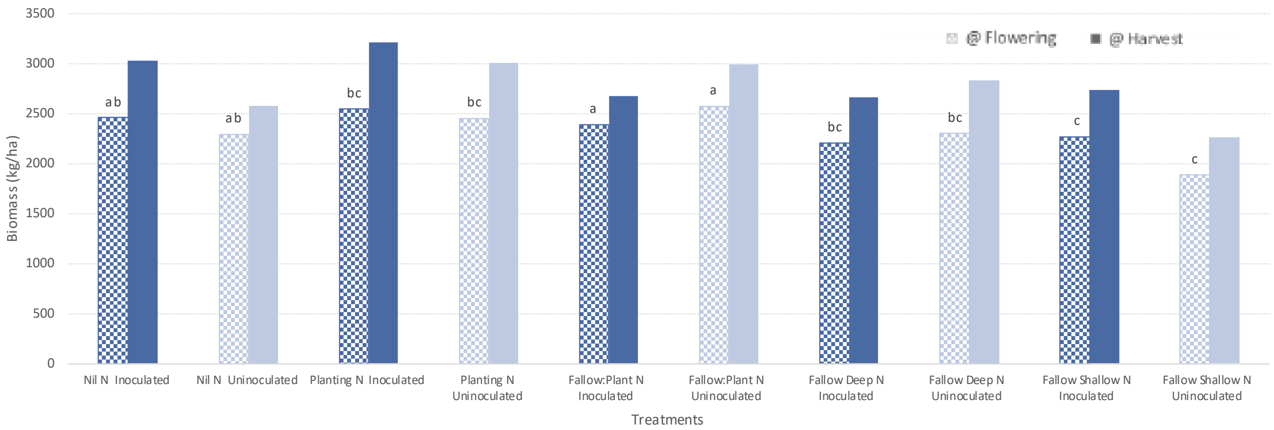


Figure 3. Biomass at flowering and harvest. Different letters indicate a significant difference at the 5% level.

Almost all days from emergence to bud initiation, and several days from bud initiation to maturity were above 35 °C, causing extreme stress on the mungbeans. There did not appear to be any differences in crop phenology between treatments. Due to the heat, the crop only took 65 days from planting to physiological maturity.

Biomass aranged from 1.5–2.1 t/ha at flowering and from 2.3–3.2 t/ha at harvest, with the only significant difference detected being between the nitrogen treatments at flowering; no inoculation effects were seen (Figure 3).

Light interception readings were taken weekly during the life of the crop (Figure 4) to determine leaf area index (LAI). The Nil N - inoculant treatment had the lowest LAI from the second reading onwards, with the Fallow Deep N – inoculant recording the highest.

Starting plant available water (PAW) was 145 mm with the majority available from 0–80 cm (Figure 5). The only recorded in-crop rain occurred after desiccation was unused by the crop, and so was detected in the surface PAW measurements. There were no significant differences detected in PAW at harvest between the treatments.

There was no nodulation across all treatments. As the trial was inoculated utilising stringent inoculation techniques, this is most likely due to the high levels of starting N in the soil. The low AMF levels observed in the trial may also have reduced nodulation (further research is currently being undertaken in this area by DAF and the University of Southern Queensland).

Soil nitrogen was measured at harvest. However, the lack of in-crop rain meant the nitrogen applied at planting may have still have been concentrated in narrow bands and not captured in the soil sampling. The most valuable comparison is the Nil N treatments. Both the inoculated and uninoculated treatments utilised similar amounts of N during the growing season (Figure 6), which was not surprising due to the lack of visual nodulation within all treatments. Both treatments utilised mineral nitrogen (46 kg/ha Nitrate-N) mainly from 10 cm through to 90 cm.

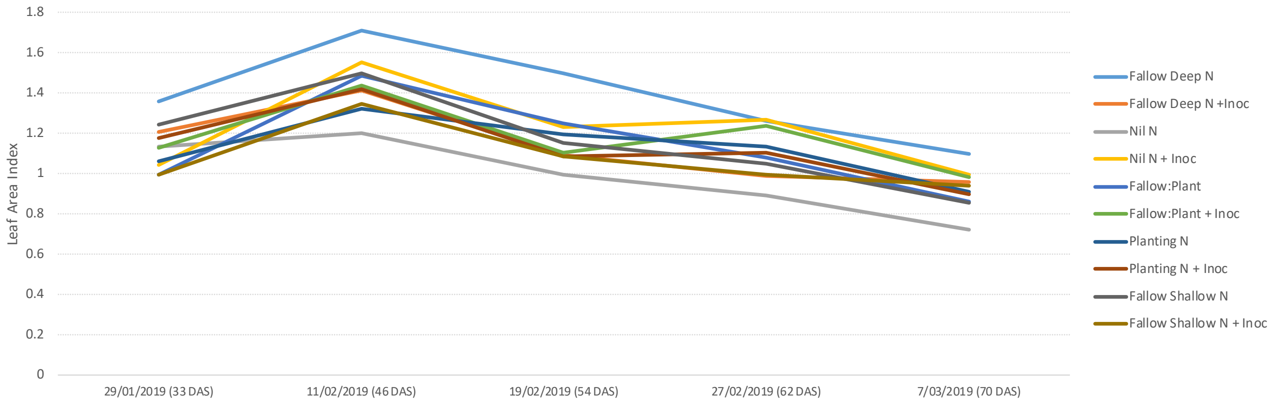


Figure 4. Leaf area index readings. DAS = days after sowing.

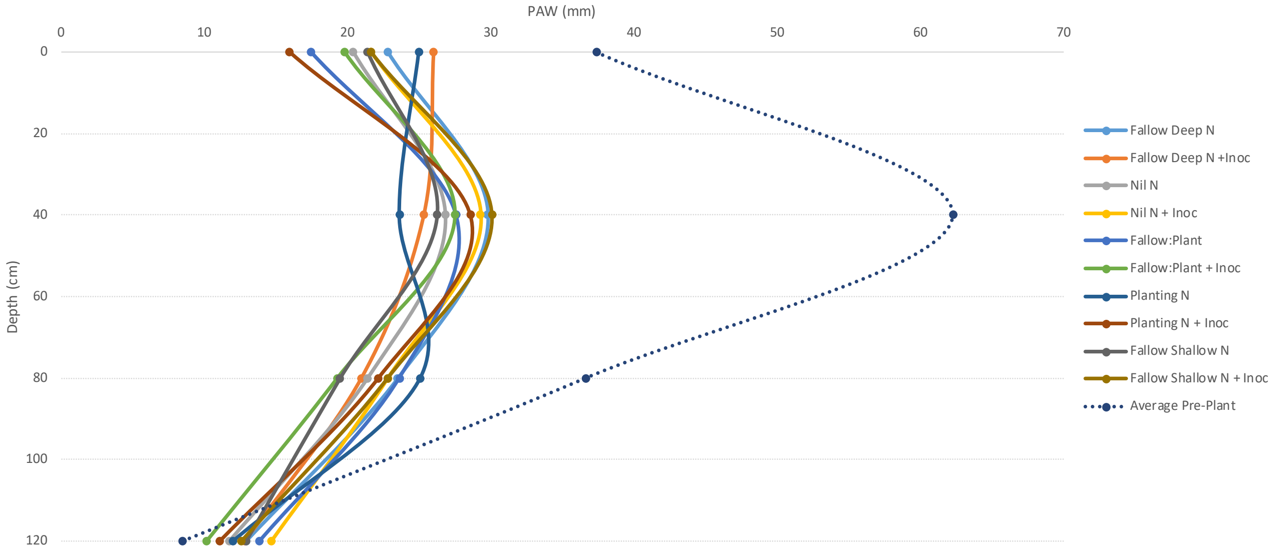


Figure 5. Plant available water (mm) at harvest.

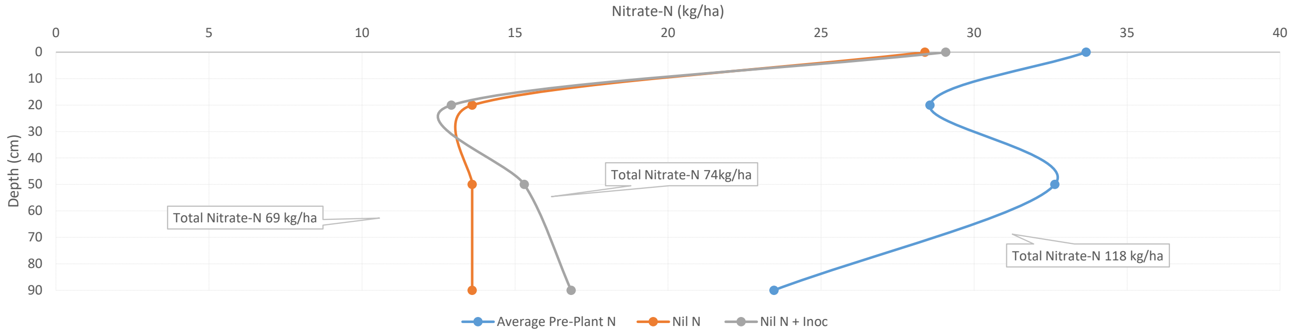


Figure 6. Nitrate nitrogen at planting compared to harvest for both Nil N treatments.

Implication for growers

The application of nitrogen fertiliser at a range of depths and timings did not result in a change in mungbean grain yield in this dry season with yields around 1 t/ha. Prior to planting, mineralisation contributed considerably to the plant available nitrogen pool. This highlights the importance of understanding highly dynamic soil types before making a planting decision. In just over two months with a total of 64 mm of rain, the soil mineralised 30 kg N/ha, which dramatically changed the dynamics of the soil and hence the mungbeans' ability to nodulate. As the crop had this additional nitrogen available at planting it may not have drawn on nitrogen fertiliser nor nodulated as there was adequate mineralised nitrogen readily available.

This however doesn't rule out the need to inoculate mungbeans as soil dynamics mean nodulation may be called on by the plant when soil N is low. Further investigation is currently underway to establish the point at which nodulation is reduced or stopped at varying levels of nitrogen.

Trial details

Location:	Irvingdale
Crop:	Mungbeans
Soil type:	Grey Vertosol
Rainfall:	See Figure 1
Fertiliser:	25 kg/ha Supreme Z® and as per treatment list.

Nutrient analysis of paddock prior to planting:

Nutrients	0-10 cm	10-30 cm	30-60 cm	60-90 cm
Nitrate at planting (kg/ha)	34	29	33	18
Phosphorus Colwell (mg/kg)	76	12	-	-
Phosphorus BSES (mg/kg)	351	167	-	-
Sulfur (mg/kg)	6.0	3.7	-	-
Organic carbon (%)	1	0.89	-	-

Mungbean: Yield response to applied nitrogen—Emerald

Douglas Sands and Peter Agius
Department of Agriculture and Fisheries

Research Question: *Do N application parameters influence mungbean yields more than inoculation?*

Key findings

1. Background nitrogen was too high to ascertain response to additional nitrogen treatments.
2. Inoculation had a slightly negative effect on yield in some nitrogen treatments.
3. Mungbean roots maybe more sensitive to banded nitrogen than first anticipated.

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 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 in relation 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 examine whether this anecdotal evidence can be replicated in a small plot field experiment.

The other question in relation to N application was whether inoculation had a positive or negative impact in relation to applied N. While the majority of 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 for the nodules to have a chance to establish, or the plant is obtaining its N from another source.

What was done

A low N site was identified at the research station located on the Emerald Research Facility. The soil analysis from this site calculated a total of 44 kg N/ha in the profile down to 120 cm, with 28 kg N/ha in the top 30 cm. This soil test was done in November 2017, 12 months prior to application of the first N treatments. The fallow N treatments were accompanied by 75 mm of overhead irrigation. All N treatments were applied at a rate of 100 kg N/ha to ensure there was a large difference between the applied N and the mineralised N already in the profile.

Treatments included:

1. Nil (No applied N), +/- inoculation (**Nil N**)
2. Fallowed applied N; Shallow (banded in the top 5cm), +/- inoculation (**Fallow Surf N**)
3. Fallow applied N; Deep (banded at 15cm depth), +/- inoculation (**Fallow Deep N**)
4. Fallow applied N Split; Deep & Shallow (50% banded at 15cm and 50% banded top 5cm), +/- inoculation (**Fallow Surf:Deep**)
5. Applied N Split; Fallow & Plant (50% banded at 5cm in fallow and 50% banded at planting at 5cm and offset to the planter row), +/- inoculation (**Fallow:Plant**)
6. Applied N: at planting (100% N banded in between rows at planting), +/- inoculation (**Planting N**)
7. Applied N Split; Planting & Sidedress (50% banded at planting and 50% banded after crop establishment), +/- inoculation (**Plant:S/dress**)

The site was planted on 25 February with Jade-AU$^{(D)}$ mungbeans, and irrigated. Establishment issues caused the initial planting to be sprayed out and the site was replanted on 25 March. This planting date was considered late for mungbeans but the project team decided to replant to ensure good plant establishment. The second planting was sown into a full profile of moisture from prior rainfall events and no additional irrigation was used in-crop. Plant establishment was adequate with most treatments averaging 19–23 plants/m^2.

Soil cores were taken at planting for chemical soil analysis and soil moisture assessments along with soil samples taken to assess nematode populations (Predicta® B). Full destructive biomass cuts were taken at first flower and full maturity. A third biomass cut was taken at peak biomass for 15N assessment along with cuts taken from associated sorghum strips planted within each replicate of the trial and grown on the same N treatments.

Light interception measures were taken at 35, 44, 56 and 65 days after sowing (DAS) to capture canopy development. Grain yields were measured using a two metre plot harvester and soil cores were taken from every plot after harvesting and analysed for N and soil water content.

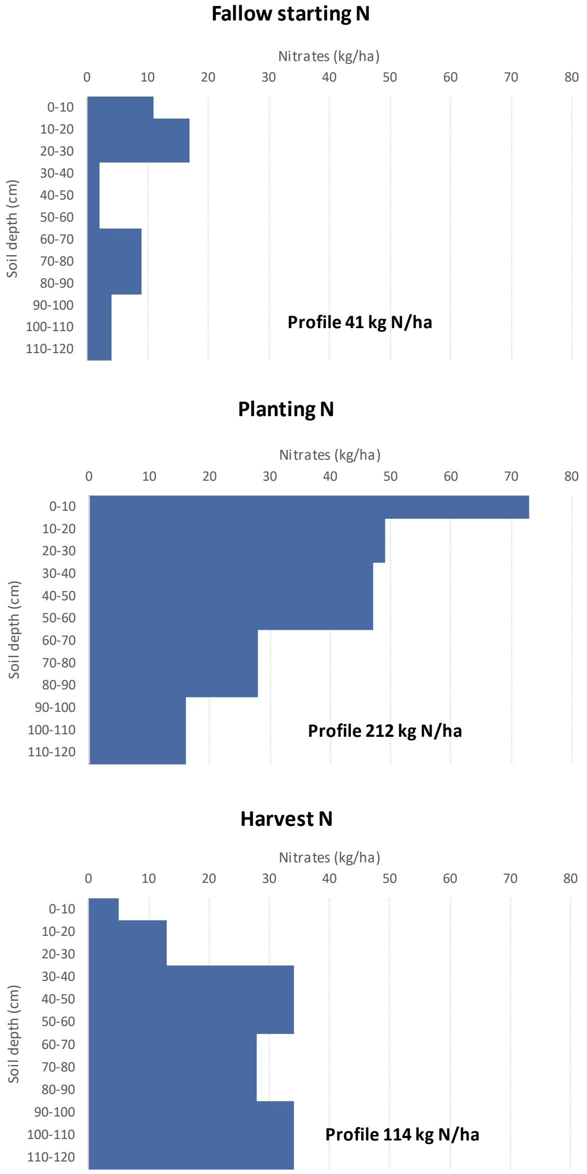
The crop was harvested on 25 July after a major frost event occurred on 18 July.

Results

The critical assumption made in regards to this trial was that the soil had minimal levels of N. Although N levels were low at the end of the previous crop grown on this site, soil tests at planting revealed that a large amount of N had been mineralised (Figure 1) even though organic carbon levels for this site (0.55%) would suggest mineralisation should have been low.

The soil results from Nil N (Figure 1), suggest that ~100 kg N/ha was removed from the profile over the duration of the crop. It can be assumed that the majority of this N would have been used by the crop although there could have been some small losses in leaching and denitrification. These losses cannot be quantified, however given the late planting of the crop and the cooler temperatures experienced for much of the crop's life, denitrification processes should have been limited. The nature of strongly cracking, self-mulching Vertosol soils would also result in very minor leaching through the profile.

The amount of mineralised N available in the profile after the fallow would suggest that this soil was no longer N limited therefore the response to further applied N would be minimal.


Fallow starting N

Planting N

Harvest N

Figure 1. Comparison of mineralised N in the profile in the control (Nil N) treatments: starting fallow (25/6/17), at planting (25/3/19) and post harvest (6/8/19).

Overall machine-harvested yield results for the trial were low compared to long term averages for the region (0.8 t/ha) (Figure 2). There were significant losses across the header front because of the general height of the crop. In some replicates there was also damage from pigs walking through the plots. In addition to this, plants were frosted near maturity, which weakened the crop's standability at harvest and increased the losses over the header front.

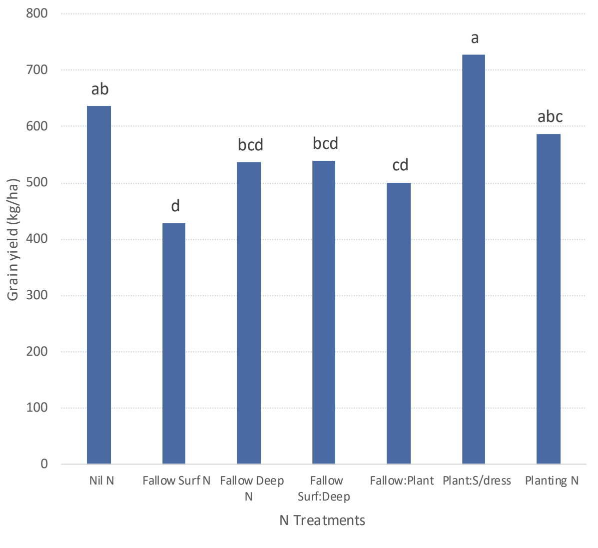


Figure 2. Mean machine harvested grain yields for N treatments. Means with same letters are not significantly different at P(0.05)

The relatively late planting date may have had an impact in regards to heat accumulation (which was slow) and the crop length meant that the plant was maturing into the colder part of the year. Harvest index figures ranging from 0.10–0.16 would also indicate that the plant did not maximise its grain production from the amount of vegetative dry matter accumulated.

Table 1. Machine and hand harvested yields across all treatments.

N treatments	Machine harvest yields (kg/ha)	Hand harvest yields (kg/ha)	Machine harvest as % of hand harvest yields
Nil N	636	1231	52
Fallow Surf N	420	1161	36
Fallow Deep N	534	1127	47
Fallow Surf:Deep	539	1094	49
Fallow:Plant	521	1217	43
Planting N	526	1251	42
Plant:S/dress	732	1460	50

Hand harvest yields (Table 1) provide a better context for the overall performance of the plant. Hand harvest yield data are almost double what was measured through the header. Using hand harvest data to calculate harvest index figures (not shown) improves the index results to between 0.26–0.30, which is much closer to the optimum harvest index of 0.30–0.35 and would indicate that the plants were much closer to achieving their full yield potential than first thought.

A number of light frost incidences in June may have reduced grain yields. Hand harvest data suggests that 10-15% of pods were underdeveloped and would not have made grain. Used as an indicator of frost damage this would amount to ~100 kg/ha.

The yield results (Figure 2) suggest that there was no clear response to additional nitrogen and this may be due to the level of mineralised N available (Figure 1) in the profile at planting. This analysis was not changed greatly by using hand harvest yield data; the proportional difference between treatments was still the same.

Early black pod maturity stage.

Impact of frost on plants nearing full maturity.

There is a clear significant difference between the highest (Plant:S/dress, 50% split) and lowest (Fallow Surf N) yielding treatments. The reasoning for this is not clear although one potential explanation could involve the positioning of the fertiliser band.

The Fallow Surf N treatment had the most concentrated band of fertiliser (100 kg N/ha) at a shallow depth (5 cm) and positioned on the plant row. The Plant:S/dress treatment would have had all its fertiliser banded ~25 cm to the side of the plant row because of the machinery configuration required to plant and fertilise at the same time. Although the Fallow Surf N treatment was applied four months prior to planting and had two irrigations plus significant rainfall to help dissolve and redistribute the band, this may not have been enough in a heavy Vertosol soil to avoid some fertiliser burn or implications to root development.

The other treatments would have had varying levels of band concentration in and around the plant row which may explain some of the variability in the results. It is worth noting that the three highest yielding treatments (Figure 2) had no fertiliser placed in line with the plant row.

The other significant issue in the yield data is the control treatment (Nil N) was one of the highest yielding treatments, which indicates that the response to applied N was limited. Possible explanations for this include that the background N that had mineralised during the fallow was sufficient for the plants' requirements (Figure 1) or that the plant is simply not responsive to soil nitrate.

A comparison of residual N left after harvest for each treatment (Figure 3) would suggest that there was little significant difference between treatments in relation to how much N was utilised by the plant. The Nil N treatments had the least amount of N in the profile, which is not surprising given it was the only treatment that did not have additional 100 kg of N applied.

The split Plant:S/dress treatment was the only application that had a residual N mean that differed greatly from the other treatments, however even in this case the confidence intervals would suggest that the standard errors for each treatment are too large to be able to make any comment on the differences in residual N values.

It is worth noting that the split Plant:S/dresss treatment utilised the largest amount of N out of the profile (Table 2; 157 kg/ha) and coincidentally this treatment was also the highest yielding (Figure 2).

Table 2. Calculated nitrates used by the crop across all treatments (all treatments had a starting N of 212 kg/ha measured at planting).

Treatments	N applied in treatments (kg/ha)	Post-harvest residual N (kg/ha)	Total N used by plant or lost from system (kg/ha)
Nil N	0	114	98
Fallow Surf N	100	194	118
Fallow Deep N	100	188	124
Fallow Surf:Deep	100	194	118
Fallow:Plant	100	236	76
Planting N	100	196	116
Plant:S/dress	100	155	157

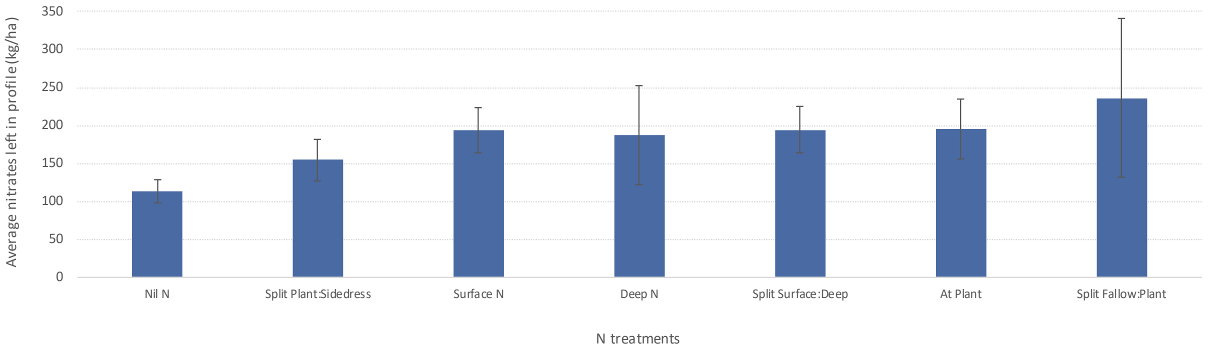


Figure 3. Comparison of the amount of total residual nitrates left in the profile (120 cm) after harvest.
The error bars represent the 95% confidence intervals for each of the treatment means.

The comparison between inoculated and non-inoculated seed showed no significant difference as a main effect, however there was some interaction between the inoculation split and the N treatments (Figure 4).

Three N treatments showed a significant difference approaching the 5% level between the inoculated and non-inoculated plots. Surprisingly the non-inoculated plots had the superior yield by over 200 kg/ha (~30%). It is not clear why these treatments (Nil N, Fallow Deep N and Planting N) responded in this way while the rest of the treatments had no significant interaction with the inoculant.

It is possible that the three treatments that showed an interaction did not have banded N close to the plant row and this would have created a more hospitable environment for the bacteria to expand. If the plant was required to contribute some resources to the development of the rhizobia then this may have impacted negatively on the plant compared to a plant that had no inoculant and was not obligated to contribute any resources to the symbiotic relationship.

This concept could be supported by the fact that there was a significant difference in dry matter production at first flower between inoculated and non-inoculated treatments (P=0.02). Analysis showed that the non-inoculated treatments averaged 1942 kg/ha versus 1805 kg/ha in the inoculated treatments. This was the only significant difference obtained from all the dry matter production data recorded.

While there is no statistical difference between N treatments in regard to vegetative dry matter production it is worth noting that all treatments grew more vegetative dry matter after first flower was reached (Figure 5). This crop response is normally associated with stress conditions in the vegetative or early flowering growth phases, however this crop was planted in a much later planting window than normal, so heat stress should not have been a factor as maximum temperatures did not exceed 32 °C (Figure 9). There may have been other stresses that occurred during the vegetative period or even the flowering period that caused this response in dry matter production.

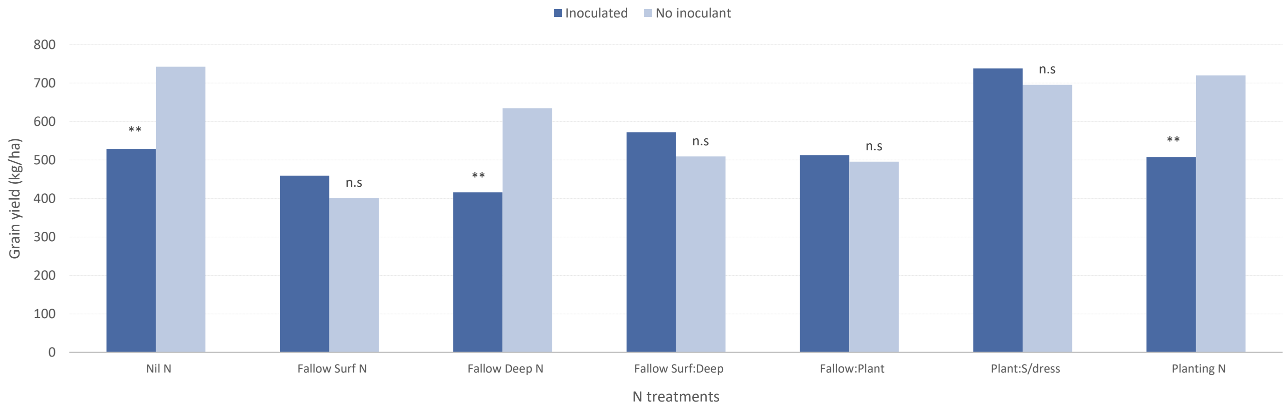


Figure 4. Comparison of mean grain yields between inoculated and non-inoculated plots across N treatments (** significant interaction at P=0.058).

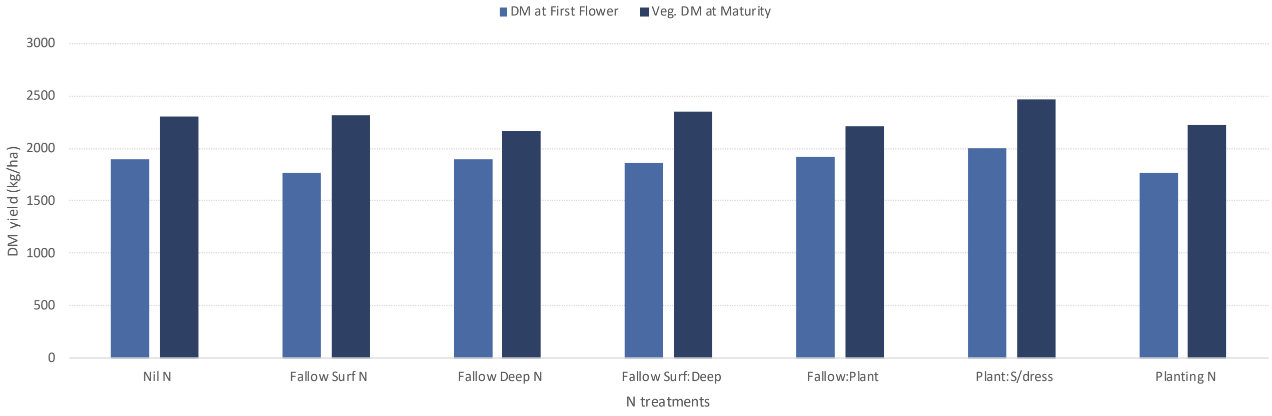


Figure 5. Comparative vegetative dry matter production between first flower and maturity across all N treatments.

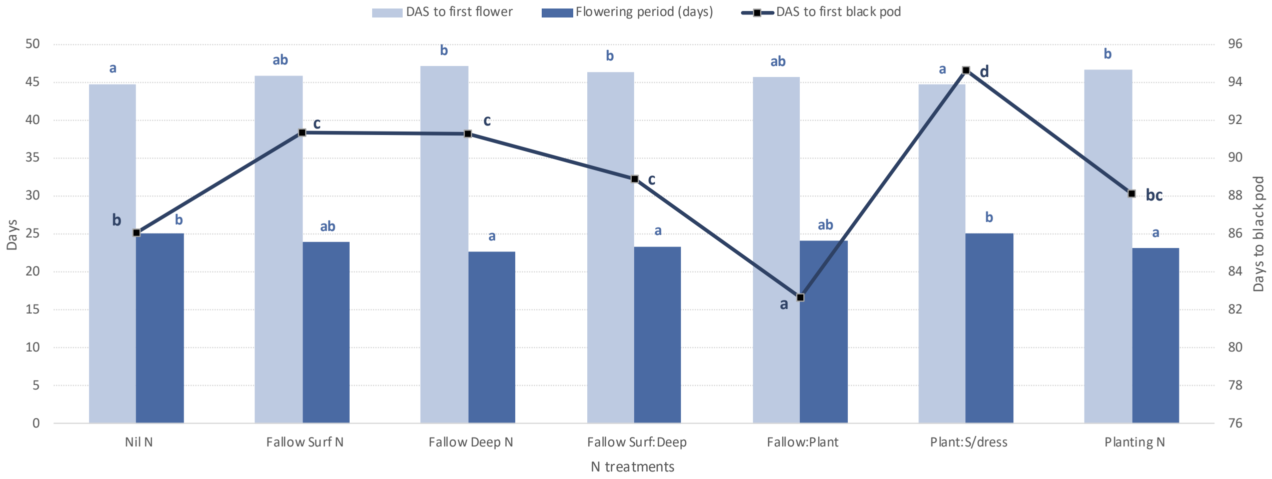


Figure 6. Comparison of days to first flower, flowering period and days to first black pod across all N treatments.
Means with the same letters are not significantly different at P(0.05).

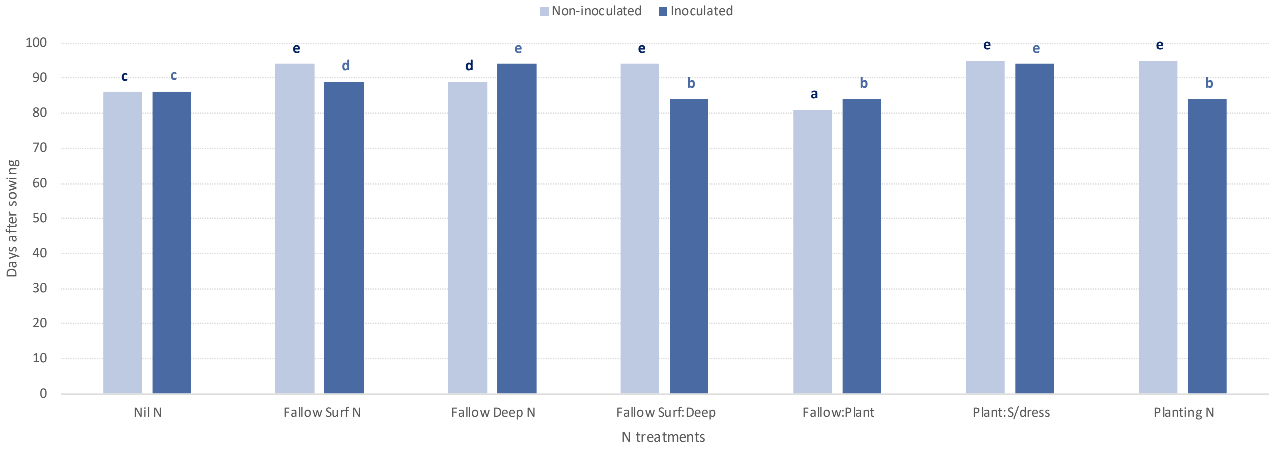


Figure 7. Comparison of the interaction between inoculated and non-inoculated plots across all N treatments in relation to days to first black pod.
Means with the same letters are not significantly different at P(0.05).

The only other physiology data that was significant in this trial is the flowering and maturity data (Figure 6). While the days to first flower and the flowering period data showed some significant differences; these difference were relatively small and as result it is difficult to make an inference about treatment effect.

Days to first black pod (Figure 6) showed some significant differences across three of the treatments (Nil N, Fallow:Plant split, Plant:Sidedress split). The biggest difference in time to maturity was 12 days between the Fallow:plant and Plant:sidedress treatments with all the other treatments falling in a six day period between 86 DAS and 92 DAS (Figure 6). This difference in maturity was still consistent when the split between inoculated and non-inoculated plots was added into the analysis (Figure 7).

The interaction between inoculated and non-inoculated plots has shown some significant differences in days to first black pod (Figure 7) and in most cases the non-inoculated plots have been slower to maturity (Fallow Surface N, Fallow Surface:Deep split and Planting N). A lack of obvious correlation with the grain yield results makes it unclear whether timing of development is particularly important to overall productivity. The Nil N treatment has shown no interaction with inoculation in relation to time to maturity, which might indicate that the inoculation interaction has a low impact on maturity.

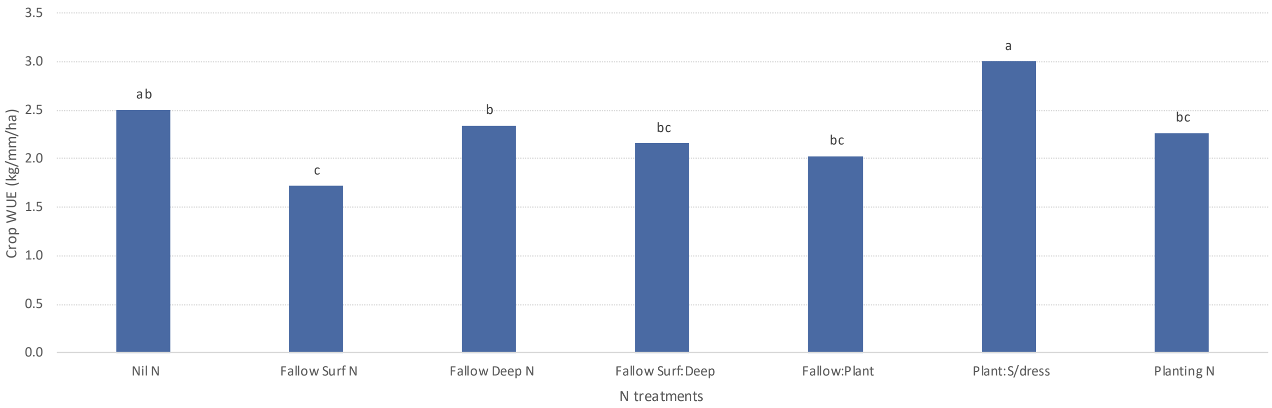


Figure 8. Comparison of crop WUE performance across all N treatments.
Means with the same letter are not significantly different at P(0.05).

The crop water use efficiency (crop WUE) for the trial is relatively low (Figure 8), although hand harvest yield data would suggest crop WUE is closer to 5 kg/mm/ha than the 2-3 kg/mm/ha calculated using machine harvests. Low WUEs are not surprising given the low grain yields and the relatively high in-crop rainfall. As the crop was planted on a full profile of moisture (160–180 mm PAWC to 120 cm) and had 145 mm of in-crop rainfall, it could be assumed that the trial was not water stressed. The relatively low yields are therefore more likely to be a symptom of the late planting and cool conditions after flowering (Figure 9).

The Plant:S/dress split treatment had significantly higher WUE than nearly all the other treatments (Figure 8); this treatment also had the highest grain yield (Figure 2). This may indicate better root development leading to better extraction of soil water.

Implications for growers

In this particular trial, mungbean response to additional nitrogen is negligible, however the yield response to inoculation was also negligible. It is likely that the background N mineralised over the fallow was sufficient to meet plant needs and maximise yield. Further trials should examine a range of applied N levels to ascertain what a critical N level might be to maximise a yield response.

The data in this trial indicates that mungbean roots may have a higher level of sensitivity to concentrated fertiliser application and that rates of redistribution of fertiliser bands in Vertosols may be slower than first thought. It is worth considering trying to offset plant rows from fertiliser rows if planting within six months of a banded fertiliser application.

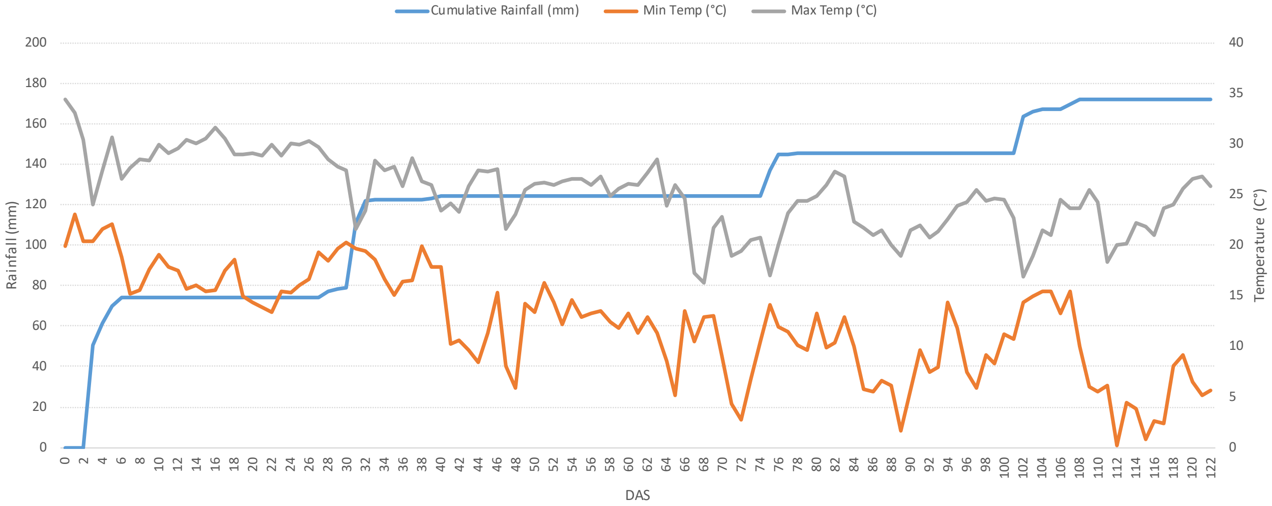


Figure 9. Rainfall accumulation, and minimum and maximum temperatures for trial duration.

This experiment has highlighted that there was very little yield difference between inoculated and non-inoculated treatments. This may be because background nitrate levels were high enough that the plant did not need the rhizobia relationship for normal growth. While further research is required to confirm this issue, it does highlight that soil nitrate testing prior to planting may well influence the decision whether to inoculate at planting along with cropping history.

Acknowledgements

The Mungbean Agronomy Project (DAQ1805-003RTX) is funded by the Grains Research and Development Corporation and the Department of Agriculture and Fisheries.

Trial details

Location:	Emerald Research Facility (formerly the Emerald agricultural college).
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:

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

Although most treatments (even the uninoculated ones) showed evidence of nodulation, whether they were truly active in the presence of high levels of N is questionable.

Mungbean: Impact of soil nitrogen levels on nodulation

Cameron Silburn and Nikki Seymour
Department of Agriculture and Fisheries

Research Question: *At what level of soil nitrogen is nodulation of mungbean reduced and/or inhibited?*

Key findings

1. Mungbeans may stop nodulating when soil nitrogen concentration is >10 mg N/kg (32 kg N/ha).
2. Inoculated mungbeans achieved optimum growth at very low levels of soil N.
3. Growth was reduced at all rates of nitrogen when plants were uninoculated.
4. Benefits due to inoculation of mungbeans when high levels of nitrogen are present in the soil remain in question.

Background

Mungbeans are an increasingly important component of northern grain region farming systems. Currently, most growers inoculate crops with commercial rhizobia to promote nodulation and nitrogen fixation, which is believed to supply adequate nitrogen (N) for that crop. Some trials in the region have demonstrated yield responses to additional N fertiliser. Others have shown no response to either inoculation, N fertiliser or both. Soil nitrate level is a key factor influencing this result. Research shows for all legumes that the proportion of N in the plant derived from fixation decreases with increasing levels of soil mineral N. Levels for chickpea and soybean have been estimated from trial work[1]. Anecdotal evidence suggests that the threshold level of mineral N is lower for mungbean than for other legumes but the points at which nodulation starts to be reduced and then inhibited have not been established.

What was done

A glasshouse trial was conducted under controlled conditions to determine the soil nitrogen levels where nodulation and N fixation are affected. A potting medium containing no available N (sand:vermiculite mix) was used to grow inoculated (rhizobia strain CB1015) and uninoculated mungbean plants in pots at a range of soil nitrogen levels (Table 1). These N levels (mg N/kg) have been converted to an approximate N level in a field soil (kg N/ha) in the top 30 cm of profile for comparative purposes.

Table 1. Rates of applied nitrogen to pots showing equivalent rate in kg N/ha.

Nitrogen applied	
(mg N/kg)	(kg N/ha)
0	0
5	16
10	32
20	65
30	97
40	129
60	194
80	259
100	323
120	388
160	517
200	647

A sand and vermiculite (2:1) mix was prepared, and evenly distributed into 96 pots that were individually autoclaved to ensure no microbes were present in the substrate. The pots were transferred into a clean glasshouse; the mungbeans were planted into the pots and the treatments applied on 29 October 2019. The inoculated treatments were exposed to a commercial freeze dried rhizobium that was mixed into water and applied directly onto the seed via water injection; the uninoculated treatments were given a sucrose water injection.

The N was delivered as potassium nitrate (KNO3) in solution. Four pre-germinated, surface-sterilised seeds (cv. Jade-AU$^{(\phi)}$) were planted into each pot and then thinned down to two plants per pot 12 days later.

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[1] Doughton JA, Vallis I and Saffigna PG (1993) Nitrogen fixation in chickpea. I. Influence of prior cropping or fallow, nitrogen fertilizer and tillage. *Australian Journal of Agricultural Research* 44:1403-13.
Salvagiotti F, Cassman KG, Specht JE, Walters DT, Weiss A and Dobermann A (2008) Nitrogen uptake, fixation and response to fertilizer N in soybeans: A review. *Field Crops Research* 108:1-13.

A basal application of all essential nutrients (excluding nitrogen)in solution was added on a weekly basis to supplement the mungbeans. Basal applications contained magnesium sulfate ($MgSO_4$), potassium phosphate (KH_2PO_4), potassium sulfate (K_2SO_4), calcium sulfate (CaSO4) and trace elements (Fe, Zn, Cu, Mn, Mo, Bo). The first basal application was applied 18 days after planting. The plants were watered using sterilised deionized water when required. Glasshouse temperatures were maintained between 20° C and 40° C throughout the trial.

The mungbeans were grown for 53 days. Growth stage and number of pods was recorded before plant tops were removed, dried and weighed for total shoot dry weight. Roots were washed from the substrate and inoculated plants assessed for nodulation number and dry weight. Roots were then dried for two days at 60° C and weighed.

Results

The results showed that soil N levels in which mungbeans are able to produce optimal growth could be as low as 10 mg N/kg. Inoculated plants combined with low rates of nitrogen had significantly higher growth compared to other treatments (Figure 1).

Significant growth responses occurred to 10 mg N/kg, however as N rates increased growth reduced significantly. The above ground biomass of inoculated plants began to decline once nitrogen in the pot reached 20 mg N/kg. Uninoculated plants reached maximum growth at 10 mg N/kg with no significant increase thereafter. This suggests that something was limiting plant growth other than N at this point. Similarly, pod biomass for the inoculated plants was significantly greater in the 0 to 10 mg N/kg range, but not generally at higher rates of N (Figure 2).

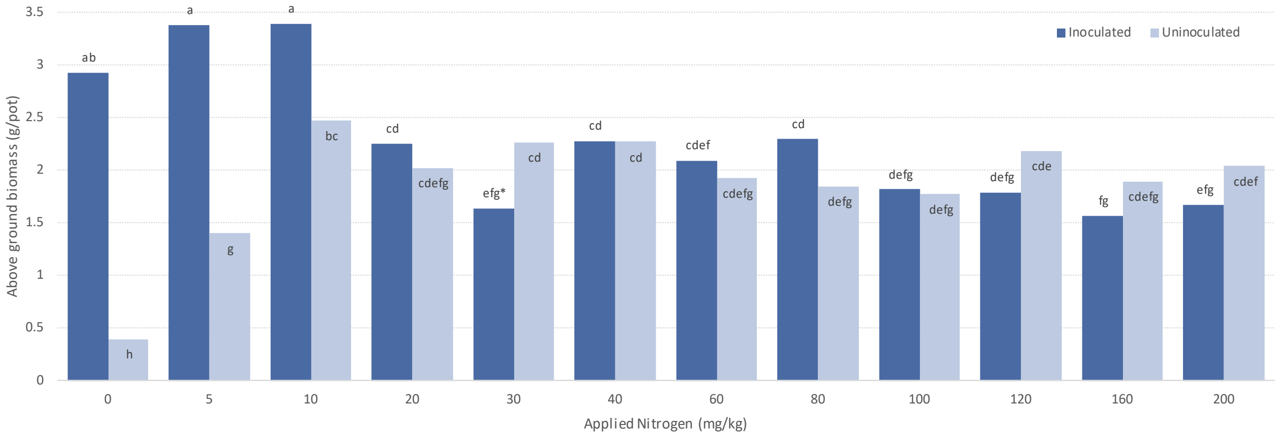

Figure 1. Above-ground biomass response of mungbeans to applied nitrogen with and without inoculation with rhizobia (strain CB1015). The letters on each bar are presented to show significant differences at P(0.05).

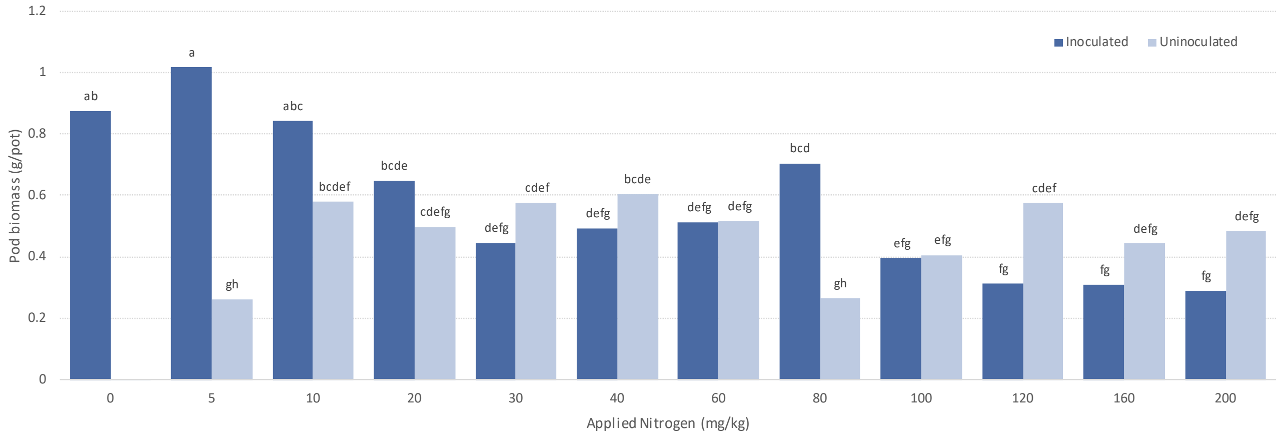

Figure 2. Pod biomass of pods greater than 5 cm (biomass/pot of 2 plants) as impacted by N rate, with and without inoculation with rhizobia (CB1015). The letters on each bar are presented to show significant differences at P(0.05).

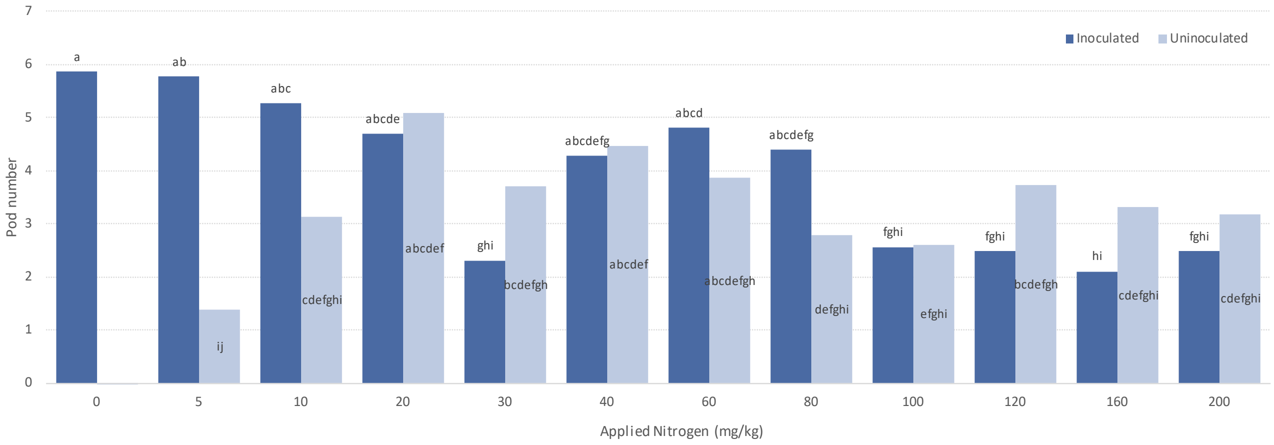

Figure 3. Number of pods greater than 5 cm (number/pot of 2 plants) as impacted by N rate, with and without inoculation with rhizobia (CB1015). The letters on each bar are presented to show significant differences at P(0.05).

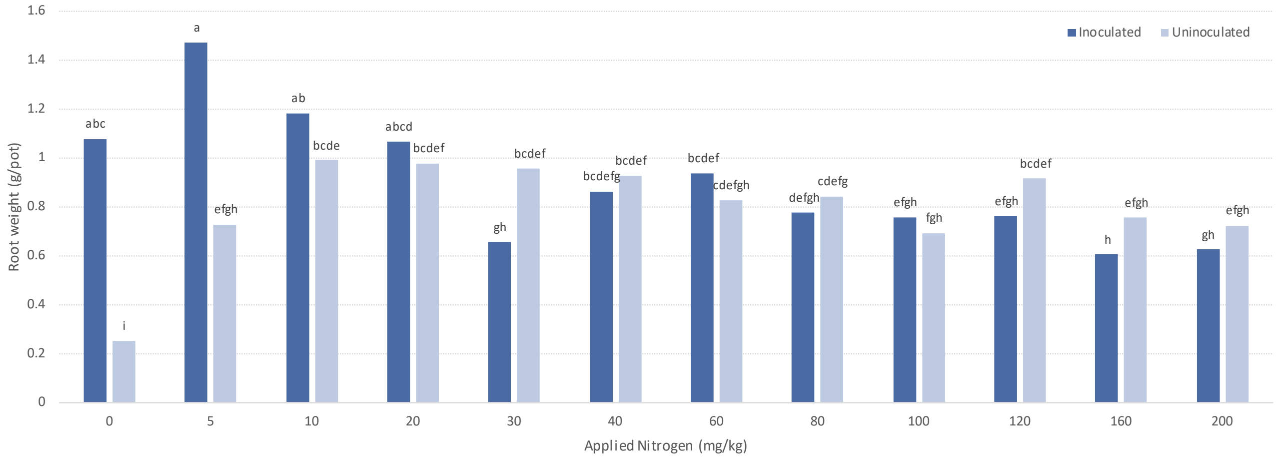

Figure 4. Root biomass response of mungbean plants (g/pot of 2 plants) to applied N, with and without inoculation with rhizobia (CB1015). The letters on each bar are presented to show significant differences at P(0.05).

Above 80 mg N/kg there was a slight trend towards reduced (though not significant) pod biomass as plants were generally behind in growth stages at the time of harvest due to the increased rate of nitrogen. Pod number (Figure 3) shows a similar story to above ground and pod biomass.

Root biomass (g/pot) in the inoculated plants (Figure 4) responded in the same manner as the above ground and pod biomass measures, with an increase in root growth up to 10 mg N/kg but then a levelling off and trending reduction as levels of N above 30 mg N/kg were applied.

No nodulation was found in the vast majority of uninoculated treatment pots indicating that the quality control techniques to avoid contamination of uninoculated pots were generally successful.

A few pots were found to have nodulated late in the experiment and while this would have only marginally affected N nutrition in those plants, they were still removed from the experiment. Nodulation was at its highest for this trial when 0, 5 or 10 mg N/kg was applied but above this level of N, nodulation number and dry weight of nodules per pot significantly declined for all N levels to 200 mg N/kg (Figure 5).

This complements the response seen in the ground biomass and root weights, and shows that when inoculated, a significant amount of N can be fixed by the rhizobia in the nodules formed. However, N concentration in the soil of more than 10 mg N/kg will significantly reduce nodulation to less than half and thereby affect fixation, nutrition and growth of the plants.

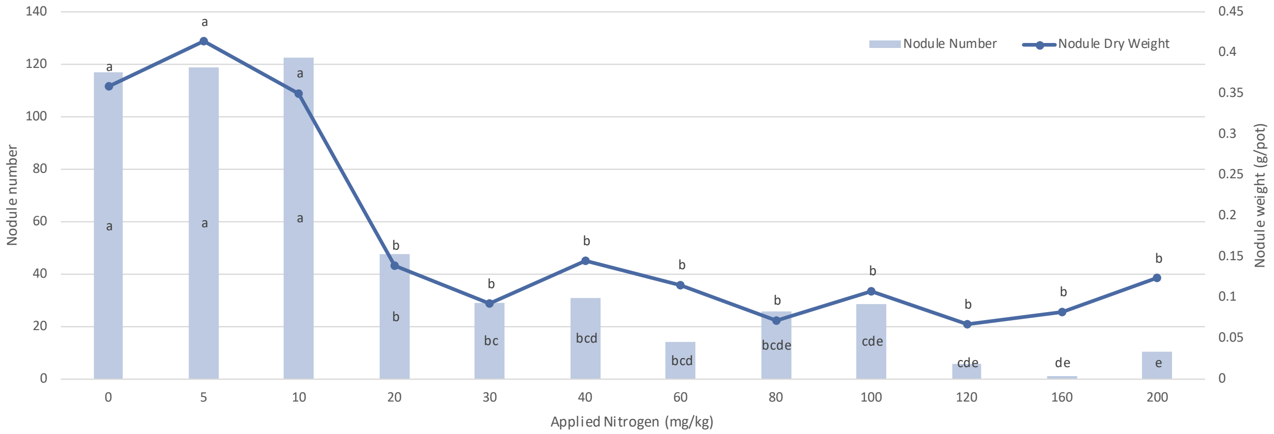

Figure 5. Number and weights of nodules on roots of mungbean plants at maximum biomass (day 53) that were inoculated with rhizobia (strain CB1015) at planting. The letters on each bar are presented to show significant differences at P(0.05).

Implications for growers

This pot trial has established that nodulation in mungbeans is severely reduced at soil N concentrations above 10 mg N/kg, which equates to 32 kg N/ha in the top 30 cm of the soil profile. Mungbeans are already widely thought to have a low N threshold for effective nodulation, however to be inhibited at such a low rate could have wide ranging effects on their production. Combining this with the fact that optimal growth was only achieved at low rates of nitrogen in combination with inoculation could mean that mungbean yield potential may never be achieved in high nitrogen situations. This could be due to mungbeans not being able to effectively take nitrogen from soil pool and convert it efficiently into yield. The addition of nitrogen when plants were not inoculated also didn't improve yield over inoculation treatments. More investigation needs to be done to confirm the results of the trial regarding mungbeans' unique relationship with rhizobium and to determine what level of N truly compensates for having no or low levels of nodulation on the plants. However, based on these results, inoculation is certainly recommended as best practice and a knowledge of soil N levels at planting will also be useful.

Acknowledgements

We wish to acknowledge the co-funding for this work from Grains Research and Development Corporation in conjunction with support from DAF.

Trial details

Location:	Leslie Research Facility, Toowoomba.
Crop:	Mungbean (Jade-AU$^{Ⓟ}$)
Soil type:	Sand:Vermiculite mix
In-crop rainfall:	N/A
Fertiliser:	Nitrogen at increasing rates (Table 1); all other nutrients supplied at luxury levels in basal applications. Plants were inoculated with *Bradyrhizobium* sp., strain CB1015.

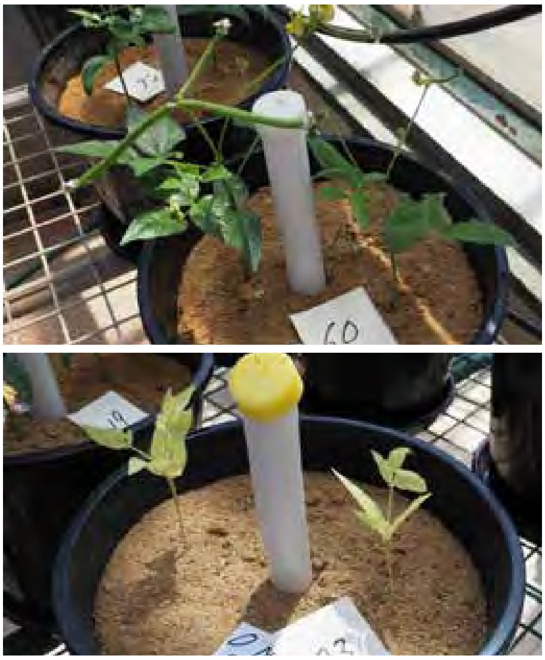

Photo comparison of 0 kg N/ha—inoculated (top), uninoculated (bottom).

Mungbean: Impact of arbuscular mycorrhizal fungi on phosphorus requirements

Cameron Silburn and Nikki Seymour
Department of Agriculture and Fisheries

Research Question: *How do different arbuscular mycorrhizal fungi levels influence the phosphorus requirements of mungbeans to maximise growth?*

Key findings

1. Mungbean growth increased as soil phosphorus levels increased.
2. Pod weight was significantly greater from 40 mg/kg upwards, indicating mungbean yield is maximized under very high levels of available phosphorus.
3. Phosphorus concentration and uptake increased significantly for each level of phosphorus up to 320 mg/kg.
4. If arbuscular mycorrhizal fungi levels are low at planting and/or soil phosphorus is low, consider applying a higher rate of phosphorus fertiliser (approximately 10 mg P/kg or 44 kg P/ha or above) to improve growth and production.

Background

Ensuring adequate phosphorus (P) supply to plants is key for good mungbean production. Arbuscular mycorrhizal fungi (AMF), previously known as VAM, form a symbiotic relationship with plant roots to supply them with P and zinc (Zn).

Recent weather patterns that have enforced long fallows can reduce AMF levels in the soil. Mungbean has a high mycorrhizal dependency, so there is a risk to mungbean production if growers do not adequately address P nutrition.

Recent nutrition trials in the northern grains region have provided only limited information on mungbean responses to deep-placed P. Gaps remain in our understanding of munbean's P nutrient requirements to maximize productivity, particularly if mycorrhizal levels are low.
It is expected that mungbeans will respond differently to applied P at different levels of mycorrhiza colonisation, with higher soil levels of P required for growth when arbuscular mycorrhiza fungi (AMF) are low or not present.

What was done

A glasshouse trial under controlled temperature conditions was established. The trial design was a full factorial of three AMF levels (nil, low and high), eight P rates and four replicates of each treatment (Table 1).

Table 1. Rates of applied phosphorus into pots showing equivalent in kg P/ha.

Applied phosphorus (mg/kg)	Calculated equivalent rate of applied phosphorus (kg/ha)
0	0
5	22
10	44
20	87
40	174
80	348
160	696
320	1392

A Vertosol soil from a cropping property south-east of Chinchilla was used for this experiment due to its low nitrogen (N) and P status; bicarbonate-extractable (Colwell) P of 16 mg/kg for surface 0-10 cm, 3 mg/kg for 10-30 cm.

The top 0-10 cm of soil was removed and the 10-30 cm profile layer used. The site had recently grown sorghum, so moderate to high levels of AMF were expected. A Predicta®B test showed that 34 kDNA copies of AMFa/g soil and 1 kDNA copies of AMFb/g soil were present in the 10-30 cm layer at the time of soil collection.

The soil was sieved to remove particles >1 cm. This 'untreated' sieved soil was used for the *High AMF* treatment. The *Nil AMF* treatments were prepared by slightly moistening the sieved soil with water and heating at 60°C for 24 hours. The *Low AMF* treatment combined 90% *Nil AMF* soil with 10% soil from the *High AMF* treatment.

For each of the three AMF treatments 8 kg oven-dried equivalent of soil was mixed with each level of P in solution and mixed thoroughly to give an even concentration of P throughout. The soil was then placed into large pots (8 L capacity) and arranged in a randomised block design in the glasshouse.

Four pre-germinated mungbean (cv. Jade-AU$^{\phi}$) seeds were planted on 31 October 2019 and thinned to two plants per pot after 10 days. All seeds were inoculated at planting with a solution of *Bradyrhizobia* sp. (strain CB1015). The mungbeans were grown for 47 days with supplementary basal fertiliser applied in solution to the soil surface. The solution contained magnesium sulfate ($MgSO_4$), potassium sulfate (K_2SO_4), calcium sulfate ($CaSO_4$), and trace elements (iron, zinc, copper, manganese, molybdenum and boron). No additional N or P was added during the trial; the plants were watered using deionised water when required.

Glasshouse temperatures were maintained between 20 °C and 40 °C. Growth stages and pod numbers were recorded before plant tops were removed, dried and weighed for total shoot dry weight. Dried pods were also removed and weighed. Roots were washed, dried and weighed, with a subsample stained for mycorrhizal colonisation assessments*. Nodule assessments were conducted to determine if N was a limitation to mungbean growth.

Results

Mungbean growth, measured by the above ground biomass, significantly increased with the addition of 5-20 mg P/kg (22-87 kg P/ha) to the soil (Figure 1). There was also a significant interaction between the effects of P rate and the level of AMF. With no added P, plants at all three levels of AMF were equal in biomass. AMF can't create P in the soil, only make it easier for the plant to access it.

Mungbean cv. Jade-AU$^{\phi}$ growing in field soil in pots in a glasshouse.

When P is as low as it was in this case, with just 3 mg available P/kg (Colwell P), the level of AMF made no difference to plant growth. At 5 and 10 mg P/kg rates, the plants with nil AMF were significantly lower in biomass than those with *Low* or *High AMF* soil levels; the AMF supported a response to added P that was not seen at the rates of 20 mg P/kg and above. There was no significant difference in response to AMF until the P level reached the highest rate of 320 mg/kg, where growth at the *Low AMF* level was significantly higher than *Nil* and *High AMF*. High AMF levels may start to drain carbohydrates from the plant when there is adequate P. If the plant doesn't need AMF to assimilate P, it may become a burden on the plant and reduce biomass production.

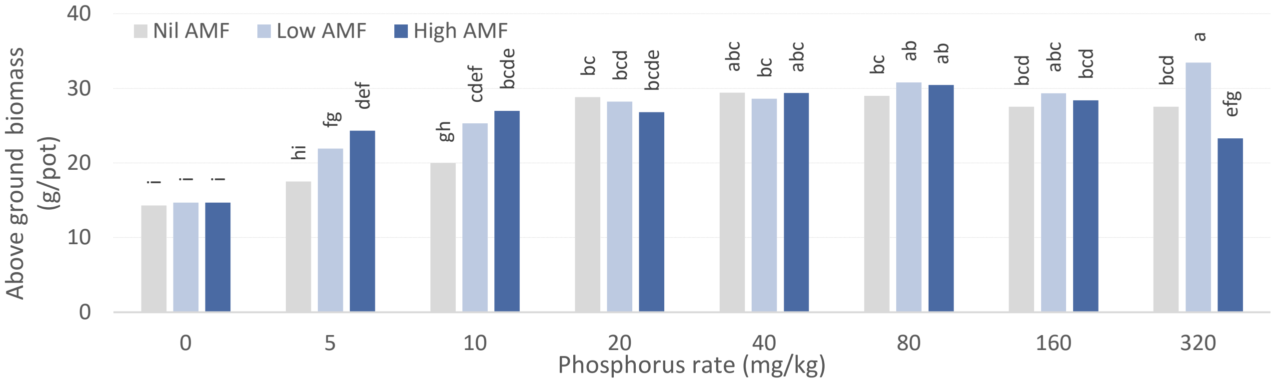

Figure 1. Above ground biomass including pods (biomass/pot of 2 plants) response of mungbean to applied phosphorus at different levels of AMF. Inoculated with rhizobia (CB1015).

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

*** Reference: Giovanetti M, Mosse B (1980) An evaluation of techniques for measuring vesicular-arbuscular mycorrhizal infection in roots. *New Phytologist* 84, 489-500.**

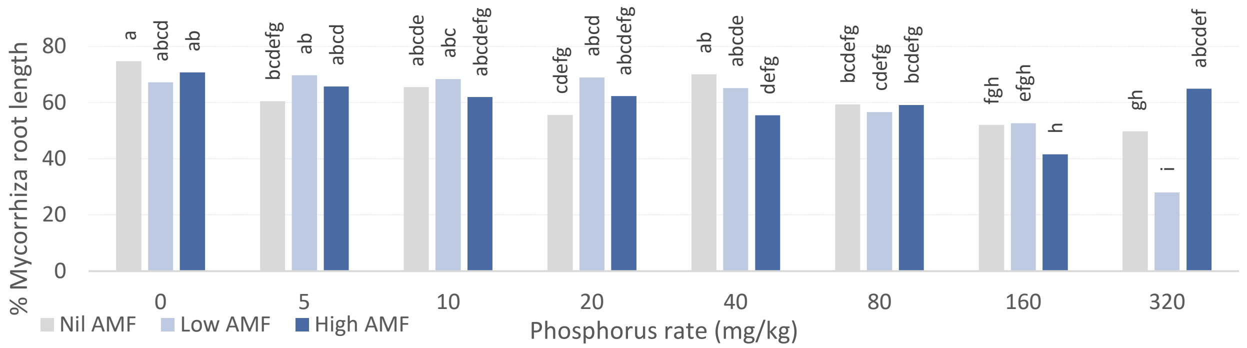

Figure 2. Percentage of mycorrhiza in roots of mungbean in response to applied phosphorus at different levels of AMF. Inoculated with rhizobia (CB1015).

The letters on each bar are presented to show significant differences. Means with the same letters are not significantly different at P(0.05).

The AMF colonisation levels (%) at 47 days did not show any differences between treatments. Differences in biomass accumulation (Figure 1) may be attributed to the heat treatment temporarily reducing the AMF propagules to a point that impacted on P uptake in early plant development. Colonisation levels caught up over the course of the experiment; colonisation of all treatments was equal at plants' removal. Steam sterilisation of the soil may be needed in future to ensure full sterilisation.

The slightly lower (not significant) colonisation levels combined with the lower root weights recorded in the 5 and 10 mg P/kg treatments may explain the lower biomass measured for the *Nil AMF* plants at these P levels and the corresponding response in biomass to *Low* and *High AMF* levels. The percentage of AMF in the roots tended to decrease as P rates increased above 40 mg/kg; indicating that mungbean relied less on AMF to extract P as soil P increased (Figure 2).

Pod weight followed a similar trend to biomass (Figure 3a). As P was added at 5 and 10 mg/kg, pod weight increased significantly, with increases up to 80 mg/kg. Pod number was particularly influenced by AMF level, with *High AMF* giving significantly more pods at the 40 and 160 mg/kg levels (Figure 3b). Although this trial wasn't taken through to harvest, pod number and weight are a good indicator of yield.

Root weights also showed a similar trend to the above-ground biomass results, with a significant P x AMF interaction. That is, no response to AMF level at 0 mg P/kg but a significant increase in root weight due to *High AMF* when 5 or 10 mg/kg was added (Figure 4). From 20 mg P/kg upwards, plant roots were not affected by levels of AMF until the obvious reduction in root weight at 320 mg P/kg at high AMF levels.

P uptake and P concentration in plants significantly increased as applied P increased up to 320 mg/kg (Figure 5). No impact of AMF was found in either P concentration or uptake.

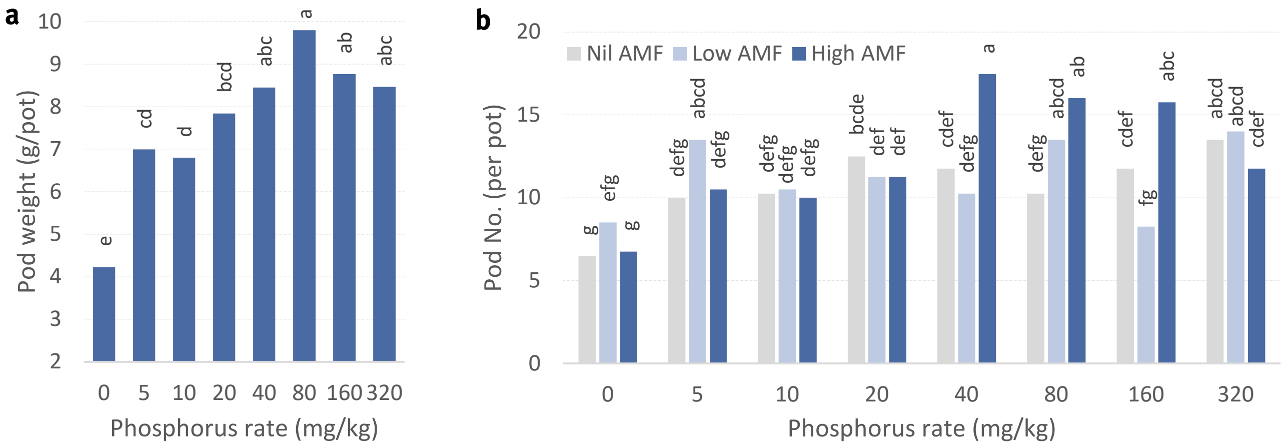

Figure 3. (a) weight of pods in response to applied phosphorus at different levels of AMF, and (b) number of pods greater than 5 cm per pot (2 plants) of mungbean. Inoculated with rhizobia (CB1015).

The letters on each bar are presented to show significant differences. Means with the same letters are not significantly different at P(0.05).

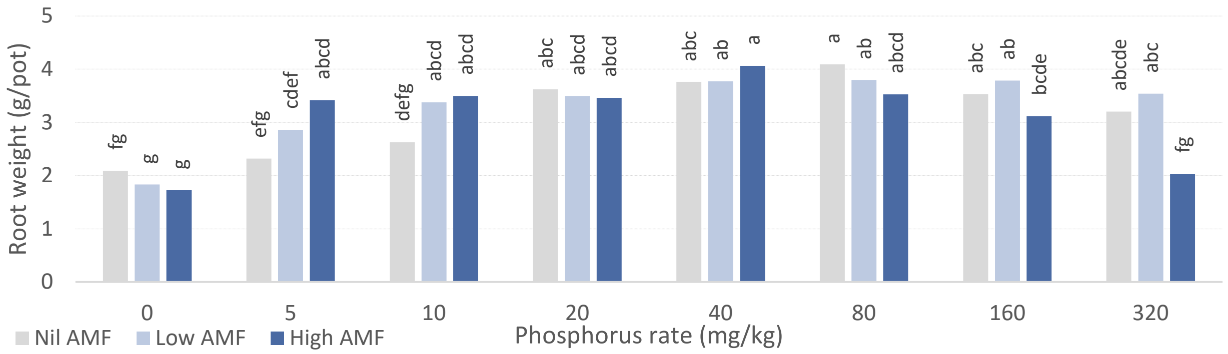

Figure 4. Dry root biomass of mungbean per pot (2 plants) in response to applied phosphorus at different levels of AMF. Inoculated with rhizobia (CB1015).

The letters on each bar are presented to show significant differences. Means with the same letters are not significantly different at P(0.05).

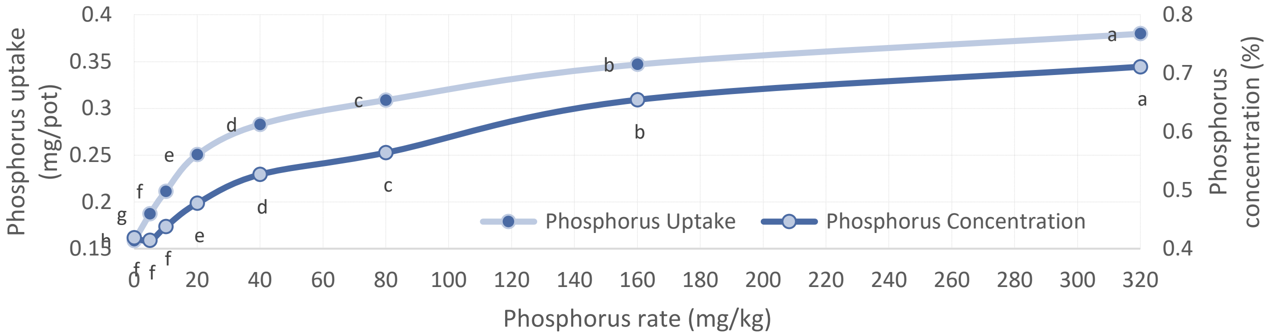

Figure 5. Phosphorus concentration (%) and uptake (mg per pot) of mungbean in response to increasing levels of applied phosphorus averaged over at different levels of AMF. Inoculated with rhizobia (CB1015).

The letters on each dot are presented to show significant differences. Means with the same letters are not significantly different at P(0.05).

All treatments were well nodulated. There was no difference in nodule scores between treatments, indicating that nitrogen was not limiting production.

Implications for growers

AMF levels can change mungbean growth response to different levels of soil P. However, the trial results reinforce that an understanding of soil P levels and the cropping history of the paddock is needed to develop fertiliser programs for mungbean crops.

While this trial didn't show differences in levels of AMF colonisation by the end of the experiment, it’s likely that the heating treatments reduced AMF levels, slowing initial colonisation in the *Nil AMF* treatments and showing significant contrasts with plants growing in the *Low* or *High AMF* treatments with low P soil (5 and 10 mg P/kg). Mungbeans grown after a long fallow where AMF levels are low and colonisation is reduced in the early crop stages will require a level of 10 to 20 mg P/kg (44 to 87 kg P/ha) to increase plant growth.

Applying P to mungbeans increases production, particularly when AMF levels are low. However, the immobility of P in the soil means fertiliser placement and AMF levels will remain important in relation to root access.

Acknowledgements

We wish to acknowledge the co-funding for this work from Grains Research and Development Corporation in conjunction with support from DAF, and the owner of the property from where we collected the soil.

Trial details

Location:	Leslie Research Facility, Toowoomba.
Crop:	Mungbean cv. Jade-AU$^{\text{Ⓟ}}$
Soil type:	Grey Vertosol
Irrigation:	Plants were watered using deionised water when required.
Fertiliser:	Phosphorus at increasing rates, all other nutrients supplied at luxury levels except N which was not applied but plants were inoculated with *Bradyrhizobium* sp., strain CB1015.

Chickpea: Effects of stubble on cold stress, plant growth and yield—Warwick

Andrew Erbacher
Department of Agriculture and Fisheries

Research Question: *Does increasing stubble loads increase the effect of cold stress on chickpeas?*

Key findings

1. Increasing stubble load caused seedling damage from frost events, but no deaths were observed.
2. Chickpeas produced more growth and grain yield from late season rainfall in the presence of stubble.

Background

Chickpea crops are susceptible to chilling injury at average daily temperatures below 15 °C. In addition to a number of other abiotic stresses, low temperature at flowering and podding is a major factor leading to reduced yield. Both freezing (below 1.5 °C) and chilling (1.5-15 °C) temperatures are known to affect chickpeas at various stages of crop development.

Research has concentrated on cold temperature effects on vigour during vegetative growth stages. Despite early flowering and pod set being very desirable traits in the northern grains region, the effect of low temperature stress on chickpeas during the reproductive phase has received far less attention. Early flowering and maturing cultivars have a yield advantage in these regions since they fill pods before soil moisture and heat stress become limiting factors at the end of the season.

Stubble retention in zero till systems is the dominant practice to maximise water storage in the summer fallow and so offset soil moisture limitations at grain fill. However, these high surface residues to improve fallow efficiency can increase the risk of radiant frosting by changing plant micro-climates and the thermal regime within the crop canopy.

This crop canopy temperature in chickpea research was part of a NSW DPI-led project on the impact of stubble loads, type, height and row placement on the thermal responses of winter pulses (BLG106), exploring the effect on floral initiation, flower retention, pod set and grain fill in a range of winter pulses.

What was done

A site was initially selected east of Goondiwindi for standing and flattened stubble experiments. Low soil moisture conditions and no planting rain meant the site could not be planted. The standing stubble experiment was abandoned and the flattened stubble load experiment moved to Hermitage Research Facility (HRF) near Warwick, where supplementary irrigation was available to promote good establishment. The trial was a split-plot design with five chickpea varieties planted in each stubble main plot (Table 1).

The HRF site was dry planted on 16 July 2018 into a bare paddock and 20 mm of irrigation was applied that day. Pre-packed wheat straw was used to establish a range of flattened stubble from 0 t/ha to 12 t/ha on 20 July. Another 10 mm of irrigation was applied to settle the straw.

Phenology data was collected throughout the growing season including; first flower observed in plot, 20% plants with a flower, 50% plants with a flower, 50% flower cessation, first pod in plot, 20% plants with at least one pod, 50% of plants with at least one pod, 50% pod maturity, 90% pod maturity or spray-out date.

Normalized difference vegetation index (NDVI) measures were used to assess crop growth throughout the season and biomass, population and plant mapping were measured at maturity before the plots were harvested. Late rain meant some treatments restarted flowering, so the site was sprayed out on 29 November 2018 and harvested on 12 December.

Table 1. Flattened stubble load treatments applied.

Stubble load (t/ha)	Chickpea varieties
0 (bare)	PBA Boundary$^{(p)}$
3	CICA1521
6	PBA HatTrick$^{(p)}$
9	Kyabra
12	PBA Seamer$^{(p)}$

Results

There were no variety by residue-load interactions measured in this trial; all varieties reacted similarly to the stubble treatments.

The establishing crop was exposed to 29 days below 0 °C in the first two months of the trial (July and August). The coldest temperature of -6.2 °C (recorded 28 days after planting) resulted in visual damage to seedlings in the higher stubble load treatments, and NDVI readings on 21 September (at first flower) were lower for the high stubble load treatments (Figure 1). Flowering was delayed 1-2 days in the higher stubble loads (Table 2), which correlates to the lower NDVI readings at this time. However, the crops did not hold a pod for another 10 days.

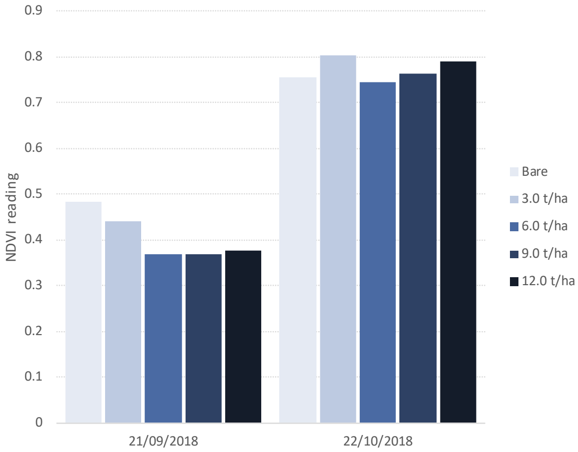

Figure 1. NDVI readings averaged across all varieties taken in September and October.

Chickpea plants 43 days (28 August 2018) after planting. Plants appear larger in the lowest cover plots. Top (front to back): 0, 9, 12, 3, and 6 t/ha; Middle (front to back): 9, 6, 3, 12 and 0 t/ha; Bottom: 3 t/ha beside 12 t/ha residue, reversed in the background.

Table 2. Average dates for key phenology stages under different stubble loads.

Stages	Bare	3 t/ha	6 t/ha	9 t/ha	12 t/ha
First flower observed in plot	20/09/2018	20/09/2018	21/09/2018	21/09/2018	22/09/2018
20% plants with a flower	25/09/2018	25/09/2018	25/09/2018	25/09/2018	25/09/2018
50% plants with a flower	25/09/2018	25/09/2018	26/09/2018	26/09/2018	27/09/2018
50% flower cessation	24/10/2018	25/10/2018	25/10/2018	25/10/2018	25/10/2018
First pod in plot	2/10/2018	1/10/2018	2/10/2018	2/10/2018	2/10/2018
20 % plants with at least one pod	4/10/2018	3/10/2018	5/10/2018	5/10/2018	4/10/2018
50% of plants with at least one pod	7/10/2018	7/10/2018	8/10/2018	9/10/2018	8/10/2018
50% pod maturity	14/11/2018	18/11/2018	18/11/2018	20/11/2018	21/11/2018
90% pod maturity or spray-out date	28/11/2018	2/12/2018	30/11/2018	3/12/2018	2/12/2018

Table 3. Statistical analysis of mature plant mapping and yield of the chickpeas.

Treatments	Plant height (cm)	Height of first pod (cm)	No. primary branches	No. secondary branches	No. pods per m^2	No. total seeds per m^2	No. plants per m^2	Dry matter (kg/ha)	Grain yield (kg/ha)
Random terms (all with Mplot)	I x I	I x I	I x I	I x I	I x I	I x I	AR1 x AR1	I x I	AR1 x AR1 + Col
Pop^{n} covariate	-	-	-	-	P<0.001	P<0.001	-	-	P=0.022
Cover (C)	P=0.032	P=0.073	P=0.213	P=0.006	P<0.001	P=0.039	P=0.581	P=0.076	P=0.003
Bare (0 t/ha)	46.9 b	21.1	5.2	4.2 b	958 c	1163 b	32.1	5257	2316 b
3 t/ha	53.7 a	22.2	6.3	6.2 a	1403 a	1715 a	29.6	6576	2733 a
6 t/ha	53.6 a	23.2	6.0	5.4 a	1173 b	1548 a	28.1	5509	2392 b
9 t/ha	53.1 a	24.2	6.5	5.8 a	1138 bc	1482 ab	27.4	5658	2767 a
12 t/ha	57.4 a	24.7	6.0	6.1 a	1251 ab	1579 a	28.1	6629	2706 a
ave. sed	2.6	1.2	0.6	0.6	99	145	3.1	523	130
ave. lsd (5%)	5.9			1.2	198	327			261
Variety (V)	P=0.049	P=0.012	P=0.017	P=0.076	P=0.002	P=0.055	P=0.002	P= 0.343	P<0.001
Boundary$^{Ⓓ}$	53.1 ab	24.2 a	5.5 bc	5.5	1308 ab	1708	29.0 b	5984	2635 ab
CICA1521	51.2 b	22.3 b	5.7 bc	4.6	999 c	1476	29.3 ab	6067	2721 a
HatTrick$^{Ⓓ}$	52.1 b	22.7 ab	5.3 c	5.7	1385 a	1579	32.4 a	5831	2596 b
Kyabra	55.5 a	24.3 a	6.6 ab	6.3	1117 bc	1328	29.1 b	6076	2595 b
Seamer$^{Ⓓ}$	52.9 ab	21.9 b	6.9 a	5.8	1114 bc	1397	25.5 c	5671	2365 c
ave. sed	1.4	0.8	0.6	0.6	100	135	1.6	228	55
ave. lsd (5%)	2.8	1.7	1.1		200		3.1		110
C x V	P=0.834	P=0.959	P=0.612	P=0.502	P= 0.212	P=0.210	P=0.180	P=0.380	P=0.207

Letters indicate significant difference at P(0.05); values with similar letters are not significantly different.

After 128 mm of rain in October, NDVI readings were similar for all stubble loads (Figure 1). This late rain had a big impact on the phenology of the crops. Higher stubble load treatments put on more late flowers, leading to a seven day difference in 50% pod maturity between the bare and 12 t/ha treatments.

Plant architecture and grain yield was improved by having stubble cover. Cover treatments recorded significantly higher plant height, pod number, seed number and grain yield than the bare soil treatment (Table 3). This is despite NDVI data showing reduced early crop growth within the higher stubble load treatments.

Additional stubble cover also produced significantly more secondary branches in the crop. This suggests the crops with higher ground cover had higher infiltration from the rain that fell in October. This extra stored moisture was utilised by putting on more branches and pods than the bare soil treatment. The higher cover plots also put on new flowers after 50% flower cessation had been reached, creating a second crop of pods and a seven day difference in 50% pod maturity dates.

Frost damage was evident in the high stubble load plots (9 t/ha pictured).

Implications for growers

Frost events in NSW experiments have caused seedling death in the presence of high residue loads. This is thought to be because a layer of stubble keeps the soil cooler during the day and reduces radiant heat released from the soil during the night. The Hermitage site frost events caused damage to seedlings but did not produce seedling mortality. Consequently, the treatments maintained similar plant populations to generate grain yield.

All treatments put on more flowers and pods when the site received 128 mm of rain in October. It is assumed the stubble-covered plots were more efficient at capturing this rainfall, and with access to better moisture conditions had increased pod and seed numbers for a grain yield advantage over the bare soil plots. The increased number of secondary branches in the stubble covered plots supports the assumption that the yield differences resulted from more pods being set and filled late in the season.

This experiment demonstrated that high stubble cover may improve the capture of in-crop rain and conversion to grain yield via secondary branches. As such, chickpea crops with high residue loads may also have a greater capacity to compensate for early damage in a dry finish by producing the additional yield on secondary branches.

Had these stubble loads been present throughout the preceding fallow, there would likely be more stored water at planting and further increases in grain yields. Unfortunately, the dry conditions in 2018 prevented us being able to compare flattened stubble to standing stubble in relation to the thermal dynamics that can compound the chilling effects on the crop.

Acknowledgements

Thanks go to the Regional Research Agronomy technical officers and Hermitage Research Facility farm staff for their contribution to this trial. This work was funded as part of the Grains Research and Development Corporation and New South Wales Department of Primary Industries GAPP thermal responses of winter pulses project (BLG106).

Trial details

Location:	Hermitage Research Facility, Warwick.
Crop:	Chickpea
Soil type:	Black vertosol
Rainfall:	205 mm + 30 mm irrigation.

Technical officer Nadia Lambert and work-experience student Phil spreading straw.

Nutrition research

Understanding the benefits of ameliorating nutrient stratification with one-off applications of deep-phosphorus (P) or potassium (K) has been a key research focus of DAF and the GRDC over the past six years. A series of trial sites have been established and cropped across these years. Challenging seasonal conditions in the past two cropping seasons resulted in few additional crops being planted on these trial sites, particularly in Southern Queensland. However, results from the last two years include;

- Sorghum in the Southern Downs had no significant yield response to deep-P
- Chickpeas in Central Queensland had positive yield responses to residual P of up to 1.2 t/ha.

With the final data now collected at all sites we are increasingly confident of where positive responses can be expected. In situations where sub-soil P is low (<10 mg/kg) we will see yield benefits in winter cereal crops in Southern Queensland (SQ), and in most summer and winter crops in Central Queensland (CQ). Some of this finalised trial data will be reported in the next edition of this publication.

Furthermore, we have confidence that treatment benefits will last for at least 5 crops after the application of deep P. Examples of significant cumulative profitability benefits across Queensland include;

Southern Queensland

- $575–$700/ha over 6 crops at Jimbour West
- $330–$390/ha over 5 crops at Condamine South

Central Queensland

- $1375–$1675/ha over 6 crops at Dysart
- $655–$800/ha over 4 crops at Comet River
- $555–$765/ha over 4 crops at Dululu.

Despite these significant positive responses there remain sites where further investigation is required to determine the long-term economics of deep nutrition, particularly in lower-yielding environments.

As researchers and industry have become increasingly confident in the benefits of deep nutrient applications as a method of ameliorating stratified P and K, questions have turned to reapplication intervals and the availability of freshly-applied P compared to that applied 5 or more years ago.

Initial results suggest that freshly-applied P provided significant additional benefits over residual treatments after 5 years. Further research will be needed to confirm and fully understand these responses.

Deep placement of nutrients: Long-term crop responses after six years of production—Dysart

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

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Research Question: *What is the residual value of deep banded phosphorus and potassium when reapplying after six years to establish a new potential yield target?*

Key findings

1. Residual deep phosphorus applied at 40 kg P/ha in 2013 produced a 1058 kg/ha (76%) yield advantage in 2019 chickpeas.
2. Re-applied deep-banded phosphorus treatments (30 kg P/ha) in 2019 produced an additional 924 kg/ha mean yield advantage over residual phosphorus treatments, irrespective of original phosphorus rate applied in 2013. The best plot yields exceeded 3.5 tonnes/ha, a 146% yield increase over the mean zero phosphorus treatment.
3. There was no significant yield response in the residual deep K applications in chickpeas, suggesting residual responses had been exhausted.
4. Reapplied deep-banded potassium treatments (50 kg K/ha) in 2019 produced a mean yield advantage of 250–500 kg/ha over the residual potassium treatments, but only where background phosphorus was applied.

Background

Over the last five years the UQ00063 project (Regional soil testing guidelines) has been monitoring a series of nutrition-based trial sites across Central Queensland (CQ). These trial sites were chosen based on soil testing evidence showing varying degrees of nutrient depletion in the surface and subsurface layers. This was particularly evident in the non-mobile nutrients of phosphorus (P) and potassium (K). Some established zero tillage production systems show 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 is becoming more evident across CQ, particularly in the brigalow scrub and open downs soil types.

This project is gathering data from these trial sites to ascertain whether a one-off application of P, K or sulfur (S) placed in these deeper more depleted layers can provide a grain yield benefit and whether that benefit can be maintained over several years.

In this final year of monitoring, three of these sites had their original plots split and a fresh application of P and K applied to half the plot. This data offers a comparison in performance and value between the older residual bands of fertiliser and more recent banded applications, providing a benchmark against which the residual value of 2013 P and K treatments can be assessed.

These results can also be used to define the economic benefit of adding these non-mobile nutrients over successive cropping cycles.

What was done

Initial soil testing was conducted (see Trial details) and the treatments were established in August 2013. Three successive sorghum crops were harvested from the site in 2014, 2015 and 2016, followed by a chickpea crop in 2017 and a sorghum crop in 2018. Grain yield responses and dry matter production were monitored for each crop, complemented by plant and grain tissue analysis to quantify the nutrient uptake and removal by the crop.

In January 2019, all plots were split in half and the P or K treatments reapplied in 50 cm bands to one half of the plots. Rainfall consolidated the ripped profile before planting chickpeas on 10 May 2019, with the crop harvested on 29 September 2019.

Phosphorus trial

Originally, there were seven unique treatments (Table 1). There were four P rates; 0, 10, 20, and 40 kg of P/ha with the 0P plots duplicated to give eight plots per replicate. Background fertiliser was applied to these P treatments at the same time to negate any other potentially limiting nutrients; comprising 80 kg of nitrogen (N), 50 kg of K, 20 kg of S and 0.5 kg of zinc (Zn) per hectare. Two further treatments included 0P and 40P without background fertiliser except N and Zn (0P-KS, 40P-KS). The final treatment was a Farmer Reference (FR) plot, which had nothing applied except what the farmer applied in line with normal commercial practice (Table 1).

Treatments were applied using a fixed tyne implement that delivered the P and K at 20 cm depth and the N and S at 10–15 cm deep. The bands of fertiliser were placed 50 cm apart in plots that were 8 m wide by 32 m long. The bands were placed in the same direction as the old stubble rows. There were six replicates making a total of 48 plots for the trial.

In 2019 the four original P treatments (0, 10, 20 and 40 kg P/ha) had their plots split and 30 kg P/ha applied in 50 cm bands at a depth of 25 cm with a Yeomans® deep ripper implement (Table 1). The band spacing for the reapplication was the same as the original treatments carried out in 2013. However, the implements and tractors were different and it is likely the residual bands and the reapplication bands were offset to some degree.

Additional background fertiliser was applied at the same time; 50 kg K/ha (granular) and 90 kg N/ha (liquid). The plot halves that received no additional P were also ripped with the same amounts of background fertiliser (N and K).

The original treatments that previously had no background fertiliser applied (0P-KS, 40P-KS) except N and Zn, were also split and had extra P applied (30 kg/ha) to one half of the plot (Table 1). These treatments had an extra 90 kg N/ha applied to both sides of the plot while they were being ripped, however received no K or S. The original Farmer Reference plots (FR) were left untreated and had no ripping.

Starter fertiliser was applied by liquid injection with the seed at planting (10 L/ha polyphosphate plus 3 L/ha Foundation™). The starter rate was split in the P trial so that all treatments could have a 'with' and 'without' starter treatment; this effectively doubled the number of plots assessed. Kyabra$^{(D)}$ chickpea was planted at 50 kg/ha on 10 May 2019 into good moisture with plant available water content (PAWC) of 176 mm two weeks after planting. The crop received 41 mm of in-crop rainfall, all before flowering.

Table 1. Summary of extra nutrient application rates and change of treatment labels after reapplication of fertiliser rates to split plots in January 2019.

Trial	Treatment labels*		Additional rates (kg/ha)		
	2013	2019	N	P	K
Phosphorus (P)	0P	0P+30P	90	30	50
		0P	90	0	50
	10P	10P+30P	90	30	50
		10P	90	0	50
	20P	20P+30P	90	30	50
		20P	90	0	50
	40P	40P+30P	90	30	50
		40P	90	0	50
	0P-KS	0P-KS+30P	90	30	0
		0P-KS	90	0	0
	40P-KS	40P-KS+30P	90	30	0
		40P-KS	90	0	0
	FR	FR	0	0	0
Potassium (K)	0K	0K+50K	90	30	50
		0K	90	30	0
	25K	25K+50K	90	30	50
		25K	90	30	0
	50K	50K+50K	90	30	50
		50K	90	30	0
	100K	100K+50K	90	30	50
		100K	90	30	0
	0K-PS	0K-PS+50K	90	0	50
		0P-KS	90	0	0
	100K-PS	100K-PS+50K	90	0	50
		100K-PS	90	0	0
	FR	FR	0	0	0

*The Results section uses the 2019 rather than 2013 (original) treatment labels to present data. No additional sulfur (S) or zinc (Zn) was added in these trials.

Potassium trial

The original trial again had seven unique treatments (Table 1) with 0K plots duplicated for a total of eight plots per replicate. There were four K rates; 0, 25, 50, 100 kg of K/ha, all with background fertiliser applied at the same time to negate any other potentially limiting nutrients (80 kg of N, 20 kg of P, 20 kg of S and 0.5 kg of Zn per hectare).

Two further treatments included 0K and 100K without any background fertiliser except N and Zn (0K-PS, 100K-PS). The final treatment was a Farmer Reference (FR) plot, which had nothing more applied than what the farmer used in line with normal commercial practice (Table 1).

In 2019 the four original K treatments (0, 25, 50 and 100 kg K/ha) had their plots split and 50 kg K/ha reapplied in 50 cm bands at a depth of 25 cm with a Yeomans® deep ripper implement (Table 1). Additional background fertiliser was also applied at the same time; 30 kg P/ha (granular) and 90 kg N/ha (liquid). The other half of the plots were again ripped and had the same amounts of background fertiliser applied but no additional K (Table 1). The original treatments that had no background fertiliser applied (0K-PS, 100K-PS) except N and Zn were also split and had the same rate of extra K applied (50 kg/ha) to one half of the plot (Table 1). These treatments also had an extra 90 kg N/ha applied as background fertiliser to both sides of the plot while they were being ripped. The original Farmer Reference plots (FR) were left untreated and had no ripping.

Applications were done in the same way as the phosphorous trial and the other trial details remain the same.

Reapplication in phosphorus and potassium trials.

Sulfur trial

A sulfur (S) trial with the same structure was also established, with S as the main rate variable and P and K added as background nutrition. With no yield response to S in the five successive crops grown on this trial, the S treatments were not reapplied in 2019. Grain yields from the 2019 chickpea crop showed no response to the residual S treatments. The S trial results have not been included in this trial report.

Results

Phosphorus trial

Mean grain yields in the 2019 chickpeas increased significantly where additional P (+30 kg/ha) was applied compared to treatments relying on the residual P (+0 kg/ha) applied in 2013 (Figure 1). There were no significant differences in grain yield between treatments that had the additional P applied (except the two treatments without background K and S), but there were significant differences within the residual P treatments (0P, 20P and 40P).

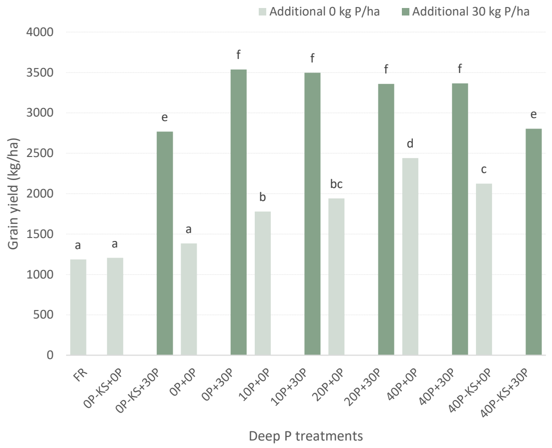

Figure 1. Comparison of mean grain yields across all deep phosphorus treatments in 2019 chickpeas.
Means with the same letters are not significantly different at the 5% level (lsd = 251.7).

While the additional P has created a universal yield increase of between 100–150% over the 0P treatment, the residual 20P and 40P rates of P still generated yield improvements of 40% and 76% respectively (Table 2). These data are similar to the relative yield increases in the 2017 chickpea crop, which was lower yielding in that much drier year (Figure 2). The residual bands were still providing strong yield improvements after being in the ground for six years.

Table 2. Mean grain yields for 2019 chickpea crop in phosphorus trial and relative phosphorus response compared to the 0P treatment.

	Deep-P treatments	Grain yield (kg/ha)	LSD P(0.05)	Relative P response in grain yield		Estimated CWUE (kg/mm/ha)
				(kg/ha)	(%)	
Residual P response	FR	1186	a	-198	-14	8.2
	0P-KS+0P	1206	a	-178	-13	
	0P+0P	1384	a	0	0	8.2
	10P+0P	1779	b	395	29	
	20P+0P	1942	bc	558	40	
	40P+0P	2442	d	1058	76	12.3
	40P-KS+0P	2124	c	740	53	
Additional P response	0P-KS+30P	2769	e	1385	100	
	0P+30P	3537	f	2153	156	20.3
	10P+30P	3497	f	2113	153	
	20P+30P	3359	f	1975	143	
	40P+30P	3366	f	1982	143	17.7
	40P-KS+30P	2805	e	1421	103	

Means with the same letters are not significantly different at the 5% level (lsd = 252)

It is worth noting that the 0P+30P treatment (no residual P) achieved the same mean yields (statistically) as all the other +30P treatments that had background K and S (Figure 1 and Table 2). This was an unexpected result as original expectations were that more bands of fertiliser in the same zone would give greater access to P and therefore more yield from those treatments that had both residual bands and re-applied bands. The residual treatments on their own have shown significantly different yield results across the different rates of P (Figure 1) and it would seem logical that those different responses should flow through into the reapplication treatments. The fact that this did not happen, and yields seem to plateau at ~3500 kg/ha may indicate the yields in the re-applied treatments were restricted by something other than P nutrition—possibly lack of water.

Selected treatments were soil cored after harvest to calculate crop water use efficiency (WUE), assuming zero runoff and drainage (Table 2). The data are from a limited number of cores; they indicate the relative difference in crop WUE achieved by reapplying P. Industry standards for chickpeas indicate that high crop WUE is between 8–12 kg/mm/ha*. The extraordinarily high crop WUE (17-20 kg/mm) in these re-applied P treatments suggests the water limited yield was reached in these treatments (Table 2). This is supported by the differences in crop WUE between a residual P treatment of 40P+0 (12.3 kg/mm/ha) and the re-applied P treatment of 40P+30P (17.7 kg/mm/ha).

The lower yields in treatments with access to residual bands of P (10P+0, 20P+0, 40P+0) only, indicate there was insufficient access to

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*Best Management Guide, 2020; www.pulseaus.com.au

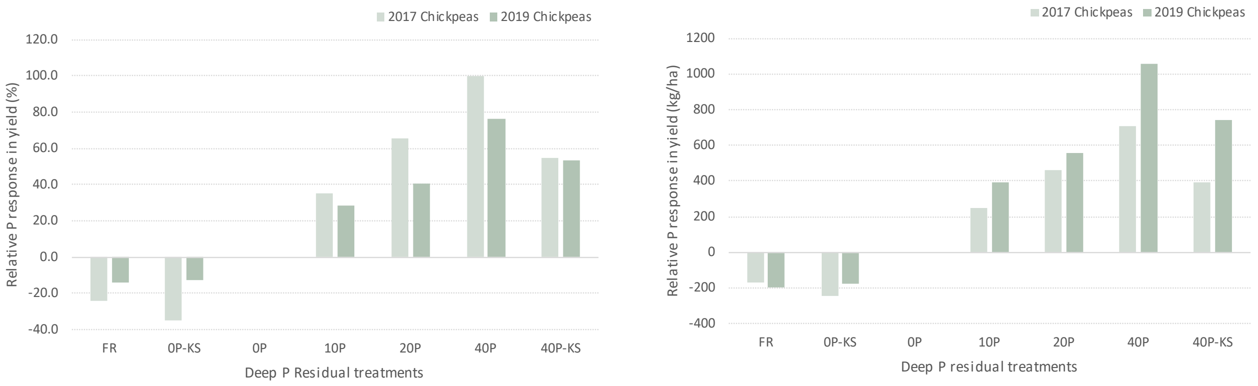

Figure 2. Relative response to phosphorus in long term residual deep phosphorus treatments across both the 2017 and 2019 chickpea crops. Relative response (%) is presented on the left and kg/ha on the right.

P to achieve water limited yield. The residual bands could not generate the same yield as the re-applied bands of P. It is assumed that the residual bands have reduced concentration and P availability after six years due to fixation/precipitation of P in the soil, and some redistribution of P taken up from the bands by the crop and being returned to the soil surface in crop residues.

Analysis of total dry matter (TDM) data taken from selected P treatments (Figure 3) shows three distinct bands of significant differences in dry matter yield. Treatments that have never had any P applied (FR, 0P-KS+0P, 0P+0P) had less than half the dry matter of treatments that were growing on residual P from 2013 (20P, 40P and 40P-KS). Treatments that had extra P re-applied in 2019, increased their dry matter production by another ~40% over the residual P treatments (Figure 3).

Visual differences in biomass were evident from emergence (top) right through to peak grain fill (bottom) in the phosphorus trial.

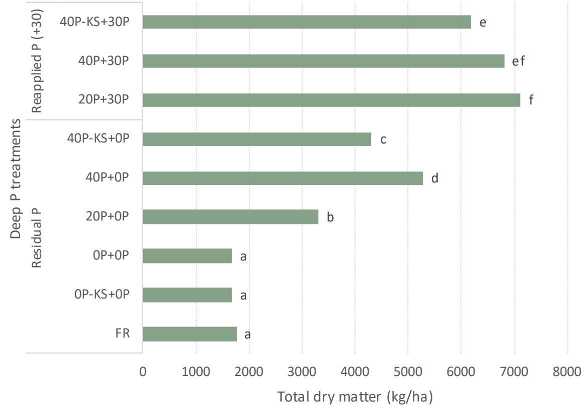

Figure 3. Comparison of total dry matter means across deep phosphorus treatments.

Means with the same letter are not significant at the 5% level.

The P tissue concentration data (Figure 4) shows no significant difference between residual P (applied 2013) and treatments that have never had P applied. The concentration of P in the plant tissue was only significantly increased by the reapplication of P in 2019. This indicates that the crops growing on residual P were struggling to get enough P to meet demand, and what P they could get was used to grow additional biomass.

Subsequent data for total plant uptake of P (Figure 4, kg/ha) shows that some of the residual P treatments were taking up significantly more P than those that had no P application (Figure 4); consistent with the higher yields produced both in grain and dry matter. However, the P concentration in the tissue did not significantly alter in these two groups, indicating that P supply was still a limiting factor. In contrast, treatments that had reapplied P in 2019 showed significant increases in P concentration, P uptake, (Figure 4) and dry matter production over the other treatments (Figure 3).

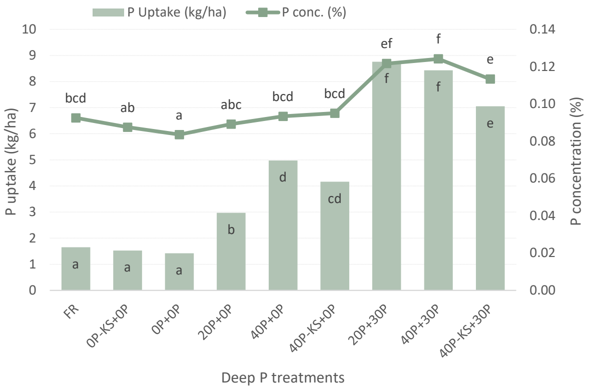

Figure 4. Plant analysis of total dry matter for deep phosphorus treatments.

Comparison of mean phosphorus uptake on primary axis and concentration of phosphorus in total dry matter on secondary axis. Means with the same letter are not significantly different at the 5% level.

There was no difference between 20P+30P and 40P+30P in both uptake and tissue concentration, unlike the related residual treatments (20P+0, 40P+0) where there was a 2 kg/ha difference in P uptake. High P status in the sub-surface layers would have stimulated root proliferation in this zone, which in turn means soil water in the fertilised layer would have been expended faster. This reduces the time that the plant has access to this enriched zone, especially in a season like this one where there was inadequate in-crop rainfall to re-wet the fertilised subsoil layers. Hence the analysis for these two treatments (20P+30P, 40P+30P) may have been limited by soil moisture.

The increased P concentration in plant tissue of the reapplication treatments may have started to overcome the worst of the P limitations to growth and yield. However, the potential for further yield increases with better moisture is unclear.

The collective data set does not suggest luxury P uptake by the crop (Figure 5). The linear relationship of increased grain yields for increasing P uptake across the whole treatment range, with no flattening of the gradient in the trial. Additionally, the highest P concentration achieved in this trial (0.124 %) (Figure 4) remained well below recommendations of ~0.2 % P in total dry matter for P sufficiency (Bell, 2020). Again, more P will likely lead to more grain yield if there is adequate water for crops to access the P from the bands.

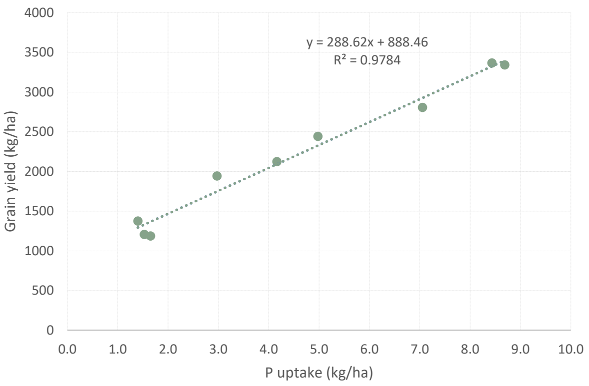

Figure 5. Scatter plot of grain yields versus plant uptake of phosphorus across selected deep phosphorus treatments.

The contribution of surface P to the 2019 yields was assessed by including a single starter rate across all treatments with a subsequent split for no application of starter fertiliser, at planting.

Overall trial mean data showed a significantly higher yield 'with' starter (2418 kg/ha), compared to 'without' starter (2270 kg/ha). However, the comparisons across each individual deep-P treatment (Figure 6) shows that most of the advantage of starter P was in treatments without any deep-P applied (FR, 0P-KS, 0P) or only the lowest rate (10P). Treatments with access to deep-P as a residual or a fresh reapplication (20P and above) gained little or no grain yield benefit (Figure 6).

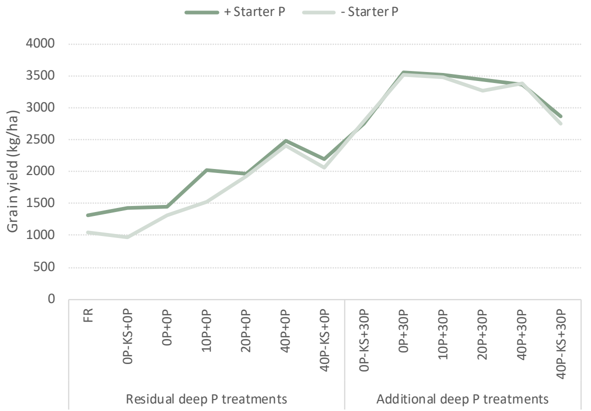

Figure 6. Comparison of mean grain yields in relation to the application of Starter phosphorus at planting across all deep phosphorus treatments (lsd = 103).

Furthermore, treatments without any deep-P applied (FR, 0P-KS, 0P+0P) gave the biggest response to starter fertiliser; taking up an extra ~1 kg P/ha (Figure 7). The residual P treatments added an extra 2–5 kg/ha of P uptake and the reapplication treatments boosted P uptake by another 4-5 kg/ha. The starter effect added nothing to the residual or the re-applied treatments. The deep banding was far more effective in getting more P into the plant than using just a starter P strategy, especially given the lack of in-crop rainfall.

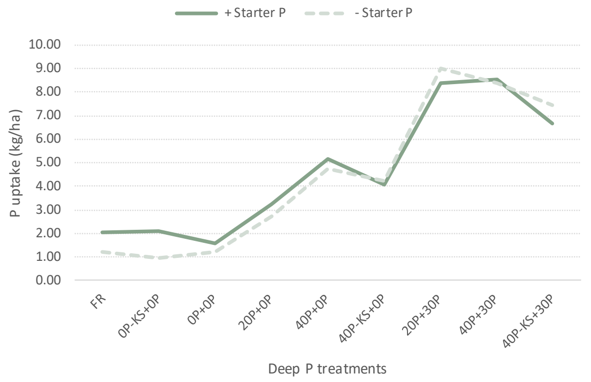

Figure 7. Comparison of 'with' and 'without' starter phosphorus in relation to mean phosphorus uptake for total dry matter across selected treatments.

Interestingly there was no difference in the mean yields of the FR and 0P-KS treatments (Figure 1); the ripping and background N (0P-KS) applied prior to this 2019 chickpea crop had no effect on grain yields on their own (Figure 1 and Table 2). If the 2019 crop had been a cereal rather than a legume, the background N may have had some impact on yield.

The accumulated grain yield response over six years to a single application of deep P was substantial with a significant economic benefit (Figure 8; reapplication yields not included). The yield response differences between the 20P and 40P residual treatments have continued to grow since the 2017 chickpea crop, reaching ~500 kg/ha (Figure 8). Ultimately, the cumulative profit increased by $1586/ha and $1677/ha in the 20P+0 and 40P+0 treatments respectively, with 40P treatment profitability pulling ahead of 20P treatment in the sixth crop.

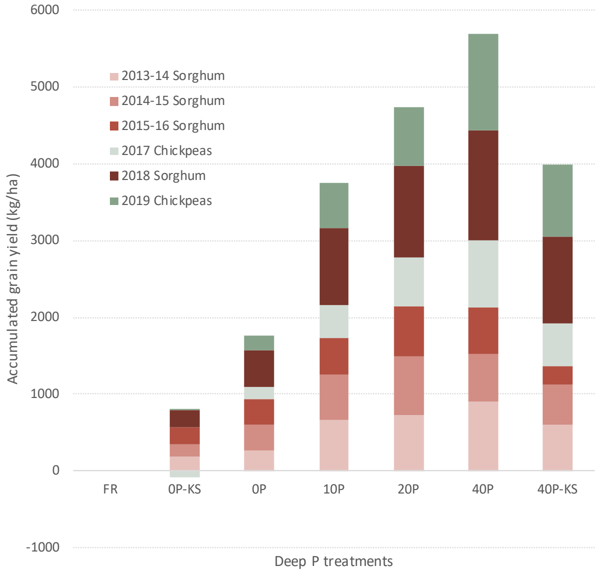

Figure 8. Mean accumulated grain yields after six crops relative to the Farmer Reference treatments across all deep phosphorus treatments based on 2013 applications only.

Reapplying P in year six of the experiment further increased yields by close to 75% above the yields achieved from the long-term residual treatments (Table 2). The reapplication of P in 2019 has added an extra 923 kg/ha (16%) of accumulated yield to the 40P treatment and 1417 kg/ha (30%) to the 20P treatment (Table 3). The cost to reapply 30 kg/ha of P, 50 kg/ha K and 90 kg/ha N was roughly $260/ha; the reapplication has paid for itself and delivered a profit in the year of application. These data suggest a considerable advantage in reapplying P prior to year six of the experiment, along with a substantial improvement between the 20P and 40P treatments.

Table 3. Comparison of the differences in mean accumulated grain yields over and above the Farmer Reference treatments; with and without the extra application of phosphorus in 2019.

Deep-P treatment	Accumulated grain yield (kg/ha)		
	Improvement (on residual P from 2013 vs FR)	Improvement (with re-additional P in 2019 vs FR)	Difference (as a result of reapplications in 2019)
FR	0	0	0
0P	1765	3919	2153 (122%)
10P	3749	5467	1717 (46%)
20P	4734	6151	1417 (30%)
40P	5697	6621	923 (16%)

The presence of 0P, 0P-KS, 40P and 40P-KS treatments allows us to break down the individual contributions of re-applied P and K. Yields in the 0P-KS+30P treatment were higher than the 0P-KS+0P treatment by over 1700 kg/ha ($1125/ha crop revenue), whilst 40P-KS+30P out-yielded 40P-KS+0P treatment by ~650 kg/ha ($420/ha crop revenue). Where background K was also re-applied (40P+30P and 40P+0P), an additional 560 kg/ha and 320 kg/ha of grain was produced respectively (Table 2). This generated another $200-350/ha in additional income. The reapplication of both P and K paid for themselves in the first year.

The total contribution of 'top-up' deep P and K applications to long term profitability will only be known in the coming years. However, the costs have already been accounted for, and we are confident in responses lasting at least five years; it is now simply a question of how big the ultimate increase in profit from this practice will be.

Chickpeas growing in phosphorus deficient soil.

Potassium trial

The K treatment effects in the trial were small unless the dominant nutrient constraint (i.e. P) was addressed. For example, the FR, 0K-PS 'with' and 'without' a 50 kg K/ha reapplication and the 100K–PS treatments without extra K were not significantly different at an average yield of 1610 kg/ha (Figure 9). There was a significantly higher yield when the fresh 50K application was made to the treatment where 100K was originally applied without PS. However, while that response was substantial (+450 kg/ha), the yields in that treatment were still 1100 (100K+0K) to 1400 (100K+50K) kg/ha lower than treatments that also received a re-application of background deep-P (Figure 9).

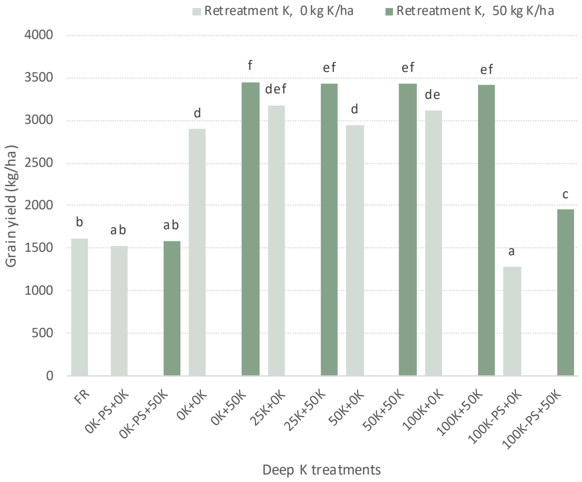

Figure 9. Comparative mean grain yields across all treatments in deep potassium trial.

Means with the same letters are not significantly different at the 5% level (lsd = 298).

Within the cohort of treatments that received background P (Figure 10), treatments that received a reapplication of 50K were always higher-yielding than those with the original K application in 2013 only. The average K response was 300 kg/ha (a 10% yield increase) but was not always statistically significant (Figure 10). There was no significant grain yield response to increasing K rate across the original residual K treatments (0K+0K, 25K+0K, 50K+0K, 100K+0K).

On average there was a ~1600 kg/ha difference in grain yield for deep-K treatments that had additional background P (Figure 10); an almost doubling of yield and similar to the ~2000 kg/ha difference in the P trial.

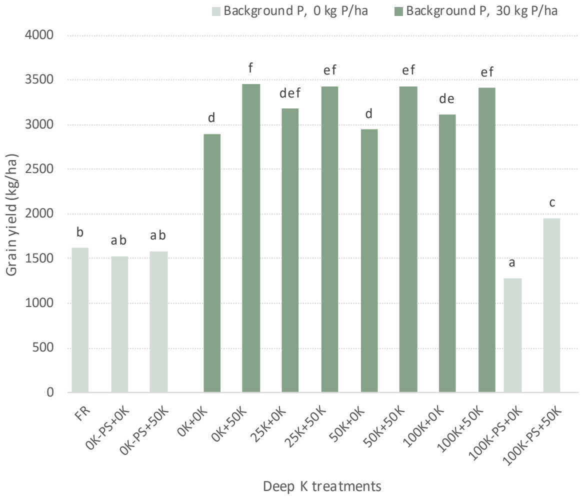

Figure 10. Comparison of mean grain yields between treatments with background phosphorus (+30 kg/ha) and no background phosphorus (0 kg/ha).

Means with the same letters are not significantly different at the 5% level.

The grain yield responses to K were also apparent in the dry matter production of the plots that were monitored (Figure 11); there was an average ~4000 kg/ha greater response where background P fertiliser was applied.

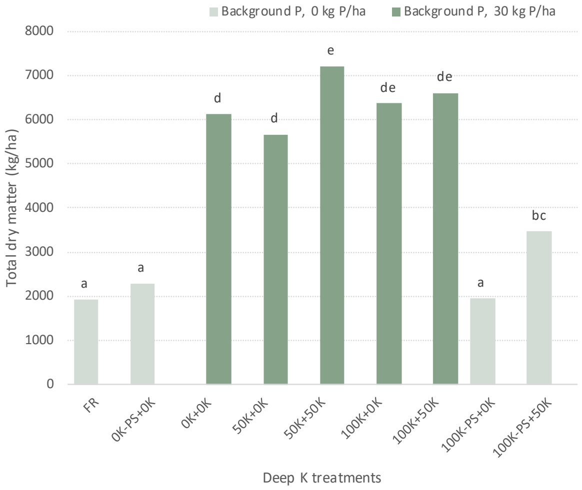

Figure 11. Comparison of mean dry matter yields in the potassium trial, between treatments that had phosphorus applied as background nutrition and treatments that never had any phosphorus applied.

Means with the same letters are not significantly different at the 5% level.

Plant tissue analysis (Figure 12) demonstrates a different pattern to the grain and dry matter analysis (Figures 10 and 11) where background P applications increased yield for a potential dilution effect on K. Plant tissue K was improved by reapplying 50 kg K/ha in 2019 for both the 50K and 100K residual treatments, and the residual K treatments applied in 2013 (50K+0 and 100K+0) produced the same or greater K concentration than those without any K applied (0K, 0K-PS, FR), regardless of background P.

Total K uptake (Figure 12) was increased in the residual K treatments, especially when background P was applied (0K+0K, 50K+0K and 100K+0K). Interestingly, the 100K-PS treatments had some of the highest tissue K concentrations, but did not increase grain or dry matter yield until background P was added (100K+50K). It is clear that P is the main limitation on grain yield and biomass production at this site—unless enough P was present to allow increased growth, additional K uptake did not increase yields.

The reapplication of 50 kg K/ha increased K uptake by 15–25 kg/ha over the residual K treatments (Figure 12) and led to an average yield increase of ~10% (Figure 9). This suggests there were still K limitations to crop yield in the residual K treatments, albeit small compared to the response to P. The value of residual K treatments (50K+0, 100K+0) reduced over time and while still contributing to higher K uptake (Figure 12), was no longer improving yields (Figure 9).

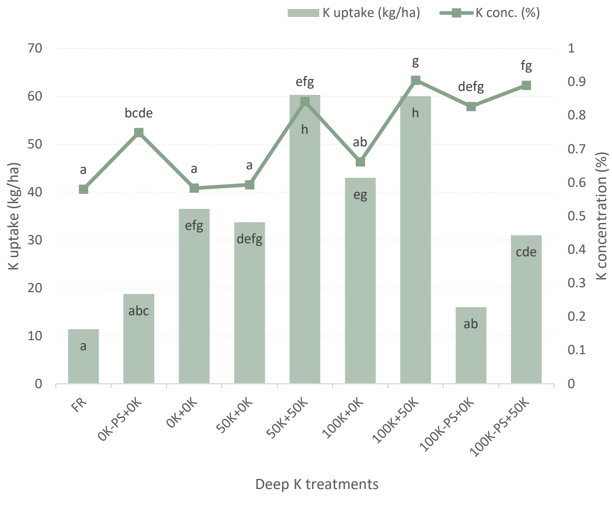

Figure 12. Comparison of mean dry matter potassium concentration and potassium uptake in selected treatments in potassium trial.

Means with the same letters are not significantly different at the 5% level.

A comparison of K tissue concentration and P tissue concentration (Figure 13) for the same selected treatments as the dry matter data (Figure 11) gives an insight into the relationship between P and K in the crop. The K concentration in dry matter often increased when K was present but there was no background P (100K-PS+0, 100K-PS+50K). Background P increased growth and dry matter production to dilute K concentration in the crop (50K+0, 100K+0). Only with reapplication of K (50K+50K, 100K+50K) did the K concentration increase with the dry matter yield increases. This explains the see-sawing relationship between P and K in the tissue analysis (Figure 13) and reinforces that increasing K concentration does not equal increased yield unless P is present.

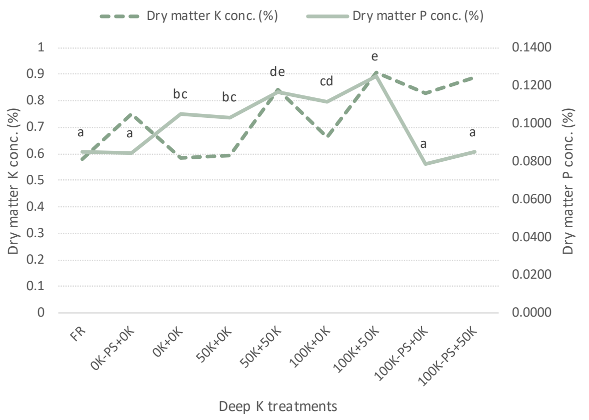

Figure 13. Comparison of mean potassium and phosphorus concentration in dry matter across selected treatments in the potassium trial.

Label means represent phosphorus concentration only. Means with the same letters are not significantly different at the 5% level.

There is a distinctive K yield response at this trial site of ~1000 kg/ha over and above the benefit from background P in the 0K treatment (Figure 14). The accumulated yield data also shows the last chickpea crop in 2019 has evened out the response to residual K across the three different rates (25K, 50K, 100K). This last crop had P reapplied, which may explain the bigger contribution by the 2019 crop to the total accumulated yield. The extra background P would have allowed better root growth and led to higher K uptake. This is a response that regularly occurs, even though the increased K uptake does not always lead to increased yield.

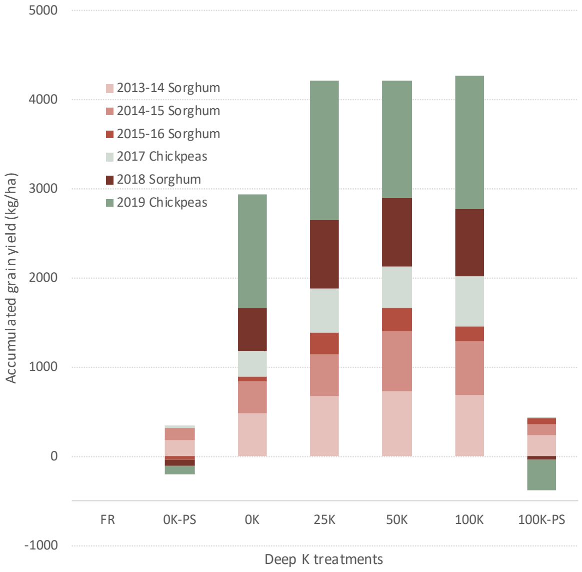

Figure 14. Mean accumulated grain yields after six crops relative to the Farmer Reference treatments across all deep potassium treatments.
This data only represents the residual potassium treatments.

Accumulated grain yield increases from reapplying K were much smaller than the responses to reapplying P. Both K treatments had background P re-applied so the net gain from reapplication of K in relation to the long-term accumulated gain yield is between 6 and 11% (Table 4), about the same net gain from the K trial over most of the cropping years, except in the 2017 chickpea crop. At this site, the yield response to K is about a 10% increase over and above the P response.

Table 4. Comparison of the differences in mean accumulated grain yields over and above the Farmer Reference treatments; with and without the extra application of potassium in 2019.

Deep-K treatment	Accumulated grain yield (kg/ha) Improvement (on residual K from 2013 vs FR)	Improvement (with re-additional K in 2019 vs FR)	Difference (as a result of reapplications in 2019)
FR	0	0	0
0K	2945	3501	555 (19%)
25K	4209	4463	253 (6%)
50K	4218	4702	483 (11%)
100K	4270	4566	296 (7%)

Implications for growers

This trial confirms that a single deep application of P at 20 kg/ha or 40 kg/ha can increase yields significantly over a period of six years, with higher application rates providing better yields in the final three years. Indeed, 40 kg P/ha produced 5.7 t/ha more accumulated grain over the life of the project than the baseline FR treatment.

The trial also shows that reapplying P after six years increased yields by nearly 1 t/ha over the highest residual banding treatment of 40 kg P/ha; reapplying with an extra 30 kg P/ha in year six lifted the accumulated grain yield response to 6.6 t/ha.

It appears the effectiveness of the residual bands reduced over time but the optimal timing for reapplying deep-P is still unknown. Given the size of yield gains, there is a likely advantage in reapplying the P earlier than six years.

Relative yield responses to deep-P have been higher in chickpeas than sorghum at this site. This may be a characteristic of grain legume crops in general, but more testing across the other legume crops is needed to be confident of that. It may also be that chickpeas are particularly sensitivity to P, or that the sorghum crops at this site ran into N constraints and could not express their full P response.

The size of the response to deep-applied P is not always just about the rate of P applied. Seasonal influences such as in-crop rainfall (amount and timing), soil type (water holding capacity) and the status of other nutrients in the soil profile will all have significant impacts on the response to deep-applied P and K.

The response to K at this site was overshadowed by the massive response to P. However over six years, the grain response was 1.2 t/ha over and above the response to P. There has been no real difference between the 100 kg K/ha and 50 kg K/ha treatments. This may reflect a marginal K deficiency, or a more rapid decline in the residual value of deep K. The latter effect could be due to more rapid crop accumulation of K from deeper layers (e.g. the 15-25 kg of additional K uptake from a 50 kg K application in the current chickpea crop) and subsequent redistributed onto the topsoil with crop residues.

There was no response to S at this site. Even though the long-term P issues are dominating the production system, it is surprising that S has not had a bigger impact at this site as soil testing suggests a deficiency. Further study is required to define where and when S deficiencies are likely to occur and how they impact on yield.

Overall, there has been a large economic gain to the deep placement of P-based fertilisers at this site. These gains are spectacular due to the very low soil P analysis and high soil water holding capacity at the site. Nevertheless, the data from this site shows what is possible in terms of grain production improvements when soil analysis of macronutrients (NPKS) are properly evaluated and the appropriate nutrition strategies are employed.

Acknowledgements

It is greatly appreciated to have the continued support of trial cooperators, by hosting this trial site. This work is funded by the Grains Research and Development Corporation, University of Queensland and the Department of Agriculture and Fisheries under UQ 00063 'Regional soil testing guidelines for the northern grains region'.

Trial details

Location:	Dysart
Crop:	Chickpeas (Kyabra)
Soil type:	Grey Vertosol (Brigalow scrub) on minor slopes.
In-crop rainfall:	41 mm
Fertiliser:	Background N applied at 90 kg N/ha as Easy N®.

Selected soil fertility characteristics:

Depth (cm)	Nitrates	Sulphur (KCl-40)	Col P	BSES P	Exc. K	ECEC
0-10	2	1.7	5	8	0.25	36
10-30	1	1.6	1	3	0.12	29
30-60	1	2.6	1	4	0.09	31

Typical symptoms of phosphorus deficiency in chickpea.

Deep-phosphorus: Long-term economics of applications—Central Queensland

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Research Question: *What are the long-term economics of deep-phosphorus applications in Central Queensland?*

Key findings

1. Higher rates of phosphorus may provide higher long-term dollar per hectare returns.
2. Yield responses have averaged 25% in low phosphorus sites that have had at least four crops in Central Queensland.
3. Yield responses have often been limited by additional constraints. Adequate nitrogen and potassium may be needed to achieve the full benefit of deep-phosphorus applications.

Background

The University of Queensland and the Department of Agriculture and Fisheries established trial sites across Queensland and northern New South Wales from summer 2011 onwards (Figure 1), with the first crops harvested in 2013. Sites were initially treated with background levels of nitrogen (N) and zinc (Zn), with potassium (K) and sulfur (S) applied where required in order to ensure that the sites were unconstrained by other nutrients. There are now multiple years of data that support the use of deep-phosphorus (P) as an economic option to address low and declining levels of subsoil P.

Figure 1. Trial site distribution

What was done

This analysis is focused on trial sites in Central Queensland (CQ) where P was applied as monoammonium phosphate (MAP) and at least four years of crop data are available. Additional sites with limited years of crop data have been excluded from the dataset. All analysed sites originally recorded less than 10 mg/kg for Colwell bicarbonate phosphorus soil tests done in the 10–30 cm layer; thus would be expected to have positive responses to improved P availability.

The fertiliser applied in commercial settings is driven by nutrients required and the price of different fertiliser mixes to achieve these requirements (e.g. monoammonium phosphate (MAP) versus diammonium phosphate (DAP)). This economic analysis is based on urea for N, MAP for P, muriate of potassium (MOP) for K, and ammonium sulfate (GranAm®) for S, with Zn applied as Trace Zn (Table 1).

Table 1. Trial nutrient makeup and cost ($/t).

Nutrient	Applied as	Price ($/t)
Nitrogen (N)	Urea (46N)	$450
Phosphorus (P)	MAP (22P, 11N)	$800
Potassium (K)	MOP (50K)	$500
Sulfur (S)	GranAm® (24S, 20.5N)	$450
Zinc (Zn)	Trace Zn (93Zn)	$2000

Note: N/ha background rate was total N applied to site pre-seeding; as MAP rate increased, urea application was lowered by ~25%. Likewise GranAm® applied for 20 kg S/ha would also supply ~17 kg of N.

Costs for the application of deep-P with current commercial farm equipment range from $15–40/ha (as determined via case studies). The analysis in this paper used a rate of $30/ha (Table 2).

Table 2. Estimated treatment costs by P rate ($/ha).

Treatment (P kg/ha)	Cost ($/ha)			
	Application	Urea	MAP	Total
0	$30	$69	$0	$99
20	$30	$61	$73	$164
30	$30	$57	$109	$196
40	$30	$52	$145	$227
60	$30	$43	$218	$291

Note: K and S were also applied as backgrounding to ensure unconstrained soil for scientific results; these costs have not been included as they may not be necessary for growers depending on soil nutrient status.

As noted above, K and S were applied to eliminate other nutrient deficiencies where required and to ensure measured responses were to P. Whilst some sites have shown positive responses to K, especially in CQ chickpea crops, no sites have responded to S. If K levels are also low, applying a blanket rate of 50 kg/ha would add ~$50/ha to the total treatment cost.

N costs could be reduced if P was applied into a high N environment. However, trial experience has been that the higher yield potential once P deficiencies have been corrected, means crops often became N constrained. Consequently, this analysis includes additional urea costs (Table 2).

Analyses have been done with five and 10 year average crop prices (Table 3) in order to smooth out the large price fluctuations that occurred during the trial period, and to ensure that a percentage change in crop production in 2013 is equivalent to the same change in 2016. The use of average prices also gives a more realistic indication of the long-term economics of deep-P.

Table 3. Average crop prices over five and ten years ($/t).

Crop	Average crop price ($/t)	
	over 5-years (2013-2017)	over 10-years (2008-2017)
Barley	$263	$243
Chickpea	$662	$565
Mungbean	$1,080	$925
Sorghum	$269	$243
Wheat	$290	$277
Fababean	$425	$397

Results

Yield responses in CQ have generally been impressive, averaging 25% above the farmers' normal practice (Farmer Reference; FR) (Table 4).

Responses at the Emerald site have been limited, despite low Colwell-P soil tests. Plant tissue and grain testing at this site suggests crops are accessing P from an unknown source, which limited the effectiveness of deep applied treatments.

Table 4. Central Queensland cumulative yield benefit vs normal farming practices (FR) (%).

P rate (kg/ha)	Comet River (4)	Emerald (5)	Dysart (6)	Dululu (4)
0	21%	7%	13%	12%
20	36%	5%	42%	19%
40	39%	7%	41%	19%
StartingColwell P (mg/kg at 10-30 cm)	6	6	1	3

Note: numbers in brackets following site names are the number of crops that have been harvested at these sites. It is expected that the benefits of higher rates of P will become more pronounced the longer the site is cropped.

At the longest running site (Dysart), both the 20P and 40P treatments have generated an additional 4.5 t/ha in yield since the first sorghum crop was harvested in 2014. It is expected that responses could have been even higher at this site with additional N, as sorghum crops in the second and third years had very low protein levels that suggest an N constraint. This is further supported by the significantly higher chickpea response in 2017, and the much higher sorghum response in year 5 following the application of additional N (Table 5).

Table 5. Dysart yield responses (kg/ha).

	2014 Sorghum	2015 Sorghum	2016 Sorghum	2017 Chickpea	2018 Sorghum	2019 Chickpea
FR	2606	2713	1845	522	2282	1243
0	2845	2994	2149	609	2655	1376
20	3342	3476	2512	1142	3496	1910
40	3355	3283	2091	1225	3553	2281

This experience of deep-P responses being limited by subsequent constraints were not uncommon across sites in both CQ and Southern Queensland. In CQ, there were positive responses of 7-21% in 0P treatments where tillage was conducted and K, N and S were applied, these treatments were included to ensure that P responses could be separated from the correction of other background constraints.

Table 6. Chickpea yield responses to deep-P in Central Queensland (kg/ha).

	Comet River 2016	Comet River 2018	Emerald 2017	Emerald 2019	Dysart 2017	Dysart 2019	Dululu 2017	Dululu 2019
FR	1623	1239	1720	2650	522	1243	2686	413
0	1998	1310	1740	2753	609	1376	2915	798
20	2424	1482	1651	2709	1142	1910	3221	981
40	2467	1562	1709	2740	1225	2281	3242	971

The positive CQ responses have been achieved consistently across almost all crop types; including winter and summer pulses and cereals. The significant chickpea yield increases (of up to 1 t/ha compared to FR; Table 6) while chickpea prices were high have contributed greatly to the bottom line (Table 7). Whilst this analysis is using 5 and 10 year average prices, it is noted that chickpea prices have exceeded $800/t in some years and thus would have provided even greater benefits in those years.

Half of the observed chickpea yield responses have been higher than 50%. Excluding the unresponsive Emerald site, the average responses are 66% for 20P and 75% for 40P (Table 6).

Of particular note is the 2019 Dysart chickpea crop, the sixth crop at this site. Here the 40P treatment achieved 371 kg/ha in additional chickpea yield over the 20P treatment ($265 or $210/ha using 5 year and 10 year average prices respectively). Importantly, this 20P treatment itself yielded 667 kg/ha over the FR treatment (Table 5).

These impressive chickpea responses have flowed through to cumulative gross margins, with the three responsive sites at least $500/ha ahead of FR treatments even at higher P rates.

Table 7. Cumulative gross margin benefit versus FR.

P rate	Comet River (4)	Emerald (5)	Dysart (6)	Dululu (4)
5 Year 20P	$770	$27	$1,586	$767
5 year 40P	$800	$38	$1,677	$686
10 year 20P	$658	$15	$1,375	$637
10 year 40P	$676	$16	$1,436	$557

Note: numbers in brackets following site names are the number of crops that have been harvested at these sites. It is expected that the benefits of higher rates of P will become more pronounced the longer the site is cropped.

Implications for growers

Where Colwell P levels are low (<10 mg/kg), deep-P appears to offer strong economic returns in most situations.

There were a number of sites where other constraints, particularly N and K deficiencies, have limited P responses in CQ. This means growers need to take into account the full nutrient status of their soils and apply nutrition in line with the improved 'non-P-limited' yield potential.

Whilst 20P is a good starting point and is typically paid off within the first two crops, it is expected that higher rates of P will provide results for a longer period of time. Currently the 40P treatment is ahead of the 20P at Comet River and is almost $100/ha ahead at Dysart after 6 crops. As other sites have more crops harvested, it is expected more will begin to favour higher P treatments over time.

Whether growers should apply more P upfront, or whether they should be looking to reapply deep-P at more regular intervals is currently unknown. However, work is currently underway to examine the benefits of reapplication.

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 across a number of projects, UQ00063/DAQ00194; the authors would like to thank them for their continued support.

Deep-phosphorus: Long-term economics of applications—Southern Queensland

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Research Question: *What are the long-term economics of deep-phosphorus applications in Southern Queensland?*

Key findings

1. Higher rates of phosphorus may provide higher long-term dollar per hectare returns.
2. Low rainfall sites are expected to have longer 'payback periods' for the investment in deep-phosphorus. However, significant benefits can be obtained in better years.
3. Understanding how the different crop species in your rotation respond to deep-placed phosphorus will give the best chance of maximising returns.

Background

The University of Queensland and the Department of Agriculture and Fisheries established trial sites across Queensland and NSW from summer 2011 onwards (Figure 1), with the first crops harvested in 2013. All sites were initially treated with background levels of nitrogen (N) and zinc (Zn), with potassium (K) and sulfur (S) applied where required in order to ensure that the sites were unconstrained by other nutrients. There are now multiple years of data that support the use of deep phosphorus (P) as being an economic option to address low and declining levels of subsoil P.

Figure 1. Trial site distribution

What was done

This analysis is focused on four trial sites in Southern Queensland (SQ) where P was applied as monoammonium phosphate (MAP) and at least four years of crop data are available. Additional sites were established, however they have been excluded from the dataset due to either the use of triple superphosphate (TSP) with consequent reduced P availability, or limited years of crop response data. All sites analysed in this dataset have Colwell bicarbonate phosphorus test below 10 mg/kg in the 10-30 cm soil layer; thus would be expected to have positive responses to improved P availability. Indeed, the Jimbour West site with a 10-30 cm Colwell-P level of 8 mg/kg, is the only one greater than 6 mg/kg.

The fertiliser applied in commercial settings will be driven by nutrients required and the price of different fertiliser mixes to achieve these requirements (e.g. monoammonium phosphate (MAP) versus diammonium phosphate (DAP)). However, this economic analysis is based on urea for N, MAP for P, muriate of potassium (MOP) for K, and ammonium sulfate (GranAm®) for S, with Zn applied as Trace Zn (Table 1).

Table 1. Trial nutrient makeup and cost ($/t).

Nutrient	Applied as	Price ($/t)
Nitrogen (N)	Urea (46N)	$450
Phosphorus (P)	MAP (22P, 11N)	$800
Potassium (K)	MOP (50K)	$500
Sulfur (S)	GranAm® (24S, 20.5N)	$450
Zinc (Zn)	Trace Zn (93Zn)	$2000

Note: N/ha background rate was total N applied to site pre-seeding; as MAP rate increased urea application was lowered by ~25%. Likewise GranAm® applied for 20 kg S/ha would also supply ~17 kg of N.

Costs for the application of deep-P when applied with current commercial farm equipment range from $15 to $40/ha (as determined via case studies). The analysis in this paper used a rate of $30/ha (Table 2).

Table 2. Estimated treatment costs by P rate ($/ha).

Treatment (P kg/ha)	Cost ($/ha)			
	Application	Urea	MAP	Total
0	$30	$69	$0	$99
20	$30	$61	$73	$164
30	$30	$57	$109	$196
40	$30	$52	$145	$227
60	$30	$43	$218	$291

Note: K and S were also applied as backgrounding to ensure unconstrained soil for scientific results; these costs have not been included as they may not be necessary for growers depending on soil nutrient status.

As noted above, K and S were applied to eliminate other nutrient deficiencies where required to ensure measured responses were to P. Whilst some sites (for example Warra) have shown positive responses to K, no sites have responded to S. If K levels are also low, applying a blanket rate of 50 kg/ha would add ~$50/ha to the total treatment cost.

N costs could be reduced if P was applied into a high N environment. However, trial experience has been that the higher yield potential once P deficiencies have been corrected, means crops often became N constrained. Consequently, this analysis includes additional urea costs (Table 2).

Analysis has been done with five and 10 year average crop prices (Table 3) in order to smooth out the large fluctuations in prices that occurred during the trial period, and to ensure that a percentage change in crop production in 2013 is equivalent to the same change in 2016. The use of average prices also gives a more realistic indication of the long-term economics of deep-P.

Table 3. Average crop prices for the last five and 10 years ($/t).

Crop	Average crop price ($/t)	
	over 5-years (2013-2017)	over 10-years (2008-2017)
Barley	$263	$243
Chickpea	$662	$565
Mungbean	$1,080	$925
Sorghum	$269	$243
Wheat	$290	$277
Faba bean	$425	$397

Results

Observed benefits to the basal K, N and tillage in the SQ experiments have been limited. The exception was at Warra, where K appeared to be adequate when trial was established, but ran into severe K deficiency when P was applied and biomass production was increased. This deficiency led to yield penalties of 400-1000 kg/ha in the first crop. K was applied following the second crop to correct this deficiency. Whilst there was no direct K response in the 0P treatment, the following sorghum crop achieved minor yield improvements of 200-600 kg/ha in the 20P, 30P and 60P treatments.

Crop responses to deep-P have been regularly positive in the SQ winter cereal crops, with 100% of 20P treatments out-yielding Farmer Reference by up to 700 kg/ha.

Responses in summer crops and winter pulses have been less consistent. Chickpeas at Jimbour West 2017 and Condamine South 2019 both had over 300 kg/ha in yield benefit from 20 kg deep-P compared to Farmer Reference. The other trials have shown minimal benefit. For example chickpeas at Warra in 2014 achieved 15% higher yields under 20P treatment, yet 2016 chickpeas at the same site had no response.

Table 4. Southern Queensland cumulative yield benefit versus Farmer Reference (FR).

P rate (kg/ha)	Mt Bindago (4)	Warra (4)	Condamine South (5)	Jimbour West (6)
0	1%	-8%	6%	9%
20	10%	1%	14%	18%
30	13%	0%	16%	19%
60	14%	4%	19%	24%
Colwell P (mg/kg at 10-30 cm)	3	3	4	8

Note: numbers in brackets following site names are the number of crops that have been harvested at these sites. It is expected that the benefits of higher rates of P will become more pronounced the longer each site is cropped.

Three of the four SQ sites that were treated with 20 kg of P as MAP had cumulative yields increases across multiple years ranging from 10-18% (700-2000 kg/ha)(Table 4). If the previously noted first year K penalty response at Warra is excluded, then the cumulative yield response to 20P at the site was 5%. The higher luxury rates at the same three sites have returned positive cumulative yields of 14-24% (1000–2600 kg/ha). This suggest that there may be additional yield benefits from higher rates of deep applied P.

Using both five and 10 year average crop prices, these yield improvements with 20P generated returns of greater than $300/ha compared to the Farmer Reference treatment at half the sites (Table 5). Mt Bindago has broken even and while Warra remains behind after taking into account treatment costs, if the first year yield penalty of 400-1000 kg/ha driven by K deficiency at the Warra site is removed, it too would approximately 'break-even'.

Table 5. Southern Queensland cumulative gross margin benefit versus Farmer Reference ($/ha).

P rate	Mt Bindago (4)	Warra (4)	Condamine South (5)	Jimbour West (6)
5 Year 20P	$60	-$94	$392	$673
5 Year 60P	44	$70	$393	$706
10 Year 20P	$46	-$106	$336	$577
10 Year 60P	$22	$18	$334	$595

The Mt Bindago site (west of Roma) is of particular interest as one of the few sites established in a low rainfall environment. Treatments at this site almost 'broke-even' in the first year with yield improvements of 500–700 kg/ha in a 4 t/ha wheat crop. Yield benefits of 10-15% continued in the following years. However, cereal crops with yields of <2 t/ha, and pulse crops of 0.5 t/ha meant that these gains have made only minor additional contributions to profit.

In contrast, the 20P treatment at Jimbour West still generated over 2 t/ha in additional cumulative yield compared to the FR treatment despite also having a number of low yielding crops (Table 6). The Jimbour West results could have been even more impressive, but hail damaged both the 2018 barley and 2019 faba bean crops that both showed strong biomass responses (Figure 2).

Table 6. Jimbour West yield responses (kg/ha).

	2014 Barley	2015 Mungbean	2016 Sorghum	2017 Chickpea	2018 Barley	2019 Faba bean
FR	4199	508	2437	1702	1542	476
0	4423	594	2608	2072	1496	656
20	4906	610	2742	2197	1713	703
60	5206	573	2825	2297	1893	665

Figure 2. Faba bean at Jimbour West 2019 prior to hail damage.

Implications for growers

Responses to P have varied, especially with seasonal conditions. Whilst percentage yield benefits have been significant in years with low water-limited yield potential, the lower absolute value of the yield increases resulted in longer average pay-off periods. Fortunately, lower rates of P removal in lower-yielding environment should also result in longer timeframes between any repeat applications.

At responsive sites, 60P has drawn even with 20P after four to six crops, and is expected to offer higher long-term dollar per hectare returns, but with significantly higher upfront risk. Methods of increasing P supply also deserve further investigation. For example, reapplying deep-P at more regular intervals; perhaps three applications of 20P at four year intervals, rather than one upfront application of 60P.

Despite the SQ sites having low subsoil P levels, responses in crops outside winter cereals have not been consistent. Variable sowing depths (e.g. chickpeas) and the frequency of rainfall events that re-wet the topsoil for summer crops may be contributing factors. Understanding how the crop species in your rotation and environment will respond to deep-P in will be key in working out the long-term economics of applying deep-P in SQ.

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 across a number of projects, UQ00063/DAQ00194; the authors would like to thank them for their continued support.

Phosphorus: Rate was more important than band spacing for uptake by summer crops in 2018-19

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Research Question: *How does the application rate and band spacing of deep-placed phosphorus affect crop recovery?*

Key findings

1. The Normalised Difference Vegetation Index (NDVI) values for the 2018–19 summer crops increased with increasing deep-phosphorus rate, and decreased with widening band spacing. There was no interaction between rate and band spacing.
2. Above ground growth responses were substantial until flowering, but hot and dry conditions resulted in limited or no grain yield change with the deep-placed phosphorus.
3. Rate rather than band spacing appears to be the major driver of yield with deep placement.

Background

Recent research (UQ63) shows that grain yield can be reliably increased with deep-placed phosphorus (P), particularly for cereal grain crops due to greater uptake of P by plants. However, this research was all done on 0.5 m fertiliser band spacing and granular monoammonium phosphate (MAP). Consequently, questions have arisen around the best approach to increase P uptake with deep placement.

Crop P uptake by roots is a diffusion-driven process, meaning banded applications are likely to provide a better opportunity for fertiliser P recovery. The concentration gradient created in the band is a function of two factors: how much is applied (the rate) and where is it applied (the band spacing). Exploratory placement experiments suggested 0.25 m bands were equivalent to 0.50 m bands, and both were better than the wider 1.00 m spacing that could be used to reduce application costs. These experiments used a constant P rate, so different band spacing were also characterised by different in-band nutrient concentrations. Research in South Australia on highly alkaline Calcarosols indicated that fluid forms of P fertiliser deliver greater crop recovery through increased diffusion compared to granular products. This aspect has not been evaluated for Queensland soils yet.

This research is attempting to assess how different fertiliser rates at different band spacing combinations alter crop response and fertiliser recovery, over a range of crop species with contrasting rooting characteristics;

a. Is phosphorus uptake increased when band spacing is reduced from 0.5 to 0.25 m?
b. Is phosphorus uptake maintained when band spacing is increased from 0.5 m to 1.0 m to save application costs?
c. Do fluid forms of P fertiliser improve crop recovery over granular products, across the range of rates and band spacings?

What was done

Two experiments from Jimbour West on the northern Darling Downs are reported here, exploring P rate x band spacing interactions for deep-placement of P fertiliser at 20 cm. Experiments at Field-W2 (W2) commenced in March 2015; the sorghum crop reported here was the fourth crop sown. At Field-W5 (W5), experiments commenced in March 2016, and this sorghum crop was the second planted.

This report focuses just on the summer crops from 2018-19. Further analysis across all crops and years will be undertaken shortly as final reports for the project are prepared.

Experimental details for Field-W2

Soil test values at W2 suggest both P and potassium (K) are low (see Trial details). The experiment compared different P application rates at each of three band spacings (0.25, 0.50 and 1.00 m) against an untreated Farmer Reference control (FR)—unamended soil representative of district production practice (Table 1). Monoammonium phosphate (MAP, 10N 22P) was used as the P source, with liquid potassium sulfate (KTS, 30K 25S) and zinc sulfate (17Zn) applied as basal nutrients. Plot size was 10 m long (8 m treated) x 24 m wide, with six replicates. Urea was used to balance nitrogen (N) application to 60 kg/ha.

Experimental details for Field-W5

The experiment was a derivate design from that at W2, with the FR treatments removed and a full factorial structure of five P application rates at each of three band spacings used. Each rate and band spacing combination was split to allow two forms of P to be applied: granular (MAP) and liquid (fluid monoammonium and diammonium phosphate mixture, 10N 15P) (Table 2). Plot size was 10 m long (8 m treated) x 24 m wide, with six replicates. Urea was used to balance nitrogen (N) application to 60 kg/ha and zinc sulfate (17Zn) was applied as a basal nutrient.

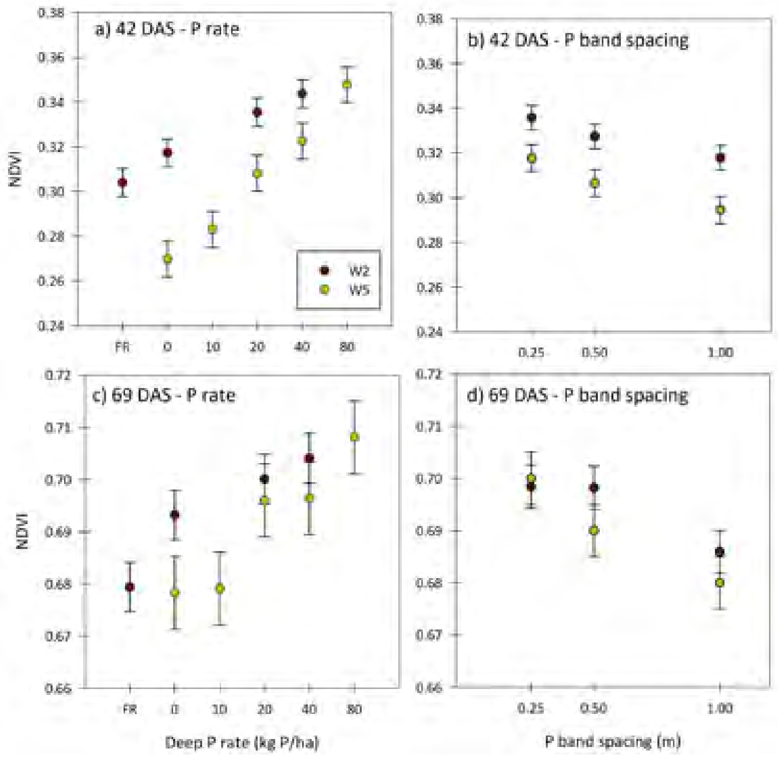

Figure 1. 2018-19 NDVI in Fields W2 and W5 for phosphorus rate and band spacing at two sampling times.

Table 1. Structure of deep-placed phosphorus rate x band spacing experiment at Jimbour West W2.

Basal treatment	P rate (kg/ha)	Band spacing (m)			
		0*	0.25	0.50	1.00
None (FR)	None	✓	✗	✗	✗
Tillage + Basal	0	✗	✓	✓	✓
Tillage + Basal	10	✗	✓	✓	✗
Tillage + Basal	20	✗	✓	✓	✓
Tillage + Basal	40	✗	✓	✓	✓
Tillage + Basal	80	✗	✗	✗	✓

Factorial plus added control structure for P rate x band spacing (*=no band spacing)

Table 2. Structure of deep-placed P rate x band spacing x P form experiment at Jimbour West W5.

P form		Fluid			Granular		
Spacing (m)		0.25	0.50	1.00	0.25	0.50	1.00
P rate (kg P/ha)	0	✓	✓	✓	✓	✓	✓
	10	✓	✓	✓	✓	✓	✓
	20	✓	✓	✓	✓	✓	✓
	40	✓	✓	✓	✓	✓	✓
	80	✓	✓	✓	✓	✓	✓

Results

Normalised difference vegetation index data

Across the two sites, flights using a drone fitted with a multispectral camera took place at 42 and 69 days after sowing (DAS); this roughly aligned with six leaves and flowering stages of growth. The normalized difference vegetation index (NDVI) was calculated using the captured wavelength data. This is a relative measure of above ground growth using the reflectance from a crop canopy—the greater the NDVI the more canopy is present.

The unbalanced treatment structure at W2 in the P rate x band spacing experiment (Table 1) made statistical analysis cumbersome. However, there was a partial factorial combining FR, 0, 20 and 40 kg P/ha rates at each of the three band spacings and this was used to process the NDVI and grain yield data. A full factorial analysis was undertaken for W5. These analyses revealed significant effects of both deep-P rate and band spacing, but no interaction, for both the 42 and 69 DAS NDVI captures at each site (Figure 1).

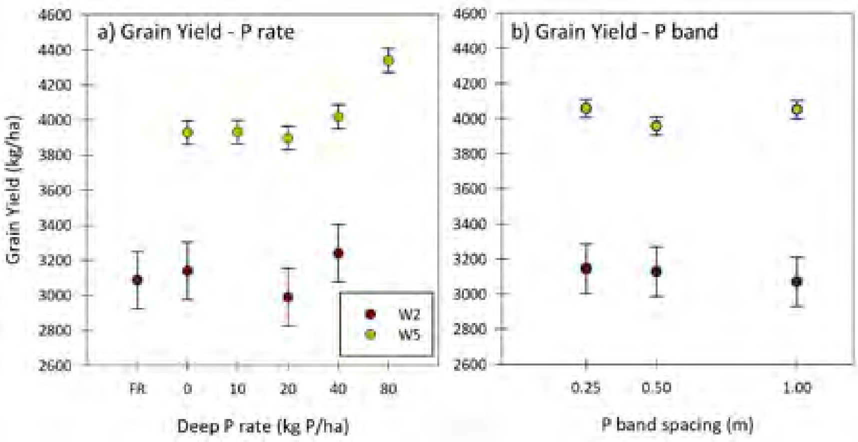

Figure 2. 2018-19 grain yield in Fields W2 and W5 for (a) P rate and (b) band spacing.

At W2, the NDVI for the 20 and 40 kg P/ha rates was >10% up on that of the FR value (Figure 1a), while increasing the band spacing from 0.25 to 1.00 m reduced the NDVI by 5% (Figure 1b) for the 42 DAS images. For W5 at 42 DAS, the NDVI values for the 20 and 40 kg P/ha rates were 14% and 20% up on the 0P value (Figure 1a). Increasing the P band spacing from 0.25 m to 1.00 m also significantly decreased the NDVI (Figure 1b).

By the 69 DAS capture, the P rate effects were still observable at both sites with increasing deep-P rate increasing NDVI (Figure 1c), but the band spacing effect was only significant at the W2 site (Figure 1d).

Maturity dry matter growth

Dry matter cuts at maturity were not significant for any treatment effect in the W2 experiment (mean DM 11,137 kg/ha). In W5, deep-P rate significantly increased maturity biomass ($p<0.05$) but band spacing had no effect. Dry matter increased from 11,140 kg/ha with 0 kg P/ha to 12,540 kg/ha with 40 kg P/ha (a 12.5% increase).

Grain yields

There was no effect of deep-P rate or band spacing on yield at W2 (Figure 2a and b). At W5, increasing deep-P rate did significantly increase grain yield (Figure 2a), but only at the highest application rate of 80 kg P/ha. Again, band spacing at W5 did not have any yield effect, and there was no effect of fluid versus granular forms of phosphorus.

Grain yields at both sites were diminished by the lack of any substantial rainfall beyond 47 DAS (Trial details Figure 3).

Implications for growers

The rate of P placed at depth had a larger influence on plant growth (as expressed by NDVI) than the band spacing that the P was placed in. Wider spacings showed slight reductions in relative growth compared to narrower bands, but it appears, at least from the trial data to date, that yields are more likely to be increased by deep placed P regardless of row spacing.

It is suggested that growers apply deep P in the direction of sowing in band spacings, no further apart than double the narrowest crop row spacing in the rotation, resulting in P bands that are roughly 50 to 70 cm apart.

Acknowledgements

This work is funded by GRDC under the 'Deep-placement of nutrients' project (UQ00078).

Aerial photo of the W2 site at 69 DAS.

Trial details

Location:	W2: Jimbour West
Crop:	Sorghum
Row spacing:	0.75 m
Population:	70 000 target
Date sown:	6 Nov 2018
Maturity biomass date:	18-Feb-2019
Harvest date:	24-Feb-2019
Variety:	Radicle Seeds 'Brazen'
Starter product:	Granulock® Z
Starter rate:	30 kg/ha
In-crop rainfall:	94 mm (Figure 3)
Selected soil characteristics:	

Depth (m)	pH H_2O	pH $CaCl_2$	Col P	BSES P	Ex Ca	Ex Mg	Ex Na	Ex K
0.0-0.1	7.1	6.0	37	97	19.2	14.2	0.8	0.47
0.1-0.3	7.5	6.6	8	12	16.2	14.7	1.6	0.20
0.3-0.6	8.1	7.0	4	7	17.7	19.4	3.8	0.22

Location:	W5: Jimbour West
Crop:	Sorghum
Row spacing:	0.75 m
Population:	70 000 target
Date sown:	9 Nov 2018
Maturity biomass date:	14-Feb-2019
Harvest date:	22-Feb-2019
Variety:	Pioneer Seeds 'A66'
Starter product:	Granulock® Z Extra
Starter rate:	30 kg/ha
In-crop rainfall:	94 mm (Figure 3)
Selected soil characteristics:	

Depth (m)	pH H_2O	pH $CaCl_2$	Col P	BSES P	Ex Ca	Ex Mg	Ex Na	Ex K
0.0-0.1	7.4	6.6	17	30	17.0	13.3	1.3	0.37
0.1-0.3	7.9	6.7	4	12	18.0	15.3	2.4	0.28
0.3-0.6	8.4	7.5			18.7	18.7	4.6	0.27

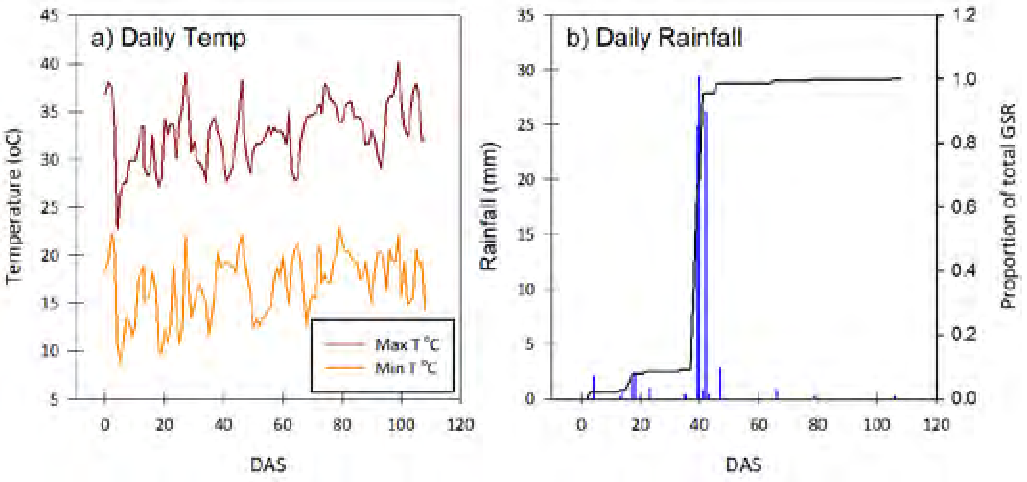

Figure 3. Daily maximum and minimum temperatures (a), and daily rainfall with propotion of total growing season (b) for W2 and W5 experiments.

Phosphorus: Sorghum yield did not respond to starter or deep-placed phosphorous in 2018-19—Western Downs

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RESEARCH QUESTIONS: *Does putting phosphorus (an immobile nutrient) in the soil at 15-20 cm deep increase grain yields several years after the initial application? | How does starter phosphorus interact with deep-placed phosphorus?*

Key findings

1. Starter application of phosphorus gave early visual crop growth responses, but there was no effect of starter phosphorus or deep-phosphorus on sorghum grain yield in 2018-19.
2. Project results across all sites are being collated for final recommendations.

Background

Immobile nutrients such as phosphorus (P) and potassium (K) are taken up by plants from the soil in the 10-30 cm layer and deposited onto the soil surface in crop residues, creating a stratified distribution of higher nutrient availability in the surface and lower availability below.

Root activity in the soil surface can be limited by rapid loss of soil moisture and low in-crop rainfall. Deeper soil layers can offer longer periods of root activity as they are not as prone to evaporative moisture loss. This research is questioning if placing immobile nutrients deeper into the soil increases grain yield and how long those responses may last.

What was done

The Condamine North deep-P experiment was the only trial in the project sown on the Western Downs in the summer of 2018-19. It was the fourth crop planted since the initial deep-P treatments were applied, followed by wheat, long-fallow sorghum and long-fallow mungbean crops.

The site had a stratified plant available P distribution between the surface 0-10 cm and subsurface 10-30 cm/30-60 cm depths (see Trial details). Electrical conductivity increased at depth with a significant gypsum layer present below 90 cm. Chloride concentration was not limiting for root growth in the 120 cm profile analysed.

Deep-P application experiments have been outlined in previous *Queensland grains research* reports. Briefly, fertiliser was placed perpendicular to the sowing direction, at a depth of 15-20 cm in bands 50 cm apart. Basal applications of zinc (Zn) application and sulfur (S) were made into the P fertiliser trench (Table 1). Urea was applied to balance the nitrogen input to 60 kg N/ha through a tyne positioned between the bands of deep-P. The untreated control (Farmer Reference; FR) provided baseline data on yield and nutrient uptake. Each deep-P plot was two planter widths across, allowing starter P to be applied to one side and not the other by growers at sowing. The starter P treatments equated to grower practice for product and rate. There were six replicates in the experiment. The deep treatments were applied during December 2013/January 2014.

Crop management and agronomic management for sites are included in the Trial details section. Phosphorus uptake at maturity was calculated from the above ground biomass cut at maturity multiplied by the biomass P concentration. Grain yield was measured using a plot harvester and grain yield corrected to Graincorp receival standard moisture content. Statistical analysis was conducted using ANOVA in Genstat® 19.

Table 1. Experimental deep-phosphorus treatments.

Treatment rates (kg/ha)	Treatment number							
	1	2	3	4	5	6	7	8
P (as mono ammonium phosphate)	FR	0	0	0	10	20	30	60
S (as ammonium sulfate)	-	10	10	10	10	10	10	10
Zn (as zinc sulfate)	-	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Results

Early vigour responses to the starter application were very evident (Figure 1), with the 'no starter' application plants being much smaller.

Figure 1. Early crop vigour with (foreground) and without (background) starter application in November 2018.

Growing season rainfall totalled 106 mm, but 90% of total rainfall (97 mm) was received by 63 days after sowing (DAS) (Figure 2). Without any rainfall during the grain filling period, grain yield responses to either starter (Figure 3a) or deep-P treatments (Figure 3b) were absent.

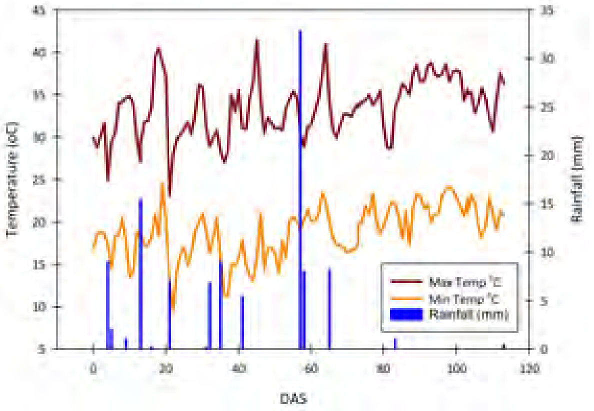

Figure 2. Daily maximum and minimum temperatures and rainfall for the sorghum growing season.

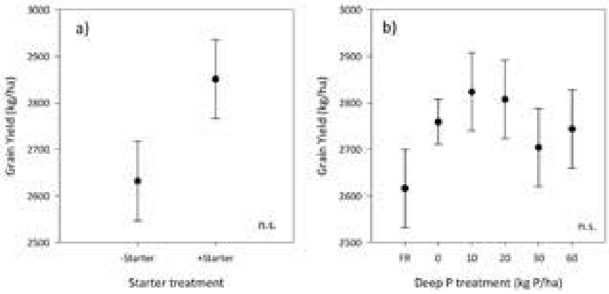

Figure 3. 2018-19 Sorghum grain yield (kg/ha) from deep-placed phosphorus treatments.
Error bars are standard error for each mean.

Implications for growers

While starter P did not respond in this season with a dry finish, application is still encouraged as its role in establishing early vigour and setting yield potential in cereal grains has been well outlined. In the broader project, increased amounts of P taken up into the plant tops (above-ground material) by cereals are well correlated with increasing yields. In the 20 kg P/ha deep treatment, dry matter P uptake increased by 17% above the untreated control for this crop (data not shown), and so would be expected to be increase yields in most seasons.

This research has been conducted under controlled experimental conditions. Before commencing a large-scale nutrient application program, growers are urged to appropriately soil test their fields to establish nutrient available levels for the surface (0-10 cm) and subsurface (10-30 cm) layers; and quantify potential yield constraints. They are then encouraged to evaluate the responses on their soils using strip-trials and on-farm experimentation to validate responses for themselves.

Acknowledgements

Thanks to the trial cooperator for hosting this trial. This work is funded by University of Queensland, the Department of Agriculture and Fisheries and the Grains Research and Development Corporation in the 'Regional soil testing guidelines for the northern grains region' project (UQ00063).

Trial details

Location:	Condamine North
Soil type:	Grey Vertosol - Kupunn
Crop:	Sorghum (Sentinal IG)
Date sown:	17/10/18 at 1 m row spacing
Population:	Sown at 2.4 kg/ha
Starter product:	Starter Z @ 20 kg/ha
Maturity biomass:	23/1/19
Harvest date:	10-11/2/19
In-crop rainfall:	106 mm

Selected soil fertility characteristics:

Depth (cm)	pH (1:5 H_2O)	EC (1:5 H_2O)	Chloride (mg/kg)	CEC (cmol/kg)	Colwell P	BSES P
0-10	8.4	0.14	19	28.8	18	66
10-30	8.6	0.14	12	29.8	6	22
30-60	8.7	0.22	29	29.4	7	17
60-90	8.3	0.28	149			
90-120	5.6	0.58	308			

Soils research

Over recent years, the Regional agronomy (research) team completed a series of projects on soil organic matter and soil carbon, key drivers to maintain healthy soils and sustainable crop production. These projects helped growers understand how soil organic matter and carbon work, and to identify practical and profitable ways to manage their soil organic matter and soil carbon into the future; hopefully to increase or at least maintain their soil organic carbon (SOC) levels. The main findings across these projects were:

- Pasture phases will increase SOC levels.
- Productive pastures (i.e. ensuring adequate nutrition for pasture growth via a legume or annual applications of nitrogen) will increase the rate of SOC build up.
- Low levels of available soil phosphorus reduces legume production. This reduces their ability to fix the amount of nitrogen needed to maximise grass dry matter production and SOM.
- A pasture phase can be economically viable in a mixed farming enterprise (particularly under high livestock values). However the pasture may be difficult to utilise in a 'pure cropping' farming system.
- Moving from a low input cropping system (i.e. no fertiliser application) into a system of maximising yields through increasing stored moisture and manure/fertiliser application will maintain/increase SOC levels.
- Current commercial rates of manure application (e.g. 5 t/ha every three years) will not lift SOC levels on their own.
- The most critical consideration in managing SOC in grain systems is providing adequate nutrition to the crops where it is needed in the soil profile.

The Regional agronomy team is now working with collaborators across DAF, DPI NSW, the University of New England and the University of Southern Queensland 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 this new research, with a series of four projects assessing the potential to ameliorate sodicity and its related soil constraints to grain production. The following article introduces new research being undertaken on soil sodicity.

Soil constraints: Research questions and logistical challenges for experiments—Southern Queensland

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RESEARCH QUESTION: *Are there options to re-engineer soils in Southern Queensland to alleviate or remove underlying chemical or physical constraints to soil water management for increased grain yields?*

Key findings

1. Experiments are exploring the impact of reducing soil sodicity on grain crop yields. Treatments include gypsum applied at surface and at depth, composted feedlot manure and elemental sulfur. After the tillage to apply treatments, the soil surface appears in good condition.
2. The impacts on soil water storage, plant growth, crop water use and grain yield will be reported in future editions of this trial book.
3. The high application rates of ameliorant products presented several logistical challenges for sourcing, transporting and applying.

Background

Models indicate a large yield gap between water-limited yield potential and current production across northern Australian grain production. This yield gap is a function of physical, chemical and biological factors in each soil, including capacity of soil to accept, store and release water for efficient plant use.

Recent diagnostic research has estimated that this costs the Queensland grains industry approximately $147M annually in lost potential. Indeed, sodicity appears to be the key constraint in the majority of fields assessed as it compromises soil structure, decreases rainwater intake, soil water availability and nutrient acquisition, and impairs biological (soil microbial and plant root) activity.

A series of linked investments from the Grains Research and Development Corporation (GRDC) is assessing the economics of ameliorating hostile subsoils in the northern region. The four focal points are:

- identification of spatial soil constraints
- amelioration and management
- economics of adoption
- communications and extension.

Led by the University of Southern Queensland (USQ), the research into soil amelioration and management has three components:

a. A scoping study surveying 30 fields in the northern grains region (15 each in Queensland and New South Wales), assessing for soil constraints.
b. A set of six small-plot core experiments 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).
c. A series of demonstration strips on farms to develop calibration models that can diagnose and define soil constraints, and identify when interventions will be economic.

This report covers the scoping assessments and core site implementation in Queensland, and describes the treatments being studied and the adaptations needed to deliver these treatments to depth in our constrained soils.

What was done

In Queensland, five fields at each of three locations (Millmerran, Meandarra and Goondiwindi) were surveyed and spatially assessed for soil constraints with an historic assessment of paddock performance through satellite NDVI (a measure of total plant growth) and yield monitored data (if available). Electromagnetic Induction (EMI) technology was used to create field maps showing the apparent Electrical Conductivity (ECa). From these maps and associated data, four survey points were collected to ground truth the chemical and physical parameters at each site. Using this survey data across the fifteen sites in Queensland, three were chosen for detailed experiments.

The characteristics of the detailed experiment sites are summarised in the *Trial Details* section.

All sites are generally alkaline in the upper profile and have an exchangeable sodium percentage (ESP) well over the 6% nominal threshold for healthy crop growth. Profile chloride (Cl) values are generally low, indicating that sodicity is likely to be the primary restriction.

Treatments (Table 1) include physical and chemical ameliorants, and aim to explore potential impacts and/or interactions:

- Tillage (shallow and subsurface)
- Deep placement of nutrients
- Gypsum (surface and subsurface applications)
- Composted feedlot manure (10 t/ha) at depth
- Elemental sulfur to decrease soil pH.

Plots were roughly 7.5 x 12 m in area and with four replicates of each treatment.

In all treatments, 'surface' or 'shallow' refers to up to 20 cm depth, and 'subsurface' or 'deep' to a depth of 20 cm or greater.

The rates for the Deep NP(K)Zn treatments were 50 kg N, 30 kg P, 50 kg K and 1.5 kg Zn apart from Treatment 10, where the rate matched N and P additions from deep compost applications. Elemental sulfur was added at 1500 kg/ha.

Surface gypsum treatments were spread over the soil, and incorporated by ripping to 20 cm. Gypsum rates were calculated to reduce the sodium percentage of cations to ≤3%, so actual application rates for gypsum varied with each site, 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. Further details on how it was applied are outlined later in the article.

Application rates for gypsum and compost ameliorants are substantial, often requiring rates greater than 6–10 t/ha. This made it logistically challenging to source, transport and apply the treatments at each site, especially with deep (~20 cm) applications. The treatments may be similarly challenging to apply on commercial farms.

Table 1. Treatment structure for core soil constraints sites in Southern Queensland.

Treatment	Tillage		Gypsum		Deep NP(K)Zn	Deep compost	Deep elemental sulfur
	to 20 cm	>20 cm	Surface	Deep			
1							
2	Yes						
3	Yes				Yes		
4	Yes		Yes		Yes		
5	Yes	Yes			Yes		
6	Yes	Yes		Yes	Yes		
7	Yes	Yes	Yes	Yes	Yes		
8	Yes		Yes		Yes		
9	Yes	Yes	Yes		Yes		Yes
10	Yes	Yes	Yes		Yes (*)		
11	Yes	Yes	Yes			Yes	
12	Yes	Yes	Yes			Yes	Yes
13	Yes	Yes	Yes	Yes		Yes	Yes

*Nitrogen and phosphorus rates in Treatment 10 were adjusted to match the levels added by the Deep compost treatments.

Figure 1. Screened feedlot compost used as soil amendment in applicator box.

The amendments needed to be relatively fine and flow easily in order to be metered and delivered to depth. This was achieved by using 6 mm screened feedlot compost (Figure 1), and air drying natural mined gypsum. Effective rate control was achieved through large fluted rollers for each outlet (Figure 2).

Further changes were undertaken to adapt a deep fertiliser placement machine for use in these experiments (Figure 3), including fabricating a larger (1 cubic metre) applicator box, 75 mm chutes for amendment delivery down the back of the applicator tyne, and adding a crumble roller for smoothing the surface slightly.

As the speed of remediation (or change) in the subsurface soil depends on the volume treated, two application passes were made over each plot area. On the applicator, the amendment tynes were set up on 50 cm spacing. For the first pass, the tractor was offset 7.5 cm from the centre line. The second pass was shifted 7.5 cm in the other direction. This created two amendment bands 15 cm apart with a 35 cm gap between them.

In the gap between the amendment bands, the deep NP(K)Zn fertilisers were placed so plant access to them is not confounded by the different amendments themselves, except for the compost applications which didn't receive an inorganic nutrient.

Figure 2. Metering unit for amendment application, with ruler for scale.

Figure 3. DAF-modified machine applying treatments.

Figure 4. Site following completion of tillage operations—September 2019.

After all tillage operations had been completed, sites were generally in very good surface condition (Figure 4).

Results

The field program is currently scheduled to run for three seasons, finishing in 2022. Now that the experiments have been established, soil water will be monitored during the fallows.

After sowing, the effects of each treatment on plant growth, water use and crop yield will be measured.

The Millmerran site had sorghum sown in January 2020, while the Dulacca site was planted to winter crop in 2020. The Talwood site is targetting sorghum in 2020-21.

Implications for growers

This research is about fundamentally eliminating ESP as a constraint for the upper 50 cm of a soil's profile. It is 'proof-of-concept' research, intended to explore what happens to soil water storage and grain yields under gypsum application rates to remediate the ESP to ≤3% in either or both of the top 20 cm of soil and half of the soil volume in bands from 20 cm down to 50 cm depth. These gypsum rates (often ≥15 t/ha) are compared against a high rate subsoil (≈ 20 cm deep) compost application (≈ 10 t/ha), and the application of elemental sulfur to dissolve calcium carbonate and produce gypsum in-situ.

Growers are advised to maintain a watching brief (rather than a call to action) on these experiments for several years. As further results and knowledge are gained, practical insights for growers to consider on their own properties can be explored.

Acknowledgements

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Trial details

Location, soil type and characteristics are listed in Table 2. Climate data from the nearest Bureau of Meteorology station is shown in Figure 5—from left to right: Dulacca (Miles Post Office), Millmerran (Millmerran Post Office for rainfall; Pittsworth Post Office for temperatures) and Talwood (St George Post Office).

Table 2. Brief chemical characterisation at Queensland's core sites.

Sample depth (cm)	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
	(H_2O)	$(CaCl_2)$	(1:5)	(cmol/kg)					%	(mg/kg)	
Dulacca (Soil type: Grey/Brown Vertosol (nominally Ulimaroa))											
0-10	8.5	7.7	0.21	18.1	8.0	2.73	0.93	29.8	9.2	43	9
10-20	8.8	7.8	0.25	15.8	9.8	3.99	0.61	30.3	13.2	53	14
30-40	8.1	7.3	0.46	15.4	12.3	7.10	0.45	35.3	20.1	102	4
60-70	6.8	6.7	0.66	12.0	12.8	8.83	0.48	34.1	25.9	275	8
Millmerran (Soil type: Grey/Brown Vertosol (nominally Moola))											
0-10	6.6	6.3	0.15	8.4	6.6	2.37	0.31	17.7	13.0	153	38
10-20	8.7	7.4	0.24	10.6	9.0	3.36	0.20	23.2	14.4	330	5
30-40	6.9	6.2	0.38	9.5	15.	6.82	0.14	31.4	21.7	428	3
60-70	6.4	5.5	0.43	10.2	16.4	8.79	0.18	35.5	24.7	457	2
Talwood (Soil type: Red/Brown Vertosol (nominally Arden))											
0-10	8.3	7.6	0.17	27.5	4.7	1.8	1.3	35.5	10.6	22	18
10-20	8.7	7.9	0.23	27.8	7.0	3.8	0.7	39.3	9.7	26	3
30-40	8.9	7.8	0.36	22.5	9.4	7.0	0.4	39.4	17.8	73	2
60-70	9.2	7.9	0.44	20.3	9.9	9.9	0.5	40.7	24.3	163	2

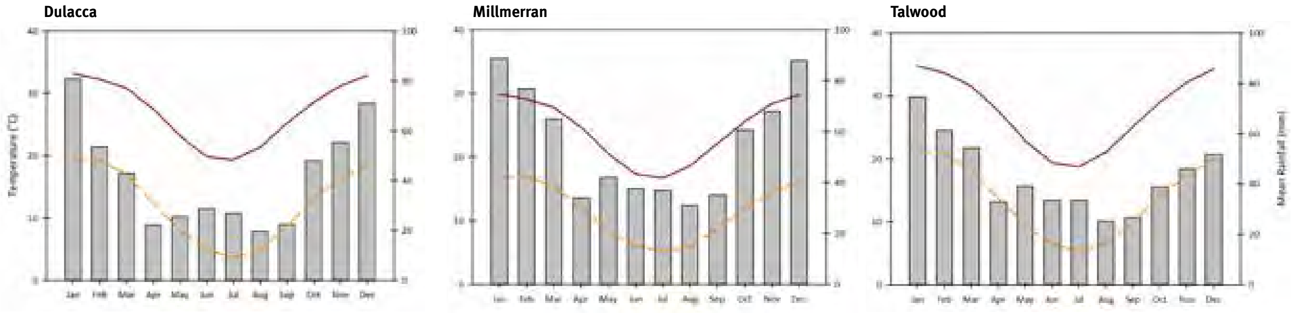

Figure 5. Maximum and minimum temperatures and mean rainfall for the three trial sites.

Farming systems research

The Regional agronomy (research) team has an extensive field-based farming systems research program in collaboration with CSIRO and the New South Wales Department of Primary Industries (NSW DPI). Projects focus on developing systems to better use the available rainfall to increase productivity and profitability, and investigating the soil water costs and benefits of growing cover crops for ground cover at key stages of the cropping systems.

While advances in agronomy and the performance of individual crops have helped grain growers to maintain their profitability, current farming systems are underperforming; with only 30% of the crop sequences in the northern grains region achieving 75% of their water limited yield potential. Growers are facing challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Changes will be needed to meet these challenges and to maintain the productivity and profitability of our farming systems. Consequently, the Regional agronomy (research) team is undertaking projects on two major questions:

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

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

   This research, with investment from the Grains Research and Development Corporation (GRDC), 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 for use across the northern region.

   Experiments were established at seven locations; a large factorial experiment managed by CSIRO at Pampas near Toowoomba, and locally relevant systems at six regional centres by Department of Agriculture and Fisheries (DAF) and the 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 each Queensland regional experiment (Emerald, Billa Billa and Mungindi), how they are implemented locally, and the results after five years of crops at each site. As the first phase of the project draws to a close, data and system performance indicators have been developed to compare performance across sites; we have also reported the effects different systems are having on water, nutrients and gross margins. There are some very interesting findings including differences of $92-494/year between systems at each site.

2. *Can cover crops increase the net water accumulation (plant available water) in grain and cotton systems with low ground cover (<30%) in the northern region?*
   a. *What is the net water cost to grow the cover crops?*
   b. *What is the net water gain to the subsequent grain/cotton crops?*
   c. *What is the impact on the yield of the subsequent grain/cotton crops?*

   This research by the same collaborating agencies has investment from both the GRDC and the Cotton Research and Development Corporation (CRDC). It has assessed opportunities to make greater use of the available rainfall and maintain more sustainable systems. The *Queensland grains research 2018-19* reports presented results from two trials; a short fallow into irrigated cotton trial and long fallow into dryland wheat, which both had a positive effect on both yield and gross margin.

This edition reports on another four sites in a much drier season; a long fallow after sorghum with no yield differences in dryland wheat, a short fallow after chickpea that reduced grain yield in dryland wheat and two sites planned for cotton 2018-19 and 2019-20 that remained unplanted.

To date the research indicates that cover crops can increase fallow water storage, and improve crop performance and returns in northern farming systems:

- Ground cover was improved by both winter and summer cover crops, which in turn improved infiltration and water accumulation.
- The best cover crop treatment had more soil water than the bare control in five of the six trial sites.
- Optimum spray-out timing varied with the length of fallow; with early spray-out suitable for a short fallow; but more resilient stubble, achieved by later spray-out, necessary for longer fallows.
- Grain yield was directly related to soil water at planting when even populations were able to be established.

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	*					

Farming systems site report—Billa Billa

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Research Questions: *Can systems performance be improved by modifying farming systems in the northern grains region? | In the Goondiwindi area, 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. Increasing or decreasing cropping intensity has reduced production and profitability.
2. *Higher crop intensity* produced more biomass per mm rainfall than *Lower crop intensity*, but was less efficient converting biomass to grain yield.
3. Increasing the frequency of legumes (*Higher legume*) or long fallows (*Lower crop intensity*) has maintained higher levels of available mineral nitrogen in the profile, but reduced soil organic carbon.
4. Grass ley pastures have increased organic carbon.

Background

Grain production around Goondiwindi is largely based on a winter cropping system with summer crops grown as a disease break. Most farms operate on a zero or minimum tillage system, with strong reliance on stored fallow moisture. Summer crops are seen as an important part of the system, often planted in spring on a greater water profile than winter crops as an insurance against hot growing seasons with variable rainfall.

The Farm Practices Research project (DAQ00192) was established in 2014 with the first crops planted winter 2015. This report investigates the activities and insights from the Billa Billa site in 2018-19 summer and 2019 winter seasons, and then draws insights across all experimental years from 2015. Previous activities and insights can be found in previous editions of *Queensland grains research.*

The Billa Billa site is located 50 km north of Goondiwindi on the Leichhardt Highway. The soil is a Grey Vertosol. The original belah and brigalow trees were cleared and the paddock used as long-term pasture before being developed for crops in the late 1990s.

What was done

Consultation meetings in late 2014 and early 2015 developed nine locally relevant systems to investigate at Billa Billa:

1. **Baseline** is typical of local zero tillage farming systems with approximately one crop per year grown using moderate planting moisture triggers of 90 mm plant available water (PAW) for winter and 120 mm PAW for summer. Crops are limited to wheat/barley, chickpea and sorghum, and are fertilised with nitrogen (N) and phosphorus (P) to achieve average seasonal yield potential for the PAW prior to planting.
2. **Lower crop intensity** reflects a conservative approach, accumulating more PAW prior to planting (150 mm for wheat, barley and sorghum; 90 mm for chickpea). Long fallows provide a cropping frequency of two crops in three years (0.7/year). Nutrient management is the same as the *Baseline* system.
3. **Higher crop intensity** aims to minimise fallow periods and potentially grow three crops every two years. Crops are planted on lower PAW (50 mm for winter and 70 mm for summer) and have a greater reliance on in-crop rainfall. Crop choice and nutrient management is the same as the *Baseline* system, but with mungbean as a short double-crop option.
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 for planting (90–120 mm) are used to manage

individual crop risk and to target one crop per year. The unique rules for this system are: 50% of selected crops must be resistant to *Pratylenchus thornei*, and one in four resistant to *Pratlenchus neglectus*. To manage herbicide resistance, crops are also selected to ensure two herbicides of the same mode-of-action cannot follow each other. Crops grown include wheat/barley, chickpea, sorghum, mungbean, maize, faba bean, field pea, canola/mustard and millet. Nutrient management follows the *Baseline* system.

5. **Higher legume** aims to minimise the use of nitrogen fertiliser by growing a pulse (legume) every second crop, with a preference for those that produce greater biomass and carry-over nitrogen benefits. Crops grown in this system are similar to the *Baseline* with additional pulse options (faba bean, field pea and mungbean). Moderate planting triggers of 90–120 mm PAW are used. Crops are again fertilised with N and P to achieve an average yield potential for the PAW at planting, with nitrogen only applied to the cereal crops.
6. **Higher nutrient supply** has N and P fertiliser applied to allow crops to achieve 90% of the maximum seasonal yield potential for the PAW at planting; with the risk that crops will be over-fertilised in some years. Planted to the same crops as the *Baseline* each year.
7. **Higher soil fertility** is treated the same as the *Higher nutrient supply* system, but with the addition of 10 t/ha organic carbon (70 t/ha compost) at the start of the experiment to raise the inherent fertility of the site. It examines whether the higher fertility level can be sustained with higher nutrient inputs.
8. **Grass ley pasture** uses the perennial Bambatsi grass pasture to increase the soil carbon levels naturally. Half the pasture will be removed after four years, and the remainder after seven years, and returned to the *Baseline* cropping system to quantify the benefits gained by the pasture phase. The pasture is managed with simulated grazing using a forage harvester to utilise a pre-determined amount of biomass.
9. **Grass ley pasture + nitrogen fertiliser** repeats the *Grass ley pasture* but with 100 kg N/ha (217 kg/ha urea) applied each year over the growing season. This aims to boost dry matter production. Pasutre growth is nearly always constrained by nitrogen deficiency in grass-based pastures.

Results

Summer 2018 – winter 2019

The chickpeas grown in the four systems in 2018 (*Baseline*, *Higher nutrient supply*, *Higher soil fertility* and *Higher legume*) extracted very little water below 60 cm. The remaining water combined with 135 mm rainfall from crop maturity to the end of November, provided an opportunity to double-crop these systems to sorghum. The *Higher crop intensity* system was fallowed from May 2018 so also achieved its planting trigger.

On 26 November 2018, the *Baseline*, *Higher nutrient supply*, *Higher soil fertility* and *Higher legume* systems were planted to MR-Taurus sorghum, with 140 mm plant available water (PAW), and the *Higher crop intensity* system with 100 mm PAW. The sorghum was planted on two metre solid rows, but with only 35 mm of in-crop rainfall, all systems were sprayed out on 4 March 2019. Biomass was ~2 t/ha in the four systems double-cropped from chickpeas, and 1.2 t/ha in *Higher crop intensity* fallowed from sorghum. At 22 kg/ha and 12 kg/ha of grain respectively, these crops would not have been harvested commercially.

The canola in *Higher crop diversity* and wheat in *Lower crop intensity* left the soil drier at harvest and so these systems did not have sufficient PAW to plant the double-cropped sorghum. Falls of 72 mm of rain in March accumulated sufficient water to plant a winter crop in 2019. Unfortunately, with no follow up rain, the moisture was too deep in the *Higher crop diversity* canola stubble to establish wheat. The only treatment planted in 2019 was the *Lower crop intensity* system; to chickpea that was able to emerge from the deep moisture. There was again very little in-crop rain resulting in a grain yield of 320 kg/ha.

The pasture plots also suffered due to the dry conditions. There was insufficient rainfall in 2019 for the Bambatsi pastures to grow to anthesis, so they were not harvested at all this year. The rain in March 2019 provided some new growth, so half of each pasture plot was sprayed out on 12 April to recommence a cropping phase in-line with the *Baseline* system. A combination of dry weather and ripping to apply deep phosphorus to these sub-plots killed the grass with only one application of herbicide. The remaining half of the pasture plots will continue to be harvested for dry matter, but the sprayed out pasture plots will return to mirror the *Baseline* system and will be monitored in future to assess their performance against the other systems.

The period reported here was one of the driest on record and resulted in some very low-yielding crops. However, with a total of four years' data it is useful to draw insights across all years of the experiment.

Crops grown at the Billa Billa site will be represented by specific colours for all figures and graphs through 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				

Overall system performance 2015–2019

System profitability performance

Economic analysis was undertaken on each of the systems using actual input rates for fertiliser and pesticides with standardised prices from a commercial reseller in Toowoomba. Commodity prices were ten year average port prices, less freight and grading/bagging costs where appropriate (i.e. pulses). Only variable costs were accounted for in this analysis, with a hectare rate applied to all machinery operations.

Differences in the economics of the systems to date have largely been driven by the high yields of the 2016 winter crops (Table 2) when both the 'crop intensity' systems were fallow.

The high starting available nitrogen levels at this site allowed the *Baseline*, *Higher nutrient supply* and *Higher soil fertility* systems to grow 11 t/ha of cereal grain over the first two years without the expense of nitrogen fertiliser. As such, these three systems have been the most profitable; their only point of difference was a higher starter P fertiliser rate in the two higher nutrient systems. The *Baseline* system produced the highest gross margin per mm of rain ($/mm) to date (Table 2).

These high starting nitrogen levels and the high proportion of winter cereal crops in the *Baseline* system produced a high income and the highest return on variable costs (ROVC, Table 2). The *Higher nutrient supply* and *Higher soil fertility* systems had similar income but lower ROVC because of their higher fertiliser expenses. The *Higher legume* and *Higher crop diversity* systems have similar ROVC to the *Higher nutrient supply* system driven by their lower income and the higher inputs (herbicide, insecticide and fungicide) when growing pulse crops.

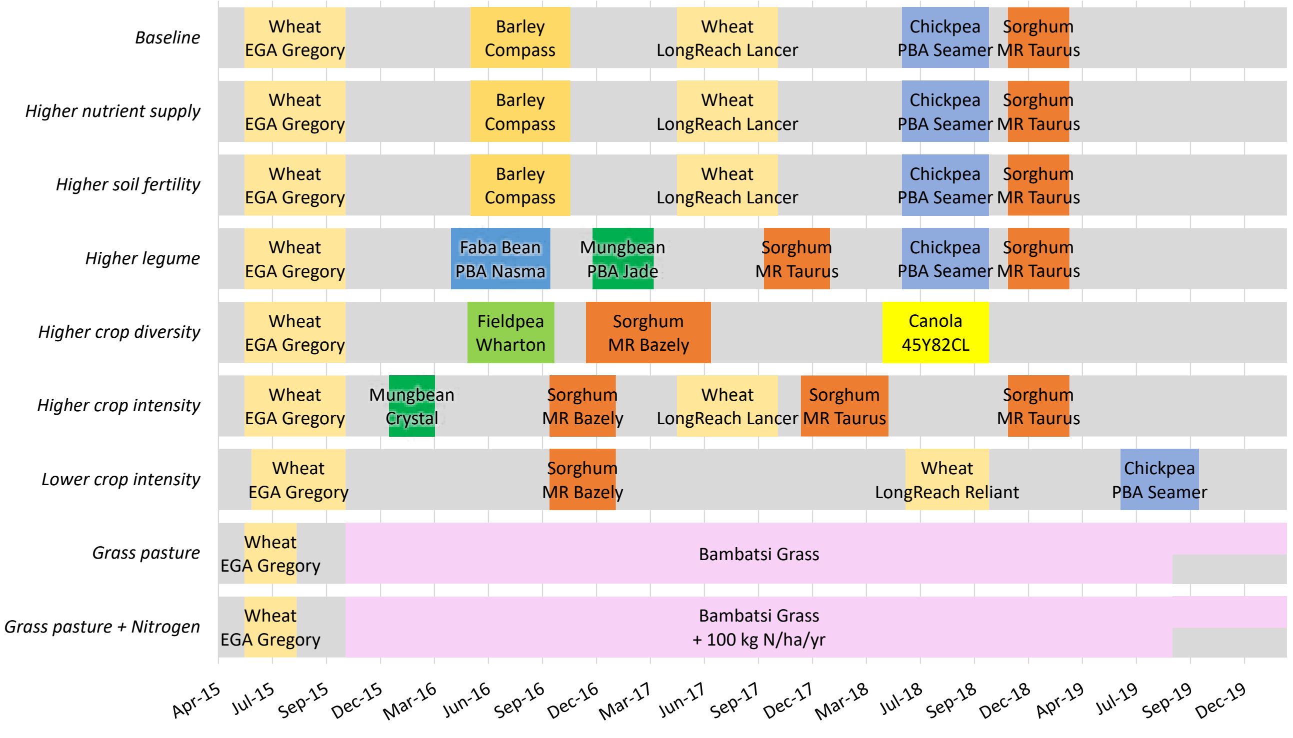

Figure 1. Crop sequences grown at Billa Billa following the defined system rules, plotted on a time scale. Colours represent the crop type as indicated in Table 1.

Table 2. Economics for the seven grain systems at Billa Billa to March 2019.

System	Total income	Total variable costs	Total gross margin	ROVC	System WUE ($GM/mm)	Maximum cash outlay ($/ha)
Baseline	$3,924	-$839	$3,086	4.68	$1.80	-$317
Higher nutrient supply	$3,851	-$1,055	$2,796	3.65	$1.60	-$326
Higher soil fertility	$3,509	-$1,003	$2,506	3.50	$1.45	-$321
Higher legume	$3,560	-$1,017	$2,544	3.50	$1.41	-$300
Higher crop diversity	$3,173	-$923	$2,250	3.44	$1.40	-$342
Higher crop intensity	$2,288	-$905	$1,384	2.53	$0.84	-$377
Lower crop intensity	$2,287	-$629	$1,658	3.65	$0.96	-$293

Cropping intensity impacted on the variable costs in the systems. The costs of planting and harvesting crops in most cases were greater than the fallow costs incurred by other systems over the same period. Therefore, the *Lower crop intensity* system has incurred less variable costs, while the *Higher crop intensity* system incurred higher variable costs than the *Baseline* system. Both 'crop intensity' systems have achieved much lower income and gross margins than the other five systems, due to being fallowed in the exceptional 2016 winter season.

While the incomes from the intensity systems were similar, the *Lower crop intensity* system had the lowest financial risk, with the lowest variable costs and lowest maximum cash outlay of all of the systems at this site. The impact of this low cost structure was that the ROVC for *Lower crop intensity* was the second highest, despite having the second lowest gross margin and gross margin per mm of rain ($/mm) (Table 2).

The system with the highest maximum cash outlay was *Higher crop intensity*. This was a result of a low yielding mungbean crop (2015/16), followed by a low yielding sorghum crop (2016/17). It took another two crops (wheat 2017 and sorghum 2017/18) to recoup the costs of these two consecutive failed crops (Table 2). The cash outlay between harvest events was also lhighest for the *Higher crop intensity* system, highlighting the impact of failed crops on profitability of systems.

Water use

There have been some interesting system effects on individual crops grown at the same time. The double-cropped mungbean crop in 2016 (*Higher crop intensity*) was planted with the same starting water as the *Baseline* system, that was fallowed over summer and planted to barley in 2016. The fallow efficiency (the change in soil stored water as a percentage of fallow rainfall) was 72% for the *Higher crop intensity* system but only 30% in the *Baseline* system (Figure 2).

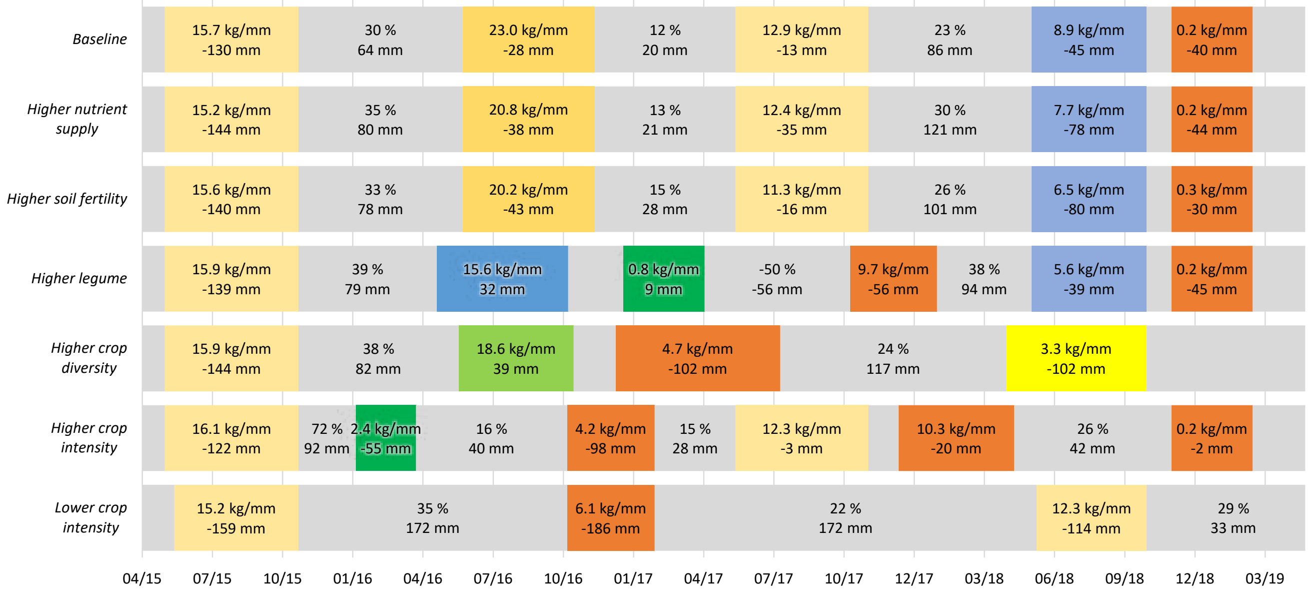

Figure 2. Changes in soil water levels and individual crop water use efficiencies within each system over the life of the Billa Billa experiment. Changes in soil water during the crop (from planting to harvest) are accompanied by the crop water use efficiency (kg/mm). Changes in the fallow (from harvest to planting the next crop) are accompanied by the fallow efficiency (%) for that period.

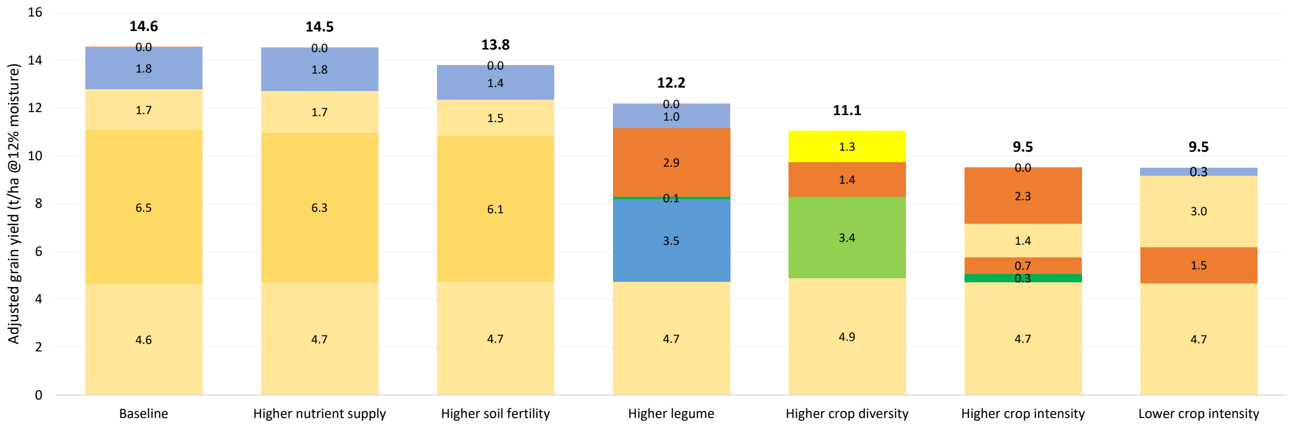

Figure 3. Grain yield of each of the crops grown at the Billa Billa site. Grain yields are stacked; the label at the top of the bar is the cumulative total.

However, differences in the timeliness of in-crop rain had a major impact on the yield outcomes of the mungbean and barley crops (Figure 2, Figure 3). The lowest fallow efficiency was seen in the *Higher legume* system after the mungbean crop in 2017, which was harvested with a nearly full soil profile that subsequently declined over the dry winter fallow. The highest fallow efficiency was achieved when fallows started with dry soil and were planted once wet, whereas the lowest fallow efficiency was achieved in fallows that started with a wet soil.

The highest water use efficiencies (kilograms of grain produced per mm of water used during the crop) were in the highest-yielding crops (2016 barley in the *Baseline*, *Higher nutrient supply* and *Higher soil fertility* systems, at 23, 20.8 and 20.2 kg/mm respectively). This high yielding barley crop has influenced the system rainfall use efficiency (RUE) (total kilograms of grain produced per mm of total rain) over the first four years, which was highest in the *Baseline* (8.3 kg/mm).

Table 3. System rainfall use indicators

System	Average FE	Average grain WUE	System grain RUE	System biomass RUE	System $/mm
Baseline	19%	14.3	8.3	21.6	1.80
Higher nutrient supply	25%	13.1	8.1	22.0	1.60
Higher soil fertility	23%	12.8	7.7	20.9	1.45
Higher legume	19%	9.3	6.7	17.9	1.41
Higher crop diversity	27%	10.6	7.1	20.1	1.40
Higher crop intensity	24%	9.2	5.7	19.6	0.84
Lower crop intensity	30%	10.9	5.6	16.1	0.96

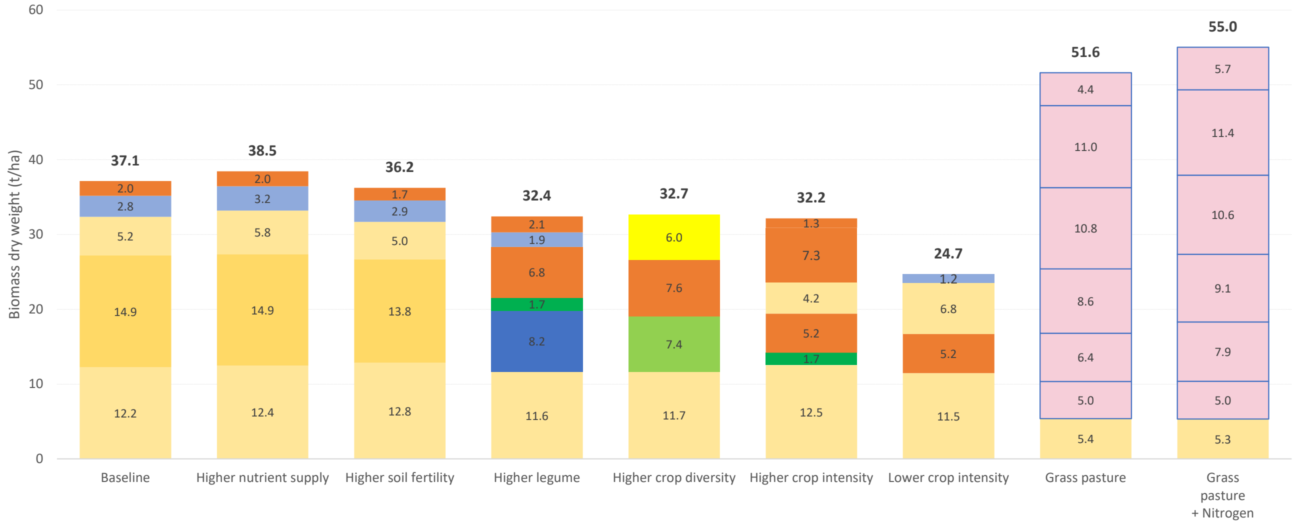

Figure 4. Biomass yield of each of the crops grown at the Billa Billa site. Yields are stacked; the label at the top of the bar is the cumulative total.

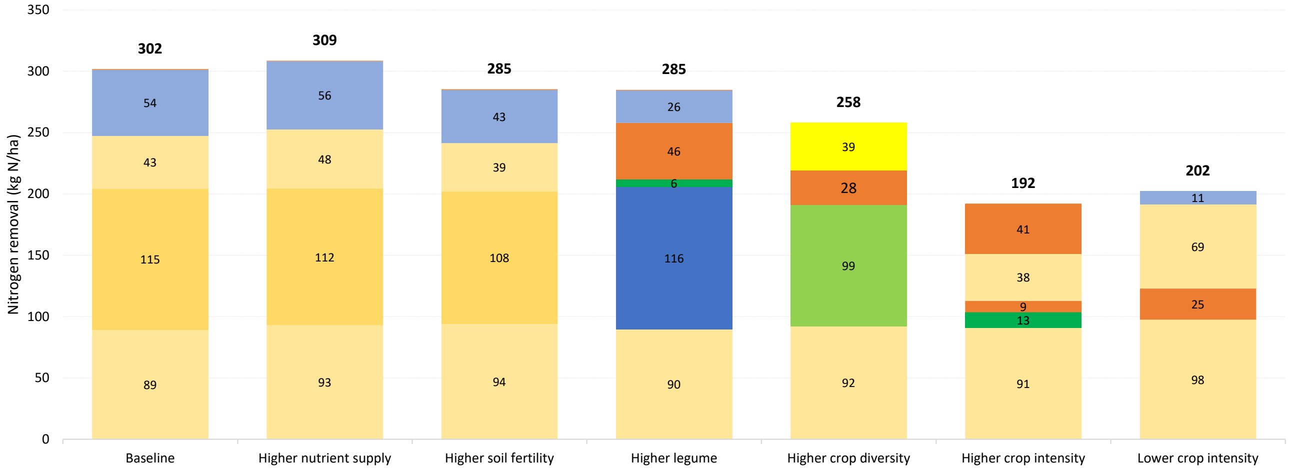

Figure 5. Nitrogen export of different cropping systems after 4 years (March 15 to April 19) calculated from the grain yield x N content.

The crop intensity systems had the lowest system grain RUE (5.6 and 5.7 kg/mm for lower and higher respectively). Despite similar grain yields and RUEs, the biomass RUE of the *Higher crop intensity* system was much higher than the *Lower crop intensity* system (Table 3, Figure 4). This highlights the importance of having enough stored water to finish crops with good grain yields.

Nitrogen

The high starting mineral N levels (average 360 kg N/ha) at the site resulted in only one application of nitrogen fertiliser; in the *Higher nutrient supply* system in 2017.

Total nitrogen export of each system was largely related to grain yield, except for the *Higher legume* and *Higher crop diversity* systems, which grew high-yielding legume (faba bean and field pea) crops in 2016. While yielding less than the cereal crops in the *Baseline* system (Figure 3), their higher grain protein meant nitrogen export of the crops was similar (Figure 5).

The high starting mineral N was largely used by the high-yielding 2015 and 2016 winter crops (Figure 6). Subsequent crops depended on freshly mineralised nitrogen and any nitrogen fixed by legume crops. Crop yields and nitrogen demand have been much lower since winter 2016.

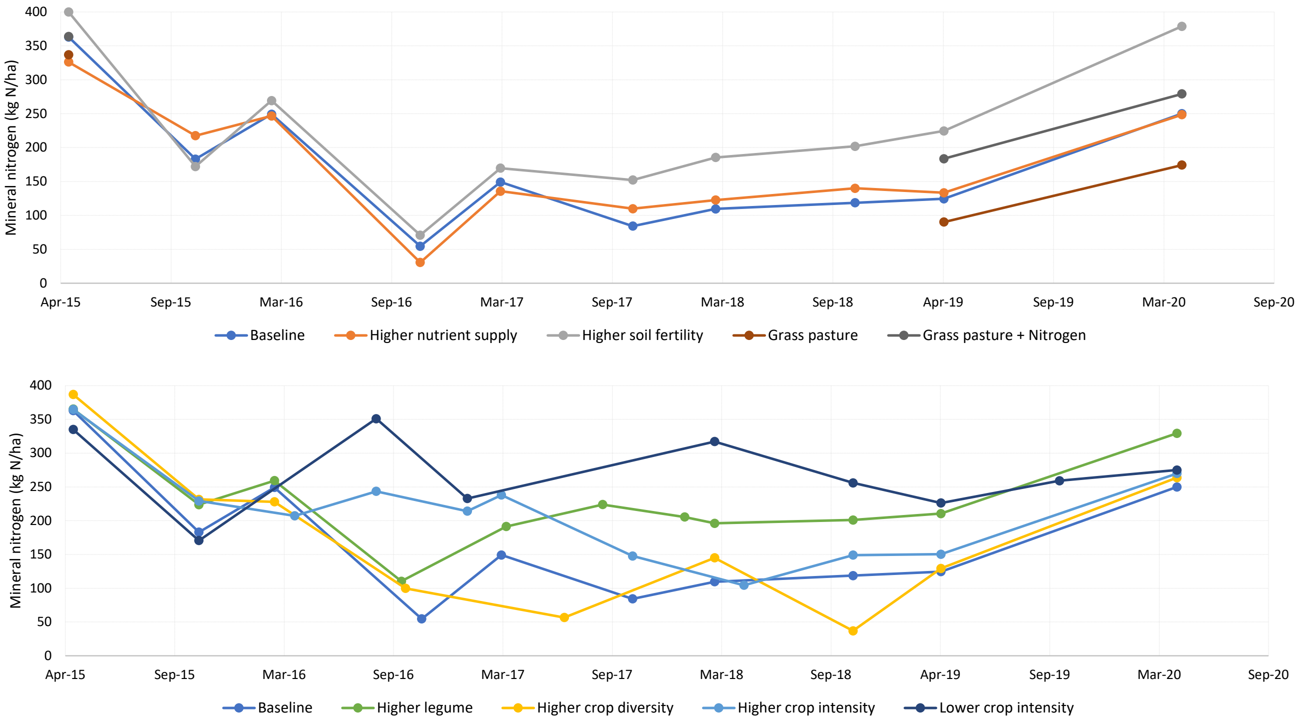

Figure 6. Mineral nitrogen of the nine systems at Billa Billa (to 90 cm) measured prior to planting and post harvest of each crop.

Baseline and *Higher nutrient supply* then maintained 100 to 150 kg N/ha to April 2019, but the *Higher soil fertility* system had mineralised an extra 100 kg N/ha. *Higher crop diversity* was similar to the *Baseline;* the 2018 canola used most of the available mineral N by harvest, but recycled this N (as the stubble decomposed) by the next sampling date. The *Higher legume* system has maintained higher mineral N than the *Baseline* for the same crop nitrogen removal, maintaining a similar level to the *Higher soil fertility* system.

Both crop intensity systems did not have the high demand of the 2016 winter crop. However, the high cropping frequency of the *Higher crop intensity* systems used the N to a level similar to the *Baseline* system in 2018. In contrast, the long fallows in *Lower crop intensity* have maintained high mineral N levels.

Organic carbon

Walkley Black organic carbon (OC) was measured in April 2015 and again in April 2019. Changes over the life of the experiment (Figure 7) have been small and shadowed by sampling variability below 10 cm. However, there were differences in the 0-10 cm topsoil.

The *Higher legume* system had a greater proportion of legume crops, a higher carbon to nitrogen ratio that resulted in more N mineralisation, and reduced OC. Similarly, the *Lower crop intensity* system has spent more time in fallow with moist soils, so mineralised more nitrogen, and combined with lower biomass production, resulted in reduced OC (Figure 7).

The *Higher soil fertility* system was achieved by adding compost (10 t OC/ha) after the initial soil sampling at the site, resulting in a measurable increase in OC in 2019. With no improvement in grain or biomass yields, the 2019 OC measures accounted for only 3 t/ha of the initial 10 t/ha OC applied.

The grass pastures at this site also increased OC in the 0-10 cm layer to similar levels as the *Higher soil fertility* system. Applying nitrogen to the grass pasture increased biomass production and resulted in an extra lift in OC, albeit from a lower starting point. Half of each pasture plot was sprayed out and returned to crops in winter 2020 to see if future crops can capitalise on the extra OC with higher biomass and grain yield. The remaining half of each plot will continue as grass pasture for another three years, to assess the impacts of a longer pasture phase.

Implications for growers

With a quarter of the annual rainfall in 2019, cropping opportunities were difficult and crop yields were low. As a result, there were limited insights from this season. However, there are interesting trends emerging across the systems from the past four experimental years.

Economic analysis of this site has been dominated by two factors; the large yielding 2015 and 2016 winter crops and the inherent fertility of the site allowing these yields without additional nitrogen inputs. The crop intensity systems highlight the risks of planting more crops with lower stored water and therefore lower yield potential, versus fallowing longer

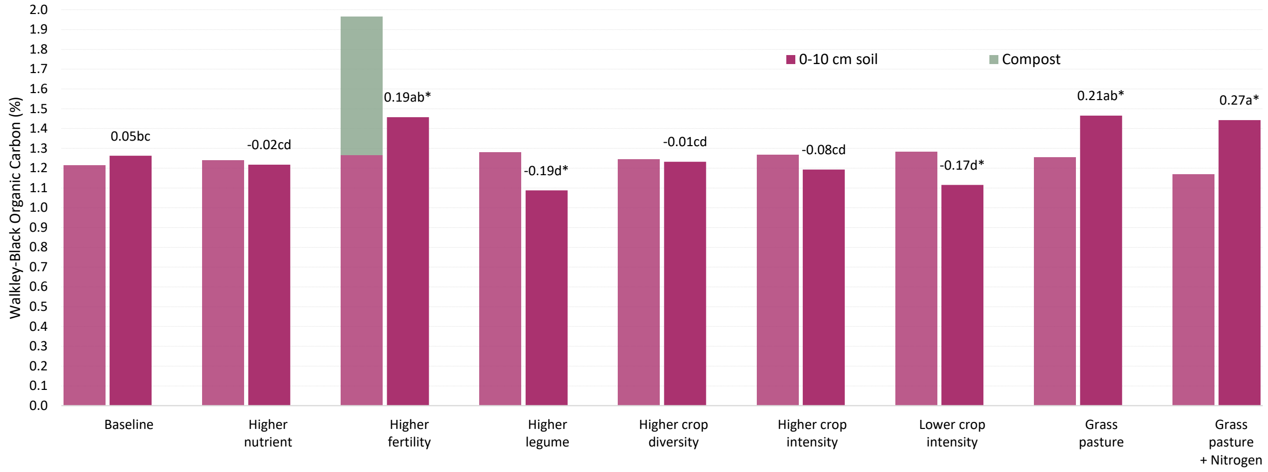

Figure 7. Walkley-Black % organic carbon measured in April 2015 and April 2019. Compost (green bar) was added to the higher fertility system in 2015 after the sampling. Initial value in each set is 2015; labels above 2019 columns show the change in measured values between the 2015 and 2019 samplings. Letters show significant differences and * denotes a change significantly different to zero.

to increase yield potential and stability. A *Lower crop intensity* system may offer the added benefit of reduced labour and machinery (capital) expenses.

The crop intensity systems also offered insights into water and rainfall use by crops. Productivity of both systems suffered relative to the *Baseline* from missing the 2016 winter crop and growing crops in some pretty hard seasons. These two systems produced grain with very similar efficiency. However, the *Lower crop intensity* system achieved higher grain yield and individual crop water use efficiency than the *Higher crop intensity* system. In contrast, the *Higher crop intensity* was more efficient in converting rainfall into biomass with better capture of fallow rainfall and rainfall use efficiency (RUE) of the system. This demonstrates the importance of stored water to allow crops to convert biomass into grain yield, especially in dry finishes.

Cumulative nitrogen removal by the systems largely reflects grain yields. However, the *Higher legume* system recorded similar N removal to the *Baseline* for lower grain yield due to the higher grain protein of the legume crops. Higher mineral N levels were maintained in the *Higher legume*, *Lower crop intensity* and *Higher soil fertility* systems than the *Baseline*, *Higher nutrient supply*, *Higher crop diversity* and *Higher crop intensity* systems. However, these differences were also reflected in the organic carbon changes that are emerging between the systems.

After four years the *Lower crop intensity* system and *Higher legume* systems have seen the greatest drop in OC. These two systems, along with *Higher soil fertility*, have also mineralised more N. The *Higher soil fertility* system is the only 'cropping' system to register an increase in soil OC, albeit with only 3 t/ha of the original 10 t/ha of OC remaining; a significant decline in four years. Otherwise, only the pasture systems have provided a significant lift in OC and the resilience of this improvement will be assessed now that these systems have been returned to cropping.

Acknowledgements

The team would like to thank the trial cooperator, 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 (DAQ00192).

Trial details

Location:	Billa Billa
Crops:	Bambatsi grass, sorghum and chickpea.
Soil type:	Belah, Duplex
2019 rainfall:	150 mm

Faba bean, barley, field pea and fallow in 2016.

Chickpea in 2018.

Farming systems site report—Mungindi

Andrew Erbacher
Department of Agriculture and Fisheries

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

Key findings

1. Improved stubble cover reduced wind erosion in a very dry season when dust storms were common and widespread.
2. Continuing dry conditions reduced root lesion nematode populations. Systems that previously grew resistant crops have maintained lower populations.
3. All systems have had a high reliance on glyphosate. However, systems with summer break crops reduced reliance on 'Group A' herbicides.

Background

Dryland farming in Western Queensland is largely based on winter cropping; primarily cereals (wheat and barley) rotated to pulses (chickpeas) with limited summer cropping (cotton and sorghum). Cropping relies heavily upon stored moisture, typically from the highest rainfall months in late summer. Most farms operate on a zero tillage system with a fairly set rotation of wheat/wheat/chickpea.

The 'Farm practices research' project (DAQ00192) was established in 2014 through consultation with local growers and agronomists to identify the key limitations, consequences and economic drivers of farming systems; to assess farming systems and crop sequences that could meet the emerging challenges; and to develop the systems with the most potential for use across the northern region. From this process, the team developed a set of key systems (strategies) to investigate. The first crops were planted in winter 2015. This report investigates the activities and insights from the Mungindi site in 2018-19 summer and 2019 winter seasons, and draws insights across all experimental years from 2015. Previous activities can be found in past editions of *Queensland Grains Research*.

The Mungindi site 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 30 years and is representative of a large proportion of cropping in the region. The site had high root lesion nematode populations (*Pratylenchus thornei*; 6-26/g of soil) at the start of the trial in 2015.

What was done

Six systems were identified as priorities through consultation with farmers and advisers in the Mungindi Cropping Group:

1. **Baseline** represents a standard cropping system for the Mungindi region, which is winter dominant with three main crops (wheat, barley and chickpeas) on a fairly set rotation of wheat/wheat/chickpea. Aggressive moisture triggers of 50 mm plant available water (PAW) for wheat and 80 mm PAW for chickpea are employed, with an average of one crop per year grown. A nitrogen (N) budget is calculated on a median yield potential for the available water measured at planting and applied to cereal crops as required. Phosphorus (P) is applied as starter to all crops at 4 kg P/ha.
2. **Lower crop intensity (winter)** is quite conservative, planting when the profile is at least ¾ full and therefore likely to grow only one crop every two years. It investigates what the system impacts are if you plant less often, but on a full moisture profile to maximise crop yield potential. The rotation includes wheat, barley and chickpeas, and the option of a cover crop when ground cover is below 30%. Nutrient management is the same as the *Baseline* system.

3. **Lower crop intensity (mixed)** is similar to the *Lower crop intensity (winter)* system, but with summer crop options added. This includes dryland cotton as a high value crop followed by wheat on a lower planting moisture for stubble cover. Nutrient management is the same as the *Baseline* system.
4. **Higher crop diversity** is investigating alternative crop options to help manage and reduce nematode populations, soil-borne disease and herbicide resistance. The unique rules for this system are; 50% of the selected crops to be resistant to *Pratylenchus thornei*, and one in four crops resistant to *P. neglectus*. To manage herbicide resistance, two crops relying on herbicides with the same mode-of-action cannot follow each other. Crop options for this system include: wheat/barley, chickpeas, sorghum, maize, sunflowers, canola/mustard, field pea, faba bean and mungbeans. PAW and nutrient strategies are similar to *Baseline*, with PAW triggers adapted to suit the individual crops' risk. A wider range of crops and fertility management options may enable growers to maintain soil health and sustainability as the age of their cropping systems increases.
5. **Higher legume** is focused on improving soil fertility and reducing the amount of nitrogen fertiliser required by growing more pulse (legume) crops. One in every two crops is a legume. Crops available for this treatment is: wheat/barley, chickpea, faba bean and field pea all based on a *Baseline* moisture trigger and nutrient strategy. Nitrogen is only applied to cereal crops.
6. **Higher nutrient supply** identifies the impacts of fertilising for a higher yield potential. Nutrient supply with fertilisers is currently very conservative in the Mungindi region. This system uses a N budget calculated for 90% of yield potential for the measured water at planting, and 100% replacement of P. The same crop as the *Baseline* is grown to compare the two systems.

Systems were implemented following these rules, with a range of crops grown in 2015 and 2016 across the different systems (Figure 1). Unfortunately, low rainfall in 2017 did not accumulate sufficient PAW to plant any systems, so a wheat cover crop was planted in *Baseline*, *Higher nutrient supply*, *Higher legume* and *Lower crop intensity (winter)* systems to maintain ground cover above 30%. There was enough fallow rain to plant all systems to winter crops in 2018.

Table 1. Crops grown at the Mungindi site. Colours are used to represent the crops in all of the figures.

🟨	Wheat	🟦	Chickpea	🟪	Sunflower	⬜	Cotton
🟫	Durum	🟧	Sorghum	▒	Fallow	▨	Cover crop

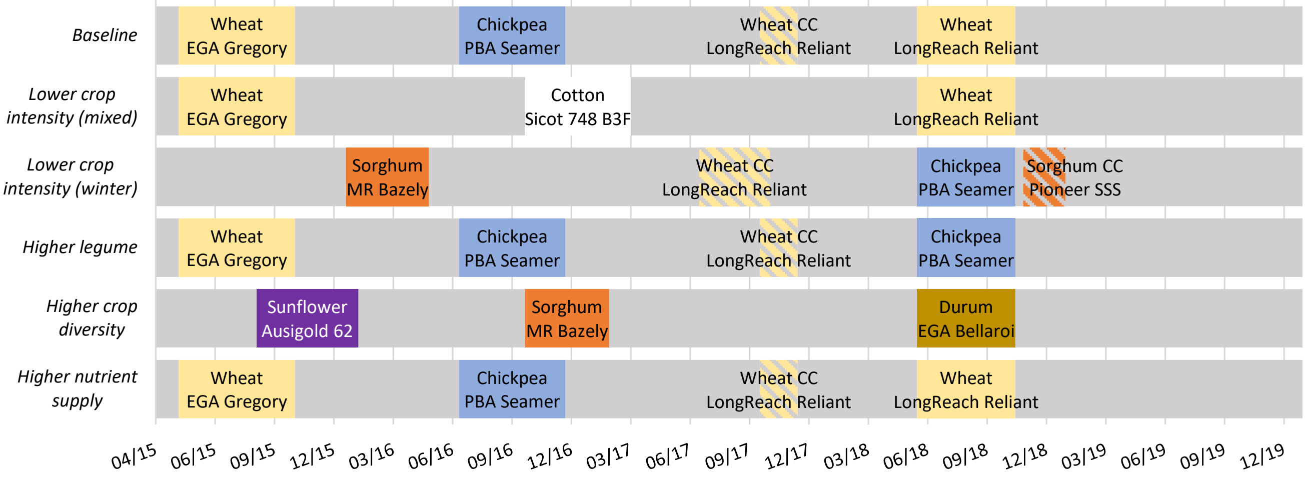

Figure 1. Crop sequences grown at Mungindi following the defined system rules, plotted on a time scale. Colours represent the crop type as indicated in Table 1.

Results

Rain just prior to harvest allowed *Lower crop intensity (winter)* to plant a sorghum cover crop post-harvest 2018; this crop had a patchy establishment, which can reduce fallow efficiency. However, with the dry conditions experienced in the district in 2019, wind erosion was a common problem and the stubble provided was sufficient to reduce this wind erosion across the *Lower crop intensity (winter)* plots (Figure 2). The soil water used by the cover crop was equivalent to that lost to evaporation in the other five systems that were left fallow during this extremely dry period.

Figure 2. Stubble provided by the cover crop aided in reducing wind erosion and captured sand from local dust storms.

With only 88 mm of rainfall received at the site in 2019, no systems accumulated enough soil moisture to plant a crop in that year.

System performance 2015-2019

Crop production

Cumulative grain yield has been dominated by the 2015 and 2016 winter crops, with the highest yield achieved in the *Baseline* system (Figure 3). *Higher nutrient supply* had a lower yielding wheat crop in 2015 but grew similar biomass. The *Higher nutrient supply* crop grew more biomass early (Figure 4), but flowered later so the crop suffered from heat stress and terminal drought.

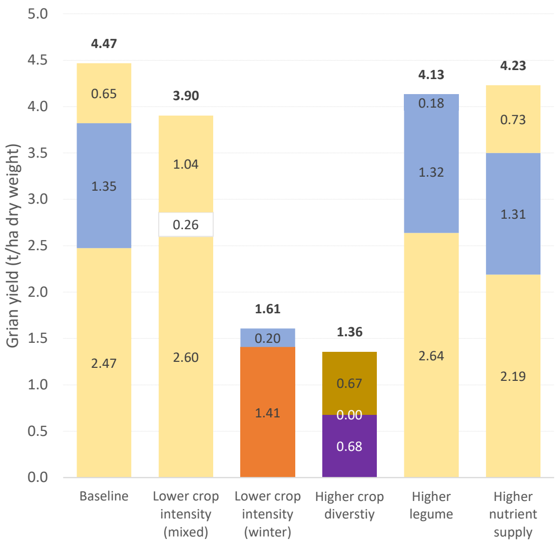

Figure 3. Grain (or lint) yield of the crops grown over the four years from 2015 to 2019.

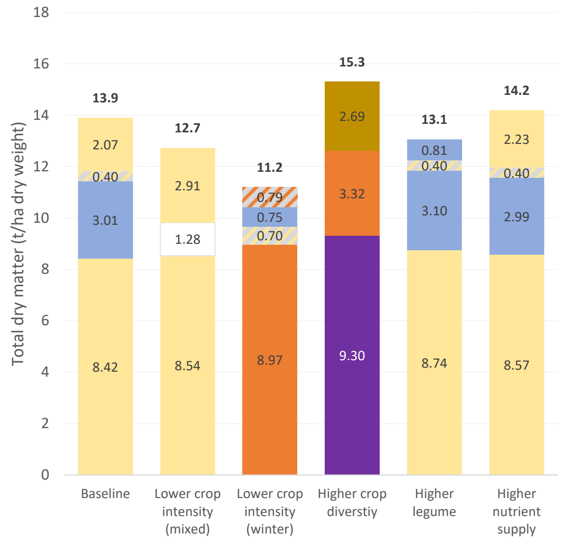

Figure 4. Total biomass production of the crops grown over the four years from 2015 to 2019.

The lowest cumulative grain yield was in the two systems that grew summer crops in 2015-16. *Higher crop diversity* produced the highest biomass, but the spring-planted crops were poor at converting biomass to grain yield.

In 2018, four systems grew wheat or durum, but produced different grain yields for similar crop water use. The wheat in *Lower crop intensity (mixed)* followed a cotton break crop and produced higher biomass and grain yield than *Baseline* and *Higher nutrient supply*. The durum in *Higher crop diversity* also followed a summer break crop and grew more biomass than the *Baseline* wheat, but the durum suffered from the warm spring and produced similar grain yield to the *Baseline*.

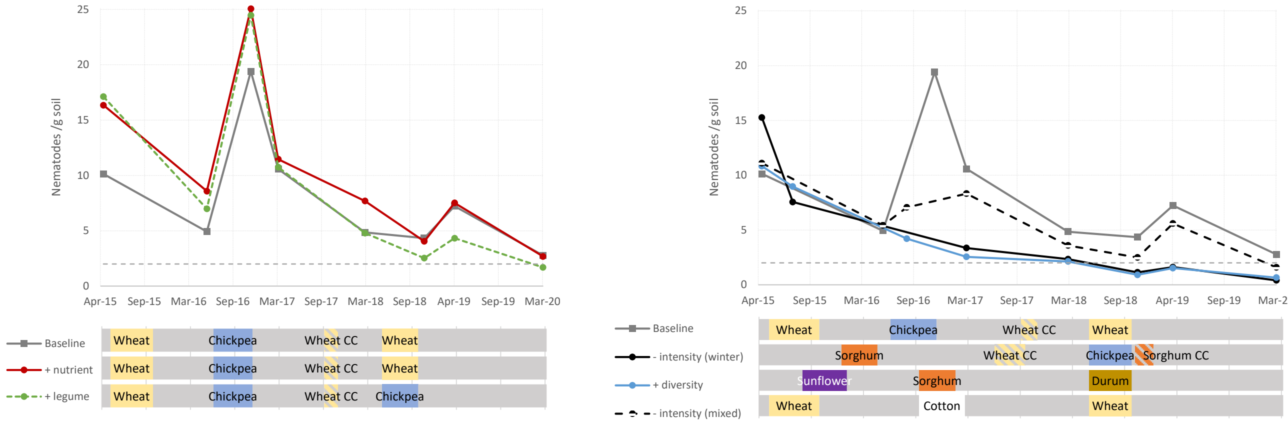

Figure 5 Root lesion nematodes (*Pratylenchus thornei*) measured with Predicta B DNA testing for all systems.
The dashed line at 2 RLN/g soil represents levels likely to reduce grain yield in susceptible crops.

Root lesion nematodes (Pratylenchus thornei)

Root lesion nematode (RLN, *Pratylenchus thornei*) populations were quite high at the beginning of the trial (Figure 5). Tracking these populations across sequences with a variety of crop types and fallow length in the past five years has shown the different population dynamics in the systems. Of particular interest is the first two years, where the *Higher crop diversity* system implemented two 'break crops' (sunflowers and sorghum) that are resistant to RLN, and the *Lower crop intensity (winter)* system had a sorghum break crop followed by a long fallow. These two management decisions have had a lasting effect on reducing RLN. In contrast, the *Baseline*, *Higher nutrient supply* and *Higher legume* systems' populations increased dramatically, especially during the 2016 chickpea crop.

Three years of drought since 2016 have reduced RLN populations in all systems. However, having a lower population in 2016 has allowed *Higher crop diversity* and *Lower crop intensity (winter)* to reduce populations below a level likely to cause a yield penalty (2 RLN/g soil) in 2019.

Herbicide use

All systems relied heavily on knockdown herbicides, with residual herbicides only used in poorly competitive crops such as chickpea, sorghum, cotton and sunflowers.

Higher crop diversity and *Lower crop intensity (winter)* have had more glyphosate applications. However, growing summer crops allowed these systems to control winter grass weeds (black oats and phalaris) without the use of 'Group A' herbicides, the group most prone to resistance development.

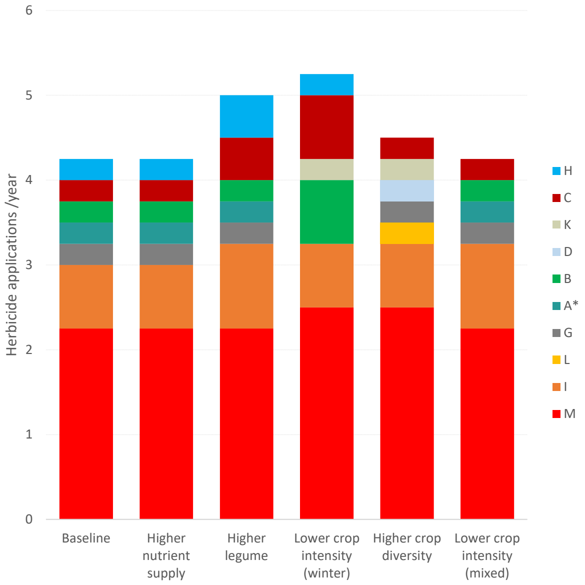

Figure 6. Number of applications per year for each of the herbicide modes of action (MOA).
*high potential for development of resistance.

Gross margin

Gross margins for each of the systems were calculated using actual grain yields, machinery operations, fertilisers, seed, herbicides and other pesticides. Prices for inputs of fertilisers, pesticides and seed were based on market prices. Commodities are valued at a 10 year average port price, less freight and grading/bagging costs as appropriate.

The most profitable system was *Baseline*, which produced all of its profit in the first two years (Figure 7). *Higher nutrient supply* had higher fertiliser expenses and a yield reduction in the first wheat crop, so returned a lower gross margin than *Baseline*. Similarly *Higher legume* returned similar crop gross income to

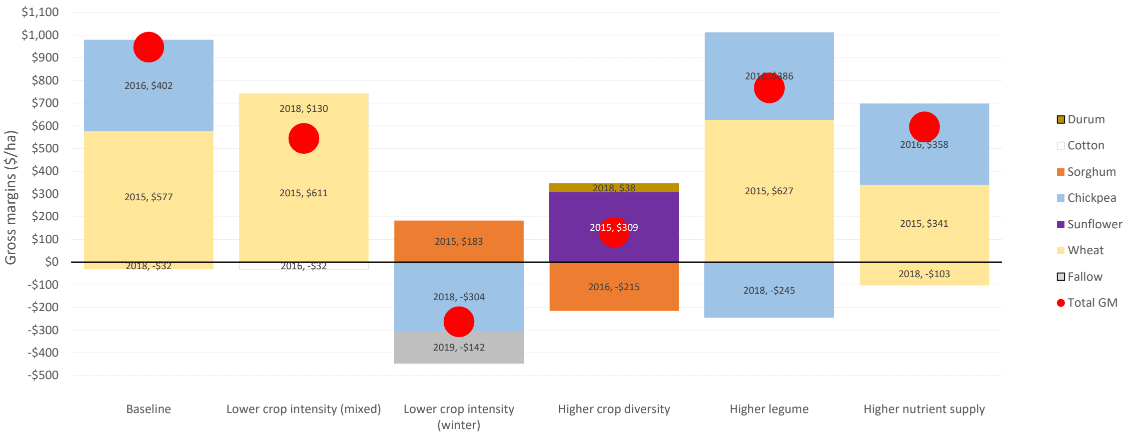

Figure 7. Gross margins of the six systems at Mungindi from 2015 to 2019. These include all variable operating expenses on a per hectare basis.

The segments represent the net profit (or loss) of individual crops and preceding fallow and the red dot indicates the net position over the four years.

Baseline, however the 2018 chickpeas had higher establishment costs so returned a larger loss than the wheat in *Baseline*.

Summer crops have been less profitable than the winter crops for the same year. However, two of the three systems with summer crops had a yield benefit to the following winter crop. The yield benefit from the cotton break crop for the 2018 wheat in *Lower crop intensity (mixed)* provided the largest return in the three drought years of 2017 to 2020, while *Higher crop diversity* was the only other system to grow a profitable crop in this period, again following the sunflower and sorghum summer crops.

Implications for growers

Maintaining high ground cover has been beneficial to accumulate soil water for cropping opportunities throughout the recent drought. While 2019 was too dry to grow crops, the presence of stubble and higher ground cover in some systems helped reduce the wind erosion that led to widespread dust storms that year.

The *Baseline* performed well in the first two years with good yields and gross margins. This relatively low-input system has minimised losses through the three drought years of 2017 to 2020 to maintain the highest gross margin over the full five years. In contrast, *Higher nutrient supply* and *Higher legume* had larger costs, and so lost more money during the drought. Both *Lower intensity (winter)* and *Higher crop diversity* missed the gains of the highly profitable 2015 and 2016 winter crops, so have the lowest gross margin to date.

Growing summer break crops has reduced soil borne pathogens, especially root lesion nematodes. Growing summer crops also provided the opportunity to control winter grass weeds without a heavy reliance on Group A herbicides. Unfortunately, the summer crop options have been less profitable than the winter crop options in the run of seasons experienced to date. Lower pathogen levels following summer break-crops improved winter crop yields in 2018, so future benefits will likely offset the lower returns from these summer crop options.

Acknowledgements

The team would like to thank the trial cooperator, 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
2019 rainfall:	88 mm

Farming systems site report—Emerald

Darren Aisthorpe and Ellie McCosker
Department of Agriculture and Fisheries

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 continues to outperform all other systems across most indices measured.
2. Several frost events in July reduced chickpea yields significantly, limiting the performance of both systems planted to chickpea in 2019 (*Higher crop intensity* and *Higher legume*).
3. Yield and soil nitrogen levels indicate that nitrogen rundown could be starting to affect both the *Higher legume* and *Integrated weed management* systems.

Background

In early 2015, the project developed six farming systems relevant to Emerald that were consistent with the Northern Farming Systems Initiative. A range of agronomic practices (i.e. row spacing, plant population), crop types and rotations, crop frequencies, planting time/windows, tillage practices, fertiliser rates and planting moisture triggers were adopted and strategically used to develop the following six farming system treatments:

1. **Baseline** - A conservative zero tillage system targeting one crop/year, with nitrogen rates on cereals targeting median seasonal yield potential. Crops include wheat, chickpea and sorghum.
2. **Higher crop intensity** - Cropping intensity increased to 1.5 crops/year when water allows. Crops include wheat, chickpea, sorghum, mungbean and forage crops/legumes with nitrogen rates on cereals targeting median seasonal yield potential.
3. **Higher legume** - Increased pulse frequency compared to the *Baseline* system (i.e. 1 pulse every 2 years) with nitrogen rates on cereals targeting median seasonal yield potential.
4. **Higher nutrient supply** - Nitrogen and phosphorus rates of the *Baseline* system are increased, targeting 90% of yield potential based on soil moisture in an environment of variable climate. Crops and other practices are the same as the *Baseline* system.
5. **Higher soil fertility** – Same as the *Higher nutirent supply* system but with an additional 60 t/ha of manure applied to change the starting soil fertility level.
6. **Integrated weed management (IWM)** - 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 in Central Queensland (CQ) farming systems. Crops include wheat, chickpea and sorghum.

What was done

All systems were planted to sorghum in the 2017/18 summer season, then the trial was fallowed, receiving 427 mm of rainfall. Winter crop was planted across all systems in 2019.

Five systems were planted on 15 April; *Baseline*, *Higher nutrient supply*, *Higher soil fertility* and *IWM* were all planted to Mitch$^{\Phi}$ wheat, while the *Higher intensity* system was planted to Kyabra$^{\Phi}$ chickpea (Table 1). Plant available water (PAW) at sowing to 150 cm for these systems varied from 140 mm for the *Higher crop intensity* system to 170 mm for the *Baseline* system. Four weeks later (14 May), the *Higher legume* system was planted to Kyabra$^{\Phi}$ chickpea with 160 mm of PAW. Pre-plant nitrogen testing indicated no system required any additional N to achieve target yields based on starting PAW.

Early in-crop rainfall assisted the April-sown systems to establish and develop quickly, with 51 mm of rain received in the first month post planting. Minor crop damage was observed because of residual herbicide toxicity due to wet planting conditions combined with additional rain during emergence. Fortunately, final establishment was not significantly affected and did not compromise yield.

Table 1. Crop rotations 2015 to 2019.

Treatment	Winter 2015	Summer 2015/16	Winter 2016	Summer 2016/17	Winter 2017	Summer 2017/18	Winter 2018	Summer 2018/19	Winter 2019
Baseline	Wheat EGA Gregory$^{\Phi}$	Fallow	Chickpea Kyabra$^{\Phi}$	Fallow	Wheat Sunguard$^{\Phi}$	Sorghum MR-Buster	Fallow	Fallow	Wheat Mitch$^{\Phi}$
Higher crop intensity	Wheat EGA Gregory$^{\Phi}$	Mungbean Jade-AU$^{\Phi}$	Wheat Condo$^{\Phi}$	Fallow	Wheat Sunguard$^{\Phi}$	Sorghum MR-Buster	Fallow	Fallow	Chickpea Kyabra$^{\Phi}$
Higher legume	Chickpea Kyabra	Fallow	Wheat Condo$^{\Phi}$	Fallow	Chickpea Seamer$^{\Phi}$	Sorghum MR-Buster	Fallow	Fallow	Chickpea Kyabra$^{\Phi}$
Higher nutrient supply	Wheat EGA Gregory$^{\Phi}$	Fallow	Chickpea Kyabra$^{\Phi}$	Fallow	Wheat Sunguard$^{\Phi}$	Sorghum MR-Buster	Fallow	Fallow	Wheat Mitch$^{\Phi}$
Higher soil fertility	Wheat EGA Gregory$^{\Phi}$	Fallow	Chickpea Kyabra$^{\Phi}$	Fallow	Wheat Sunguard$^{\Phi}$	Sorghum MR-Buster	Fallow	Fallow	Wheat Mitch$^{\Phi}$
Integrated weed management	Wheat EGA Gregory$^{\Phi}$	Fallow	Chickpea Kyabra$^{\Phi}$	Fallow	Wheat Sunguard$^{\Phi}$	Sorghum MR-Buster	Fallow	Fallow	Wheat Mitch$^{\Phi}$

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** 🟥 **Sorghum** 🟩 **Mungbean** ▨ **Fallow**

A total of 48 mm was received in-crop from 14 May (*Higher legume* planting date) to 4 July, with no further rain before harvest. Temperatures during winter were average, however there were five days where minimum temperatures dropped below 2 °C between 22 June and 22 August (which both recorded 1.6 °C). Cold events on 15 and 17 July saw minimum temperatures drop to 0.2 °C and 0.8 °C respectively, resulting in a significant flower and pod drop on both chickpea crops. No damage was observed on the wheat.

Frost damage in chickpea.

Results

Wheat

Despite reasonable PAW at sowing and significant early in-crop rain, all systems began to show signs of moisture stress during the flowering/grain fill period and senesced quickly. The wheat flowered around 4 July and reached physiological maturity by 19 August. Daytime maximum temperatures were consistently above 25 °C from mid-July, with August generally above 28–32 °C. These high temperatures, combined with a drop in relative humidity (RH%) and an increase in evaporative pressure (ETo) caused plant stress during grain fill.

Yields for the systems reflect only minor differences (Table 2) with *Baseline* the lowest yielding and almost half a tonne per hectare lower than the highest yielding system, *Higher soil fertility*. Grain protein and 1000 seed weight were all similar. Screenings (%) showed a clear difference between the systems, with the *Higher soil fertility* system 1% higher than the other

Table 2. System crop production and quality results for the winter 2019 crops.

System	Crop biomass (kg/ha)	Crop yield (kg/ha)	Protein %	Screenings %	1000 seed weight (g)
Chickpea					
Higher crop intensity	4936	877	25.2%	8.4 %	270
Higher legume	5729	1583	25.7%	3.5 %	210
Wheat					
Baseline	8541	3075	12.3%	7.1 %	36
Higher nutrient supply	8909	3228	12.0%	7.4 %	35
Higher soil fertility	9856	3531	12.7%	8.3 %	34
IWM	7990	3175	12.2%	7.1 %	35

wheat crops. This was most likely due to the higher nitrogen status of the soil (+100 kg/ha/N) compared to the other three systems (Figure 5).

Chickpea

Chickpea yields for both systems were well below expectations (Table 2), a direct result of the minimum temperatures experienced in June/July. The early planted *Higher crop intensity* system reached an estimated 50% flowering by 17 June, while the later planted *Higher legume* system achieved 50% flowering in late July. A cold period in mid-July resulted in significant flower drop/seed abortion in both systems.

In a commercial farming enterprise, some growers may have considered the option of cutting for hay, however this option did not fit with the overarching research. To assess the hay alternative, a biomass cut was taken in the *Higher crop intensity* system to quantify the amount present at the time of this frost event to economically compare these options:

Gross value of chickpea hay: $1830/ha

- Average biomass: 5.42 t/ha
- Less 25% loss from baling process
- Hay value on-farm: ~$450/t

Gross value of grain: $325/ha

- Grain yield: 0.65 t/ha
- Grain value: $500/t (long term average).

The later planted *Higher legume* system recovered from the cold events by putting on more flowers and generating additional yield, resulting in a late peak flowering. *Higher crop intensity* had already formed grain in the pods and the plants could not recover the yield lost, hence produced higher screenings.

Overall systems performance 2015–2019

Five years into the project, the effect of different systems is beginning to show. The *IWM* system has produced the greatest and *Higher legume* the least biomass over the five crops to date (Figure 1). Interestingly, when biomass production by the *IWM* system is examined by year, only in the 2015 wheat and the 2018 sorghum crops did the system out-produce the other systems. In 2019 it was the lowest-producing of all systems planted to wheat.

The *Higher soil fertility* system has produced the most grain, comfortably easing past long-time leader *Higher legume* after the sorghum crop in 2018. The *Higher crop intensity* continues to fall behind, exacerbated by the cold damage experienced in the chickpea crop this year.

Water dynamics

Water use efficiency (WUE) (kg/mm/ha) and fallow efficiency has varied considerably over the life of the project, both within and across the six systems (Figure 2). Time in fallow tends to influence fallow efficiency, with shorter fallows producing increases in efficiency of 10% relative to a traditional six-month fallow. Of interest is also the steady improvement in WUE from the first crop through to the 2019 winter crop for all systems.

With its shorter fallow periods, the *Higher crop intensity* system has had the highest fallow efficiency of all systems, however that efficiency has come at the cost of the lowest grain and biomass WUEs (Table 3). *Higher soil fertility* system's grain WUE is 0.5 kg mm/ha higher than the next closest system (*Higher legume*) which is quite substantial considering Emerald's average rainfall of 600 mm per year. *IWM* has been the most efficient at producing biomass, however the difference is relatively small compared to *Higher soil fertility* given the extra plants and narrower row spacing in *IWM*.

Nutrient dynamics

Phosphorus (P) removed in the form of grain was tested for each crop grown over the last five years (Figure 3). Typically, pulse crops tend to extract more P than cereal crops per tonne of grain produced. By the end of 2017, the *Higher legume* system had extracted more P than any other system due to the two chickpea crops and one high-yielding wheat crop in 2016.

However, this trend changed from 2017 onwards due to a low-yielding sorghum driven by lower PAW and a low yielding chickpea due to frost in 2019. The *Higher soil fertility* system, which began to show improved yields due to manure applications in 2017, has consistantly had the highest yields and consequently the highest P removal of all systems since that time.

Nitrogen (N) removed in the form of grain was tested for each crop grown over the last five years (Figure 4). Like P, N removal in the grain is highly correlated to yield, with pulse crops typically removing more N per tonne of grain than a cereal crop.

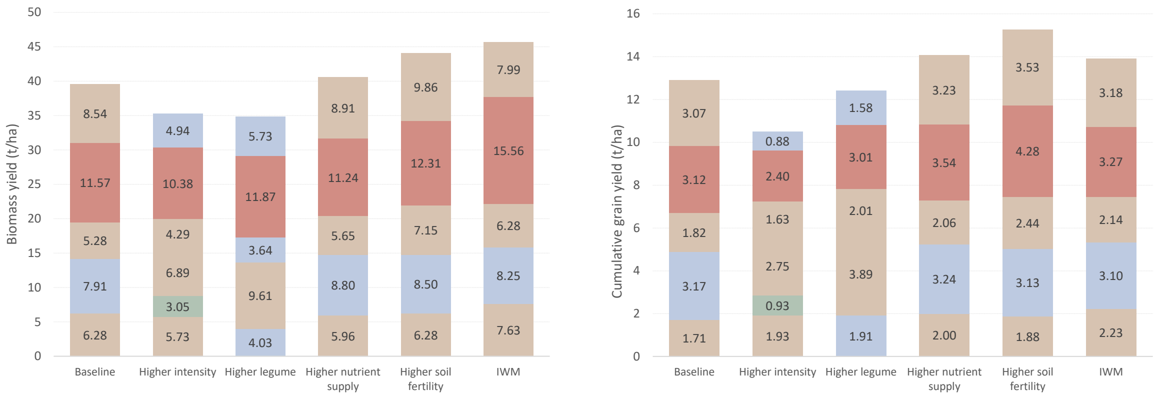

Figure 1. Accumulated biomass and grain yields for the six systems at the Emerald site.

Bar colours represent crop type (see key below Table 1).

Figure 2. Water use efficiency (kg/ha/mm) and fallow efficiency (%) since the start of the trial in 2015.

WUE indicates grain produced by the crop in each treatment per mm of water available to it. Bar colours represent crop type (see key below Table 1). The percentage number indicates how much of the fallow rainfall was captured and available at the next planting event for that treatment.

Table 3. System water efficiency indices over the duration of the trial for all six systems.

System	System fallow efficiency (%)	System crop grain WUE (kg/mm)	System crop biomass WUE (kg/mm)
Baseline	22.7%	100	30.7
Higher crop intensity	25.4%	8.1	27.0
Higher legume	19.5%	10.9	30.8
Higher nutrient supply	22.2%	10.8	31.1
Higher soil fertility	23.3%	11.4	33.0
IWM	22.8%	10.6	34.7

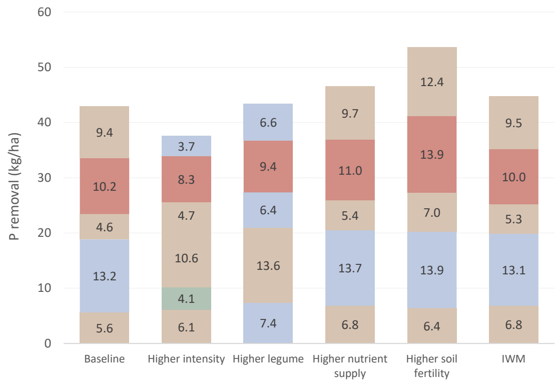

Figure 3. Cumulative and crop phosphorus removal (in the form of grain) over five years.

Bar colours represent crop type (see key below Table 1).

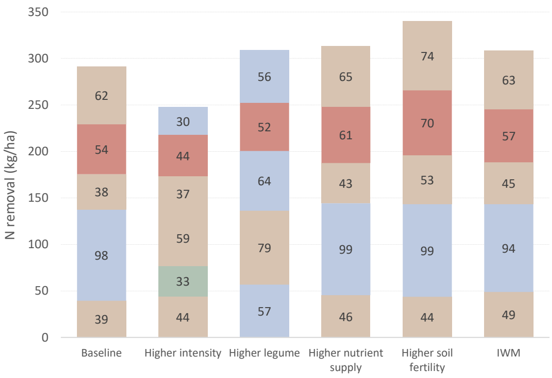

Figure 4. Cumulative and crop nitrogen removal for each system over five years.

Bar colours represent crop type (see key below Table 1).

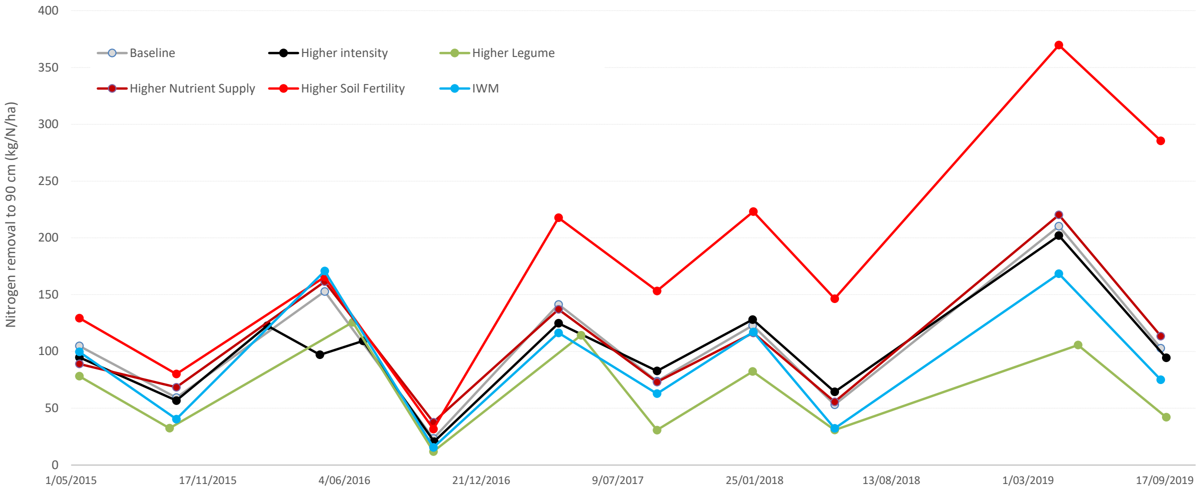

Figure 5. Nitrogen (kg/ha) to a depth of 90 cm across the duration of the trial for the six systems.

Soil N levels have also been measured across the trial at both planting and harvest for each crop. After five years, we are starting to see separation between the systems driven by crop choice and the nutrition regime (Figure 5). There is now almost 300 kg/ha difference between the highest (*Higher soil fertility*) and lowest (*Higher legume*) systems as at the 2019 harvest.

Financial return

For many, the key indicator of system performance is the ability to generate a profitable return over a sustained period. The *Higher soil fertility* system has achieved the highest gross margin to date, at $2954/ha (Table 4). Impressively, it has generated an additional $221/ha.

Table 4. Life of trial gross margin financial indices for the six systems.

System	WUE ($/mm)	Gross margin ($/ha)
Baseline	$0.93	$2,392
Higher crop intensity	$0.52	$1,343
Higher legume	$1.07	$2,733
Higher nutrient supply	$1.03	$2,659
Higher soil fertility	$1.14	$2,954
IWM	$1.05	$2,722

Even more impressive has been the capability of the *Higher soil fertility* system to convert total rainfall into profit. For every mm of rainfall/ha which has fallen on that system, $1.14 profit has been generated. When extrapolated out, with an average rainfall from 2015–2019 of 520 mm (long term average is 600 mm) and an average farmed area of 2000 ha per enterprise for the Central Highlands, a *Higher soil fertility* system potentially would have generated a gross margin of $5.9 million over the five year period. The *Baseline* system, at $0.93/mm/ha over the same period, generated $4.8 million, and *Higher crop intensity* only generated $2.7 million. This difference effectively gives a $3.2 million spread across systems, for the same rainfall and same land.

Implications for growers

The six systems are continuing to differentiate themselves across the range of indices. In isolation, the winter crop of 2019 maintained the status quo observed over the past five years. Systems with greater access to nutrition are performing better than those on a lower nutrition regime. While the damage to the chickpea crops in the *Higher legume* and *Higher crop intensity* systems was disappointing, it was a reality also experienceed by commercial crops in the region.

The *Baseline* system now sits behind all systems except *Higher crop intensity* on most indices, showing a conservative nutrient approach is not ideal for cropping in Central Queensland. The *Higher legume* system had benefited significantly from the two chickpea crops in 2015 and 2017. However, the effect of the 2017 chickpea crop on fallow efficiency into the next sorghum crop, and then the frost damage to the 2019 chickpea crop has pulled this system's economic performance back to the pack.

The manure applied in the *Higher soil fertility* system has resulted in the system excelling for most indices and it continues to draw away from the rest of the systems.

The application of manure per ha (approx. 40 t/ha dry) was never intended to be an economic reality, rather an attempt to establish a much higher starting soil nutrient status, with a view to attempting to maintain these levels. However, as the trial continues, the question must be asked, at what point could manure applications of this quantity become a feasible economic reality?

With a $300 per ha benefit over the identical system less the manure application (*Higher nutrient supply*) after five years, and showing no sign of slowing, it will be very interesting to see how the system continues to perform relative to the other five into the future.

Acknowledgements

We would like to thank the local growers and consultants that have supported and contributed to the project. The Grains Research and Development Corporation, along with the Department of Agriculture and Fisheries in Queensland and the Department of Primary Industries in New South Wales, fund the project (DAQ00192).

Trial details

Location:	Emerald Research Facility (formerly the Emerald agricultural college).
Crop:	Wheat (Mitch$^{\text{Ⓟ}}$) and chickpea (Kyabra$^{\text{Ⓟ}}$)
Soil type:	Cracking, self-mulching, Grey Vertosol, >1.5 m deep, estimated plant water holding capacity of approx. 220 mm.

Treatment summary for 2019 winter crop:

Treatment	Row spacing (cm)	In-crop rainfall (mm)	Total P applied with seed (kg/ha)
Baseline	50	97	4.25
Higher crop intensity	50	97	4.25
Higher legume	50	48	4.25
Higher nutrient supply	50	97	4.25
Higher soil fertility	50	97	5.28
Integrated weed management	25	97	4.25

Aerial image of the farming systems trials at Emerald.

Farming systems: Nitrogen dynamics and the impact of crop sequences over time

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RESEARCH QUESTIONS: *Can systems performance be improved by modifying farming systems in the northern grains region? | How does changing farming systems impact on nitrogen dynamics?*

Key findings

1. Grain legumes have utilised soil mineral nitrogen (N) to the same extent as cereal crops and have higher N export, which often offsets N fixation inputs.
2. Additional applied N reduced the depletion of background soil mineral N status at most sites; we are recovering a high percentage (>50%) in the soil mineral pool.
3. Application of ~50 t/ha of compost or manure coupled with N fertiliser rates for 90% yield potential has dramatically increased the soil mineral N in four years.
4. Decreasing cropping frequency has reduced N export and so stored more N over the longer fallows, which has reduced N fertiliser requirements for following crops.
5. Long fallows can mineralise N and move it down the soil profile even under very dry conditions.
6. Most excess N is not lost in the system; it is moved down the soil profile for future crops.

Background

Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and CSIRO are collaborating on extensive field-based farming systems research focused on developing farming systems and crop sequences to meet emerging challenges of declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens and better use the available rainfall for increased productivity and profitability.

Experiments were established in 2015 at seven locations; a large factorial experiment at Pampas near Toowoomba (summer dominant, winter dominant and mixed cropping), and locally relevant systems at six regional centres (Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red and grey soils)). A common set of strategies has been employed to examine the impacts of changes in the farming system.

One of the central aspects was to examine how farming systems compared in terms of their nitrogen dynamics. Several systems modifications explicitly targeted increasing nutrient efficiency and increased nutrient supply in the farming system.

What was done

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

Sites were selected to represent a range of climatic conditions, soil types, nutritional status and paddock history. Each site was comprehensively soil tested at the beginning of the project with additional soil sampling conducted prior to planting and after harvest of each crop (Table 1).

Table 1. Sampling depths for soil testing.

Depth (cm)	Measurements		
	Soil water	Comprehensive numtient analysis	Nitrate and ammonium (N)
0-10	Soil water	Comprehensive numtient analysis	Nitrate and ammonium (N)
10-30			
30-60			
60-90			
90-120			
120-150			

The considerable range in soil fertility across the sites dramatically influenced the requirements for inputs of fertilisers (N in particular) at some sites (e.g. Billa Billa and Pampas) where high levels were present at the start of the experimental period.

The following report explores five years of data across all geographical locations to compare the nitrogen dynamics in different farming systems across the northern region, specifically:

- Changes in system nitrogen dynamics due to increasing legume frequency, increasing fertiliser inputs and decreasing crop frequency.
- Where the nitrogen is in the soil profile, and how it moves over long fallows and different fertiliser regimes.

Results

How does increasing legume frequency impact on system N dynamics?

Grain legumes are integral to current farming systems. Legume area and frequency has consistently increased due to high grain prices and a belief that they reduce overall nitrogen (N) fertiliser input costs. Data produced from this project has allowed comparison of the effects of increasing legume frequency on N dynamics over a large geographic area. However, it is important to note that as the project only has five years of data, these systems have only planted one or two extra legume crops compared to the *Baseline*.

To date, results across our sites show that additional legume crops in the crop sequence has had little positive impact on soil mineral N except at Billa Billa (+ leg; Figures 1, 2, 3 & 4). The legumes are actually utilising soil mineral N to the same extent as cereal crops and have higher N export, which often offsets N fixation inputs. This result is consistent across various starting soil N conditions, from locations with very high starting mineral N status (e.g. Billa Billa—Figure 2 and Pampas—Figure 3) to locations with low mineral N status (Narrabri—Figure 4) where legumes would need to fix N to meet their needs. These results challenge the common assumption that grain legumes reduce N fertiliser needs in the crop sequence. Improved pulse breeding and agronomy has increased harvest index and hence the ratio of N removed in grain to that left in biomass, so residual N has been diminished after the crop.

Key to abbreviations used in figures:

+ fertility = *Higher soil fertility*
- inten = *Lower crop intensity*
+ leg = *Higher legume*
nut = *Higher nutrient supply*

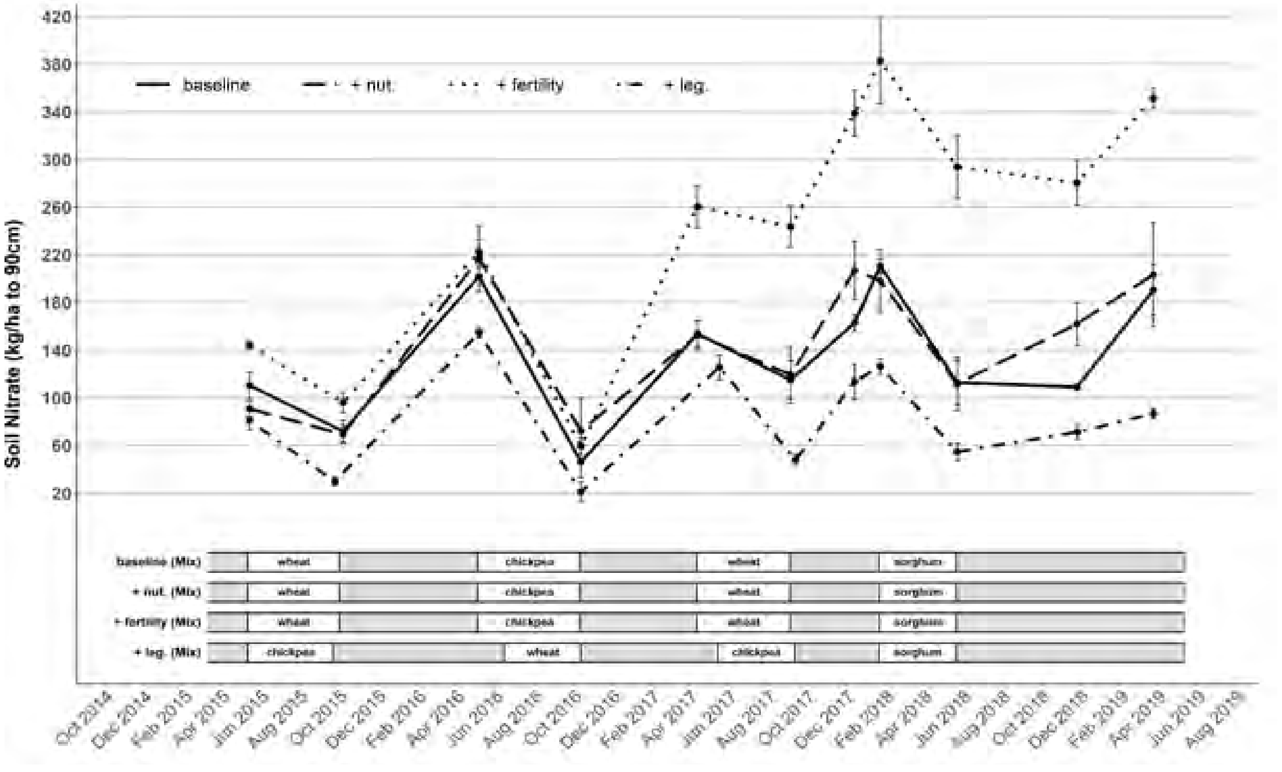

Figure 1. Dynamics of measured plant available soil nitrogen—Emerald.

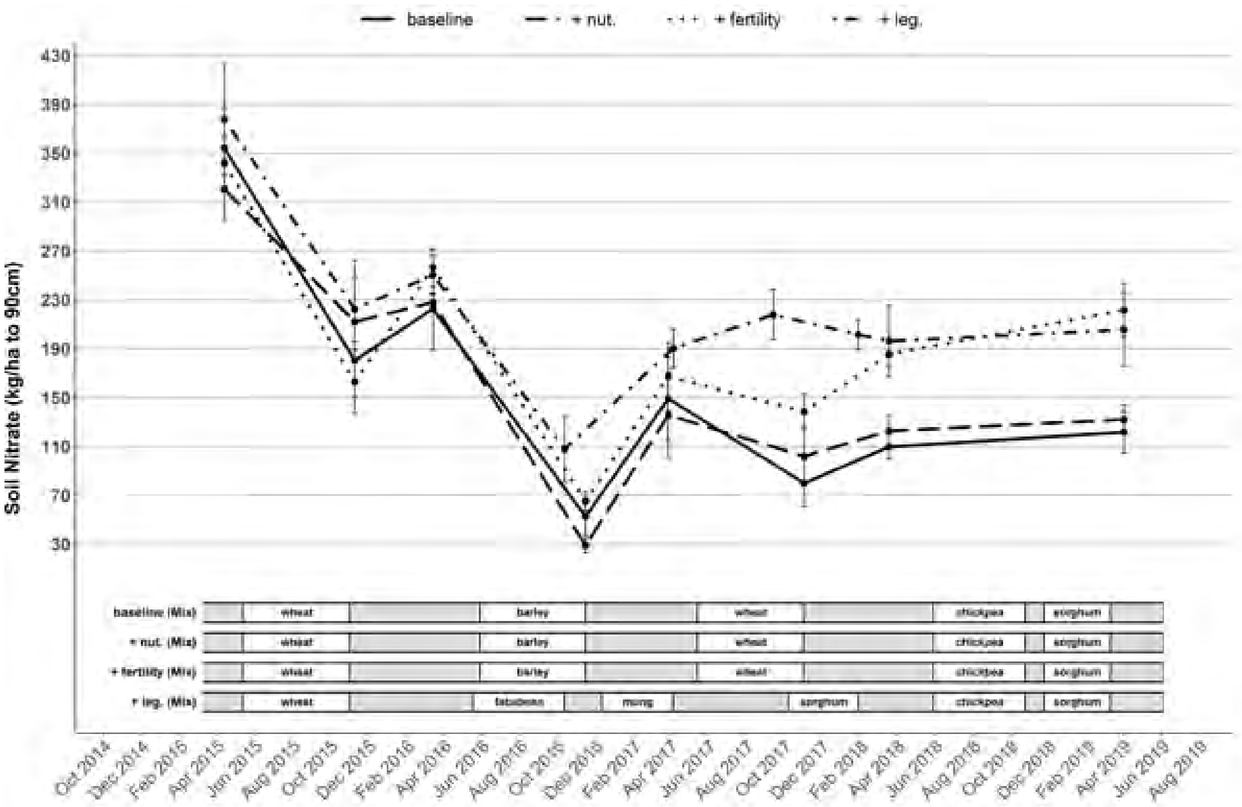

Figure 2. Dynamics of measured plant available soil nitrogen—Billa Billa.

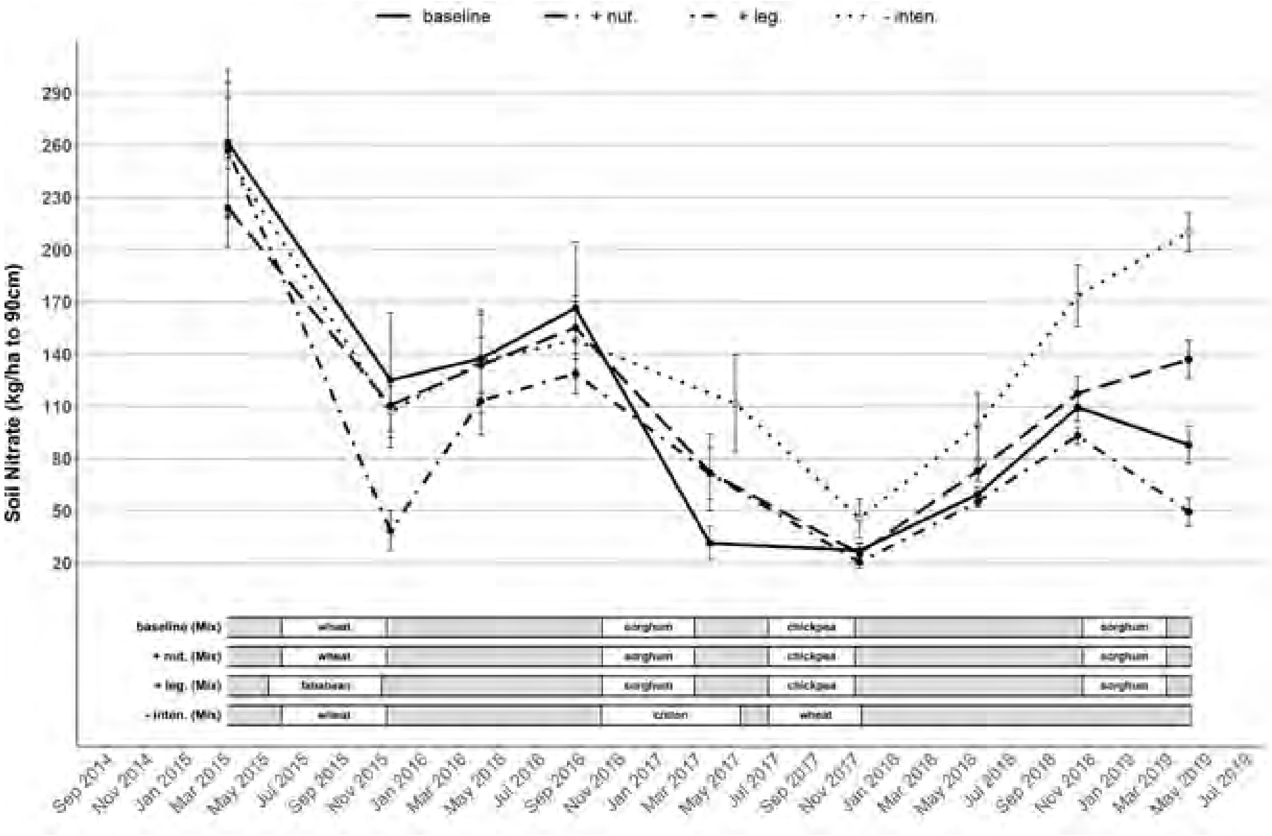

Figure 3. Dynamics of measured plant available soil nitrogen—Pampas mixed cropping.

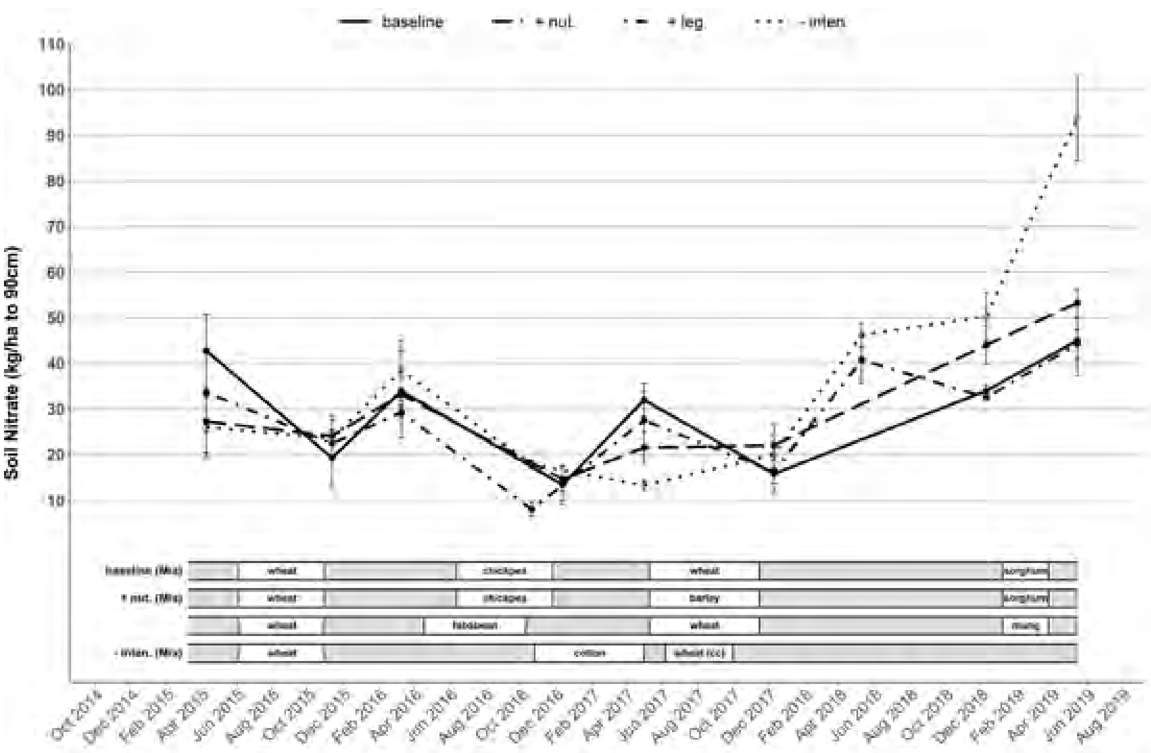

Figure 4. Dynamics of measured plant available soil nitrogen—Narrabri.

What is the impact of increasing fertiliser inputs on system N dynamics?

There is increased interest in how to combat the decline in soil fertility across the northern region. More biomass will increase soil organic matter levels, building the natural supply of nutrients such as N and phosphorus (P). However, adequate crop nutrition is critical to grow extra biomass and to promote efficient soil microbial processes.

The *Higher nutrient supply* system uses a nitrogen budget to achieve 90% of the potential yield at planting, rather than the median yield potential targeted by the *Baseline*. The aim is to maximise yields, but also support greater biomass to increase cover and soil organic matter. The *Higher soil fertility system* was also implemented at Emerald and Billa Billa, again increasing the nutrient supply to support 90% of the seasonal yield potential, along with 10 t/ha organic carbon applied by ~50 t/ha compost or manure at the start of the experiment. This treatment aimed to raise the soil fertility of the site and see if this higher fertility could be sustained with higher nutrient inputs.

The additional N applied in the *Higher nutrient supply* system (+ nut.) reduced the depletion of background soil mineral N status at a majority of sites (Emerald, Billa Billa, Pampas mixed cropping, & Narrabri; Figures 1, 2, 3 & 4). The high starting nitrogen levels at Billa Billa has resulted in only one additional application of nitrogen in the *Higher nutrient supply* system for winter crop 2017; all systems have been utilising the original pool of N.

When comparing the *Higher soil fertility* system (+ fertility) at Emerald and Billa Billa (Figures 1 & 2) the additional organic carbon applied has dramatically increased the mineral N. The last two years has seen this system move ahead of all other systems at both sites. The largest change was seen at the Emerald site with this system holding an additional 150 kg available N/ha than the *Higher nutrient supply* system.

These results show that applying N fertiliser for 90% yield potential may reduce the mining of soil available N, and that significant amounts of additional N applied remain in the mineral N pool available to subsequent crops. To confirm this, longer term trends of underlying soil fertility such as organic carbon or total N pools will need to be assessed.

What is the impact of decreasing crop intensity on system N dynamics?

The northern region farming system is centred on growing crops mainly on stored soil moisture. The nitrogen dynamics of the *Lower crop intensity* system (-inten.) are shown at Pampas (Figure 3) and Narrabri (Figure 4). These systems are storing more N over the longer fallows, which is reducing N fertiliser requirements for following crops. Given the recent dry conditions and enforced long fallows it is interesting to consider the amount and location of available N for the next crop.

Where is the nitrogen, and how does it move?

We have compared the starting available mineral N against that available after four years, and where it is positioned in the soil profile at Emerald and Billa Billa (Figure 5). The Billa Billa site with its high starting fertility has seen N throughout the profile decline over time, with the largest change seen in 0–10 cm. However, the Emerald site, with its lower starting fertility and use of N fertiliser across all systems, has seen both the *Higher nutrient supply* and *Higher soil fertility* systems building N.

The majority of this increase was in the 30–60 and 60–90 cm layers, indicating that excess N has moved down the profile during this time frame, but is still available for future crops.

We know N mineralisation is related to soil type, organic carbon, biomass and rainfall, but what happens during extended dry periods such as the last 18 months across the northern grains region? After the initial increase of mineralised N in the topsoil across several sites, there was a definite movement of mineral N down through the soil profile. For instance, the summer season of 2017/18 saw significant levels of mineralisation within the 0–30 cm depth at the northern farming systems sites (Figure 6—Narrabri and Pampas).

This summer recorded below average rainfalls, but there was still sufficient rain to trigger mineralisation. The increase in the 0–30 cm corresponds with the location of microbes responsible for the breakdown of organic matter into the plant-available form of nitrate and ammonium. Sampling after the winter of 2018 found that the N mineralised during the previous summer had filtered down the profile (30–60 cm). This pattern continued late into the fallow as the accumulated mineral N increased in the 60–90 cm depth. These results show that mineralisation can be triggered by even small falls of rain and this N can then move down the soil profile even with lower soil profile moisture levels.

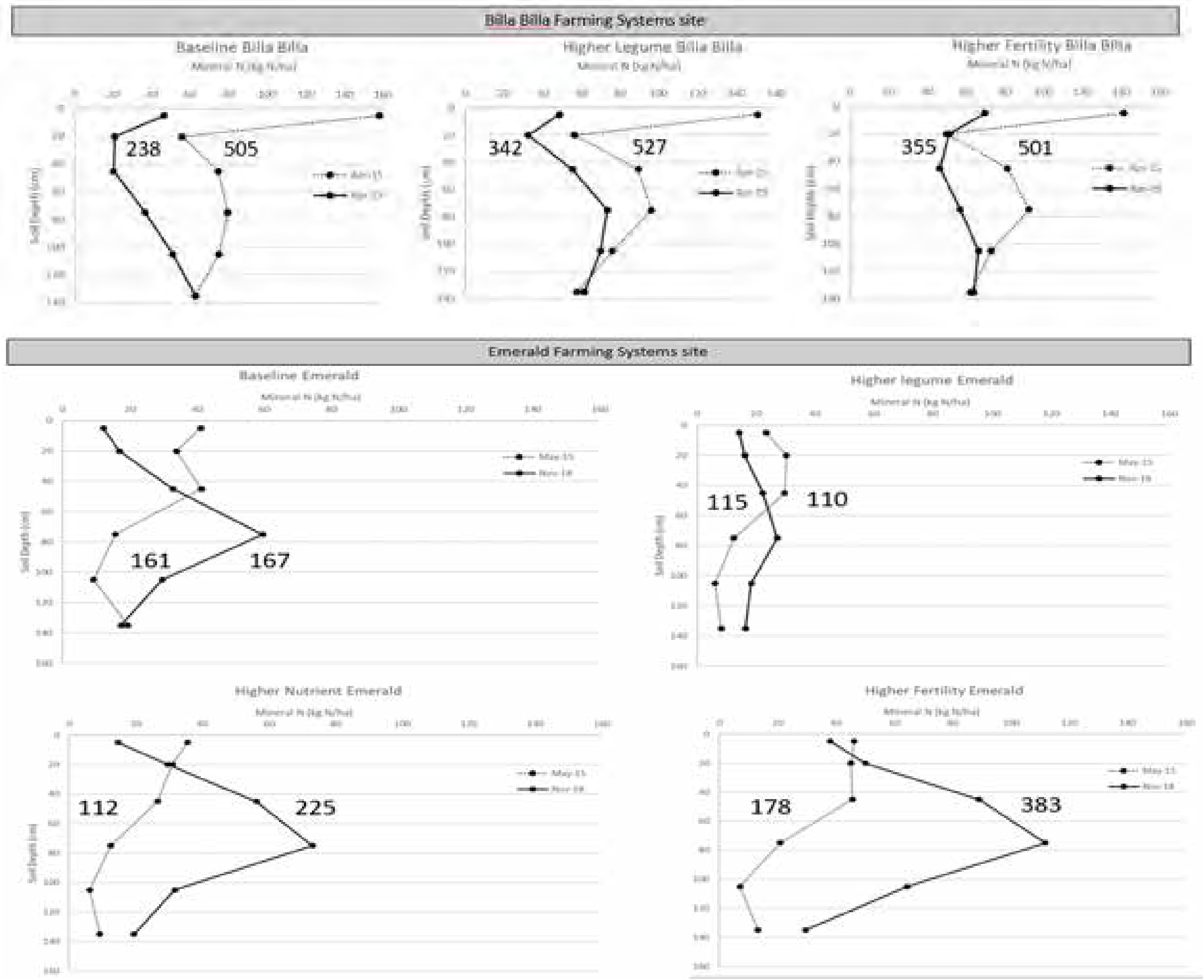

Figure 5. Distribution of mineral N within the soil profile from 2015 to 2019 at Billa Billa and Emerald.

This is important for the next phase of the cropping sequence, as it can be assumed that not only do we have ample mineral N available to maximise grain yields, but the location of the N is within the soil layers where plants require peak N uptake during key growth stages.

The Mungindi site (Figure 7) had preplant N applied for a winter crop that was not planted (2017). The *Baseline* received 20 kg N/ha and the *Higher nutrient supply* system received 80 kg N/ha in April 2017. Soil analysis the following year showed that 40 kg N/ha of N had mineralised and that this mineralised N and fertiliser N moved into the 10–30 and 30–60 cm layers during a very dry year. This data shows that if N is applied and not utilised by a crop, it is not likely to be lost from the system, but rather move down the profile to support future crop growth and grain production.

Implications for growers

The results from these experiments provide some key insights and implications for the different farming systems strategies that are being used across the northern grains region.

Nitrogen fertilisers can provide crop needs and reduce depletion of the underlying soil fertility. Fertilisers will be particularly important for high crop intensity systems that will require sufficient nitrogen and other nutrients to support greater biomass production and the higher removal of

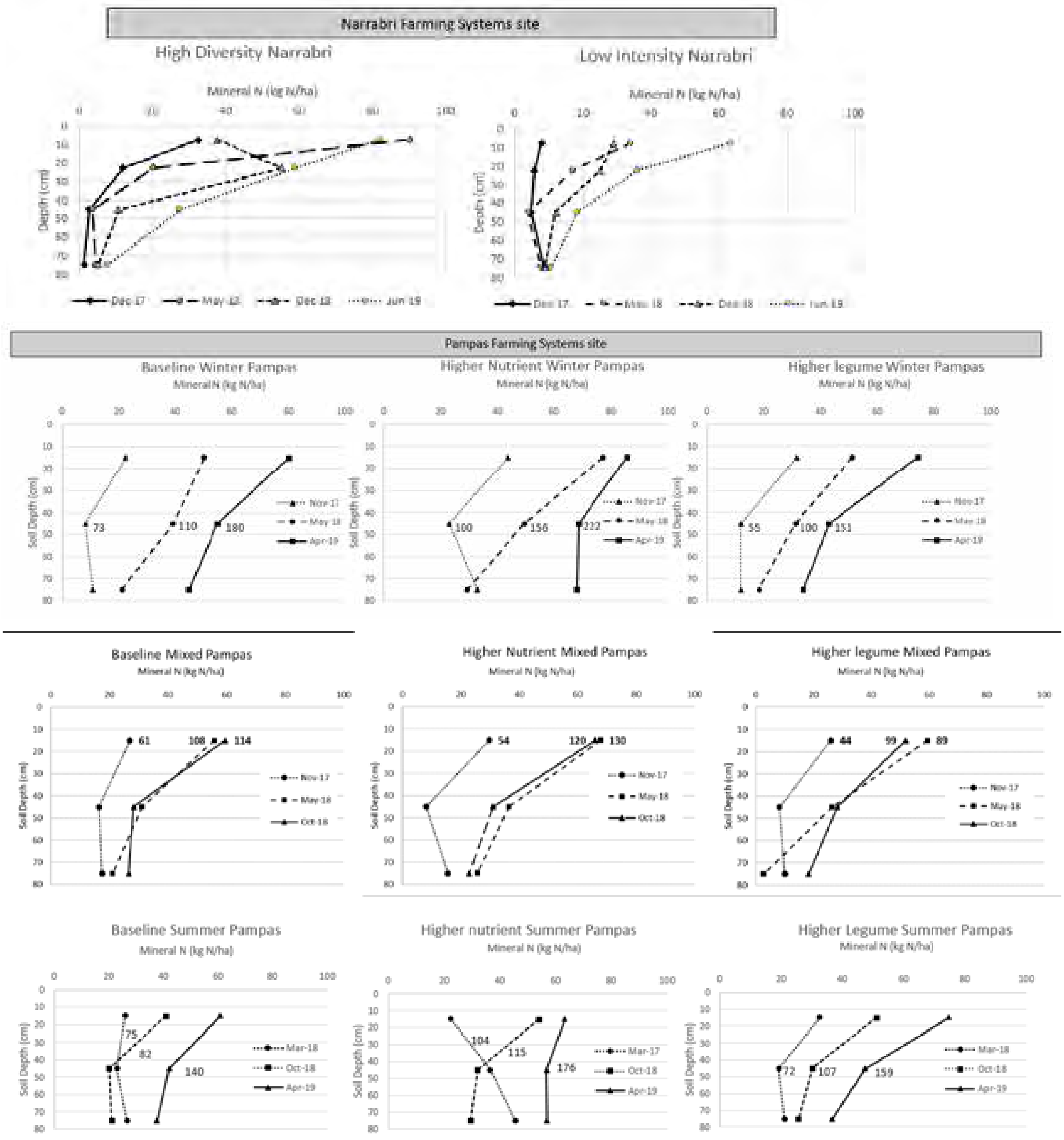

Figure 6. Distribution of mineral N within the soil profile over a long fallow period at Narrabri and Pampas.

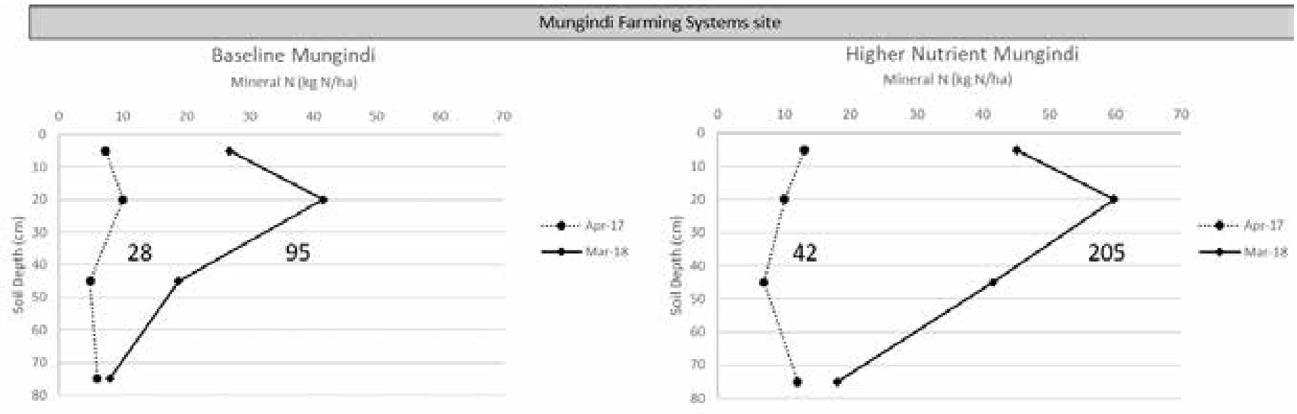

Figure 7. Distribution of mineral N within the soil profile over a long fallow period at Mungindi.

nitrogen in grain when the system is successful. Soil organic matter may increase, but only if the nutrients to support healthy crops are available.

In contrast, low intensity systems provide more time to mineralise soil organic matter and accumulate nitrogen for each crop. Growers will have lower nitrogen fertiliser costs in the short-term, but depleting soil organic matter means the need for nitrogen fertiliser may only be delayed.

Investments in nitrogen fertiliser in these experiments have not been wasted in dry seasons. Lower yielding crops may not have used all the available nitrogen, but nearly 60% of the additional nitrogen has been retained in the soil as extra available nitrogen for future crops. Indeed, mineralised nitrogen and applied nitrogen appears to have been moved down the profile even in dry seasons, away from the risk of denitrification and perhaps, available when future crop demand is highest.

Finally, we have seen greater use of pulses in recent years. Improved varieties and agronomy have seen them become very profitable. We also know that pulses can fix nitrogen to reduce fertiliser costs when soil nitrate levels are low. However, the expected nitrogen benefit to the following crops and the wider farming systems have generally not been seen in these experiments, especially where soil nitrogen levels have been maintained by higher fertiliser rates, higher soil fertility from manures and longer fallows. Nitrogen balances across the systems have been similar regardless of the number of pulse crops grown over the past five years. When pulses are grown on soil with high available nitrogen, they will fix less nitrogen and export large amounts in their grain. Pulses remain highly profitable, but large nitrogen benefits will only accrue when soil nitrate levels are low, typically in double crop situations or on soils with declining fertility.

In summary, nitrogen is dynamic and soil testing will continue to be needed to confirm the amount and position of plant available nitrogen in the soil profile.

Acknowledgements

The research undertaken as part of this project (CSA00050, DAQ00192) is made possible by the significant contributions of growers through both trial cooperation and the support of the Grains Research and Development Corporation, the authors would like to thank them for their continued support. We would also specifically like to thank all the farm and field staff contributing to the implementation and management of these experiments, the trial co-operators and host farmers.

A range of crops grown in the different systems at the Billa Billa trial (2016). Barley, field pea and fallow in the foreground; barley and faba beans in the background; and Bambatsi pasture in the far back.

Farming systems: Water dynamics and the impact of crop sequences over time

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Research Question: *How does changing farming systems impact on water use and performance of the system and its individual crops?*

Key findings

1. The water use efficiency of crops is lower when chickpea, wheat or sorghum have less than 80 mm, 100 mm or 120 mm respectively prior to planting. Waiting until soil moisture reaches these levels is critical to maximise conversion of accumulated soil moisture into grain.
2. The previous crop influences the efficiency of fallow water accumulation and the amount of water stored for the next crop. Fallow efficiency following winter cereals is higher than after sorghum, which is in turn higher than after pulses.
3. Long fallows are less efficient than shorter fallows (less than eight months).

Background

Queensland Department of Agriculture and Fisheries, New South Wales Department of Primary Industries and CSIRO are collaborating in an extensive field-based farming systems research program to develop farming systems that can make better use of available rainfall to increase productivity and profitability. Since 2015 experiments have compared farming systems and crop sequences designed to meet the emerging challenges of declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens.

Experiments were established at seven locations; a large factorial experiment at Pampas near Toowoomba, and locally relevant systems are being studied at six regional centres; Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (on both red and & grey soils). A common set of farming system strategies has examined how changes in the farming system impact on a range farming system performance measures.

What was done

Systems with current best commercial practices (*Baseline*) at each location were compared to alternative systems 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. Subsequent management 'rules' around each of these systems have driven the range of different crops and crop sequences planted at each site.

Sites were selected to represent a range of climatic conditions, soil types, nutritional status and paddock histories. Soil sampling was conducted prior to planting each crop and again after harvest to measure soil water and mineral nitrogen to standard depths indicated in Table 1:

Table 1. Sampling depths for soil testing.

Depth (cm)	Measurements	
0-10	Soil water	Nitrate and ammonium nitrogen (N)
10-30		
30-60		
60-90		
90-120		
120-150		

This soil sampling process helped track soil water accumulation in fallows, plant available water (PAW) at planting, and its use by the subsequent crop. Fallow efficiency (FE; Δsoil water/rainfall) and the individual crop's water use efficiency (WUE; grain yield/[Δsoil water + in-crop rainfall]) were then calculated to understand their impact on the underlying farming systems.

Monitoring crop water use, water use efficiency and subsequent fallow water accumulation for over 300 different crops to date has helped explore and understand how soil water accumulates and is used across different crop sequences in each system.

A range of 'system metrics' were then developed to assess each system. For example system water use efficiency of a crop sequence depends on both the efficiency of its 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 both the accumulated soil water and in-crop rainfall into grain or product.

Results

How does cropping intensity impact on plant available water dynamics?

Cropping intensity impacted on the depth of recharge in the soil profile. In two examples at Billa Billa (Figure 1) and Pampas (Figure 2) the *Higher crop intensity* soil profile never refilled as fully as the *Lower crop intensity* and *Baseline* systems. Lower soil moisture levels at planting have major implications for grain yield and WUE (discussed later in this report) and reduce plants' ability to extract nutrients from dry soil deeper in the profile.

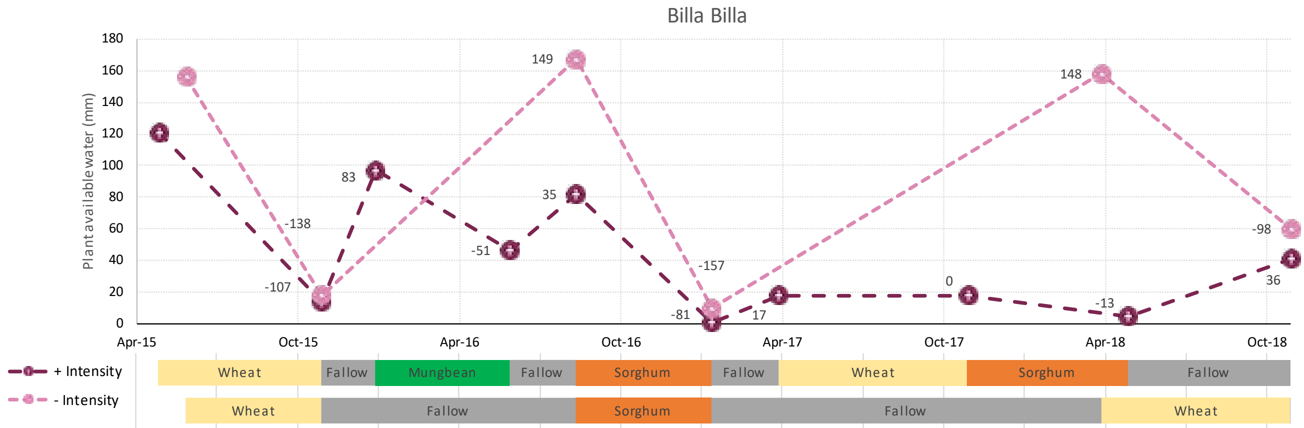

Figure 1. Plant available water (PAW) dynamics in two of the Billa Billa cropping systems.

Plots were often soil sampled up to six weeks prior to planting; crop duration indicated in the chart is from pre-plant soil sample to post-harvest soil sample (not planting to harvest). Numbers show the net change between soil water readings.

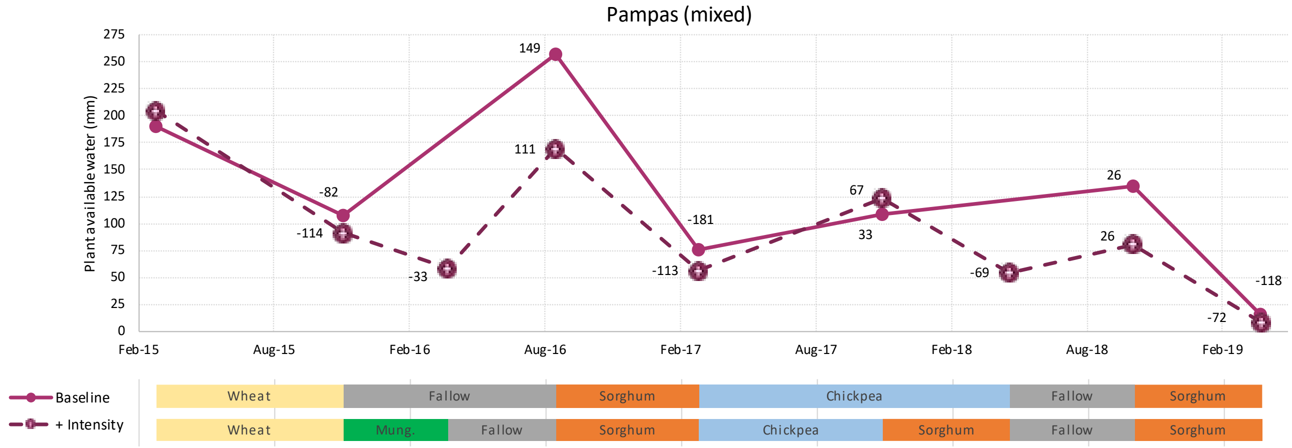

Figure 2. Plant available water (PAW) dynamics in two of the Pampas mixed summer/winter cropping systems.

Plots were often soil sampled up to six weeks prior to planting; crop duration indicated in the chart is from pre-plant soil sample to post-harvest soil sample (not planting to harvest). Numbers show the net change between soil water readings.

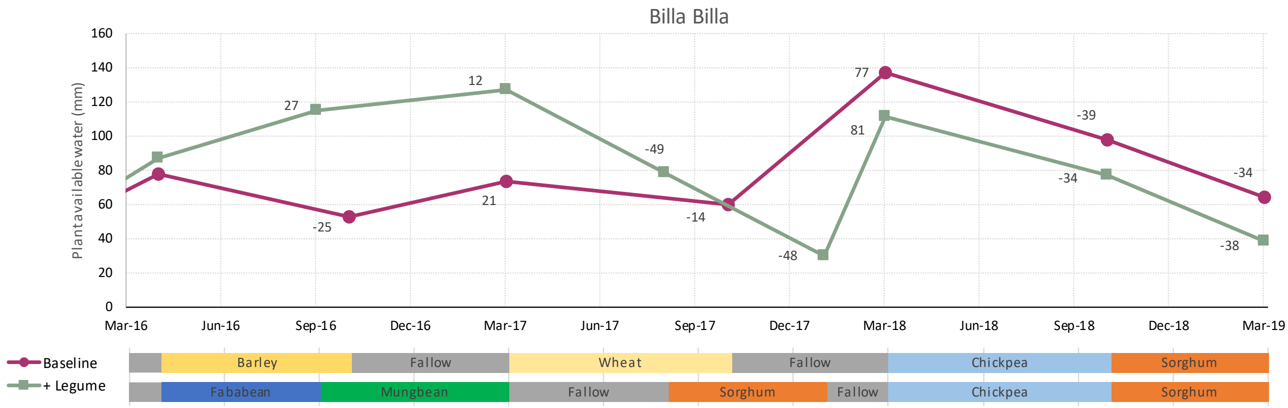

Figure 3. PAW dynamics of two of the Billa Billa cropping systems.

Plots were often soil sampled up to six weeks prior to planting; crop duration indicated in the chart is from pre-plant soil sample to post-harvest soil sample (not planting to harvest). Numbers show the net change between soil water readings.

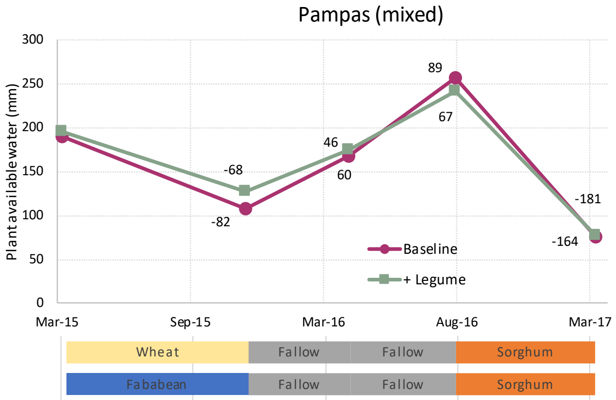

Figure 4. PAW dynamics of two of the Pampas mixed summer/winter cropping systems.

Plots were often soil sampled up to six weeks prior to planting; crop duration indicated in the chart is from pre-plant soil sample to post-harvest soil sample (not planting to harvest). Numbers show the net change between soil water readings.

Inter-row planting of chickpea into wheat stubble at Billa Billa.

How does crop choice impact on plant available water dynamics?

The Billa Billa Belah duplex soil is constrained by sodicity at depth, so pulse crops have been unable to extract all of the soil water below 50 cm in the profile. This deep PAW and rainfall at opportune times has allowed double cropping after pulses; an option that was not available in the systems where cereal crops (or canola) were grown (Figure 3) because they were able to extract this water from sodium-constrained zones. Consequently, the *Higher legume* system had an increased cropping frequency, despite having the same PAW planting triggers as the *Baseline* system. Similarly, the *Lower crop intensity* wheat grown at Billa Billa in 2018 reduced the profile by 98 mm (Figure 1) while chickpeas in the *Baseline* and *Higher legume* systems only reduced the profile by 39 and 34 mm respectively (Figure 3); again allowing a 'double-crop' to sorghum on the next rainfall event.

At Pampas, the difference in PAW extraction was much less stark on the 'less constrained' Black Vertosol. However, the cereal crops still used more water than the pulse; they have different crop lower limits of extraction. For example, when faba bean and wheat were planted in the same season with similar starting PAW (Figure 4), the wheat extracted 14 mm more water than the faba bean (compared to the 53 mm difference on the constrained soil at Billa Billa). After harvest the wheat accumulated an extra 14 mm PAW; the two systems then had the same PAW again when the winter-only systems were planted. In the mixed systems, the fallow was continued to sorghum in October 2016. The wheat stubble continued to provide higher fallow efficiency in this longer fallow, with 12 mm more PAW at planting than the faba bean stubble. The extra PAW was subsequently used by the sorghum crop and the two systems had the same PAW at harvest; they have since maintained the same rotation and similar PAW.

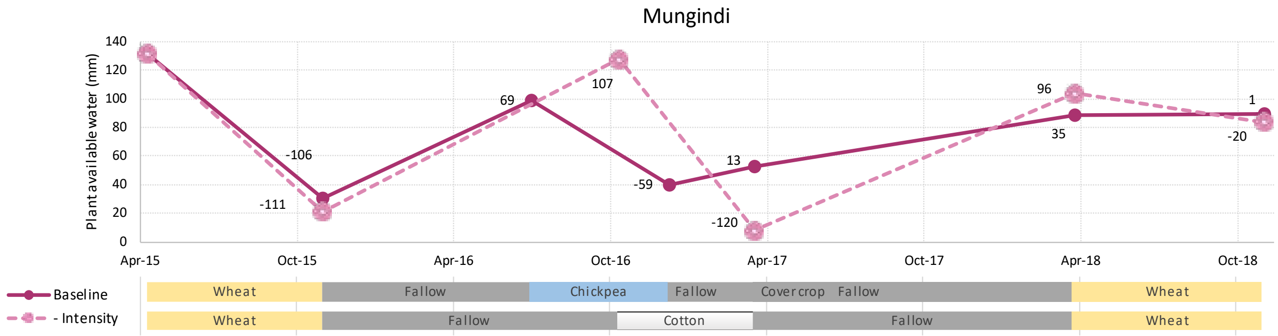

Figure 5. PAW dynamics of two of the Mungindi cropping systems.
Numbers show the net change between soil water readings.

At Mungindi, the *Baseline* and *Lower crop intensity* systems had the 2015 wheat crop in common. However, the *Baseline* was planted to chickpea in 2016, while the *Lower crop intensity* was fallowed to cotton in the spring (Figure 5). A large portion of that season's rain fell in spring, when both the chickpea and cotton crops were both in the ground, but with very little additional rainfall from chickpea harvest to cotton harvest. The cotton in the *Lower crop intensity* system left the soil 32 mm drier than the chickpea at their respective harvests. However, the chickpea ground was 19 mm drier when the cotton was picked and a combination of residual wheat stubble and dry cracked soil post-cotton resulted in the *Lower crop intensity* system having an extra 15 mm PAW when the two systems were planted to wheat in 2018.

Drivers of crop water use efficiency

Available water is a key driver of crop yields in Australia. So, understanding what drives crop water use efficiency (WUE; the kg of grain produced per mm of crop water use) is critical. In northern farming systems the water available to crops comes from stored soil water at planting and in-crop rain. Both must be considered to understand crop water use, especially as unreliable in-crop rain means stored soil moisture may comprise much of the water available to the crop. In contrast, fallow water storage is less critical in southern Australia where in-crop rain alone has often been used to calculate crop WUE.

Data collected from the farming systems experiments show that the 'marginal' WUE (kg/mm from additional crop water use) reached its potential at 24 kg/mm for wheat, 12.5 kg/mm for chickpea and 18 kg/mm for grain sorghum. Despite this potential and good crop management in these experiments, the average across all the crops measured was lower; 15.3 kg/mm for wheat, 8.8 kg/mm for chickpea and 14.3 kg/mm for sorghum (Figure 6, top row). This demonstrates that while WUE is a useful benchmark, there is large season to season variability due to the timing of rainfall events and other stresses that reduce crop yields.

These seasonal differences for in-crop rainfall mean there was no clear relationship between planting soil water and crop yield across this data, but there was an interesting relationship between available soil water at planting for the crop and the 'marginal' WUE that that crop achieved (Figure 6, middle row). The WUE of crops generally increased with the soil water available at planting. Crops of wheat, chickpea and sorghum that had less than 100 mm of plant available water coming into the season, had much less chance of achieving a high crop WUE; crops planted on lower soil moisture are more at risk of depleting the soil profile prior to flowering and grain-fill without significant in-crop rain. The data suggest that chickpea may be less susceptible to this than wheat or sorghum. Chickpea's indeterminate growth habit means it has a lower water requirement prior to the start of grain filling and the grain yield potential builds throughout the season. This makes chickpea yield less susceptible to acute water stress at critical phenological stages than cereals that build biomass and then convert it to grain yield.

Finally, the gap between the marginal WUE of each crop compared to the potential WUE (dashed lines) is greatest in crops with low soil water at planting (Figure 6, bottom row). This non-linear relationship suggests a longer fallow to increase PAW at planting will provide a bigger potential improvement in WUE (and therefore grain yield) when PAW is low at the proposed planting time. Fallow efficiency (FE) is also often higher at low PAW levels as infiltration is greater in drier soils. In contrast,

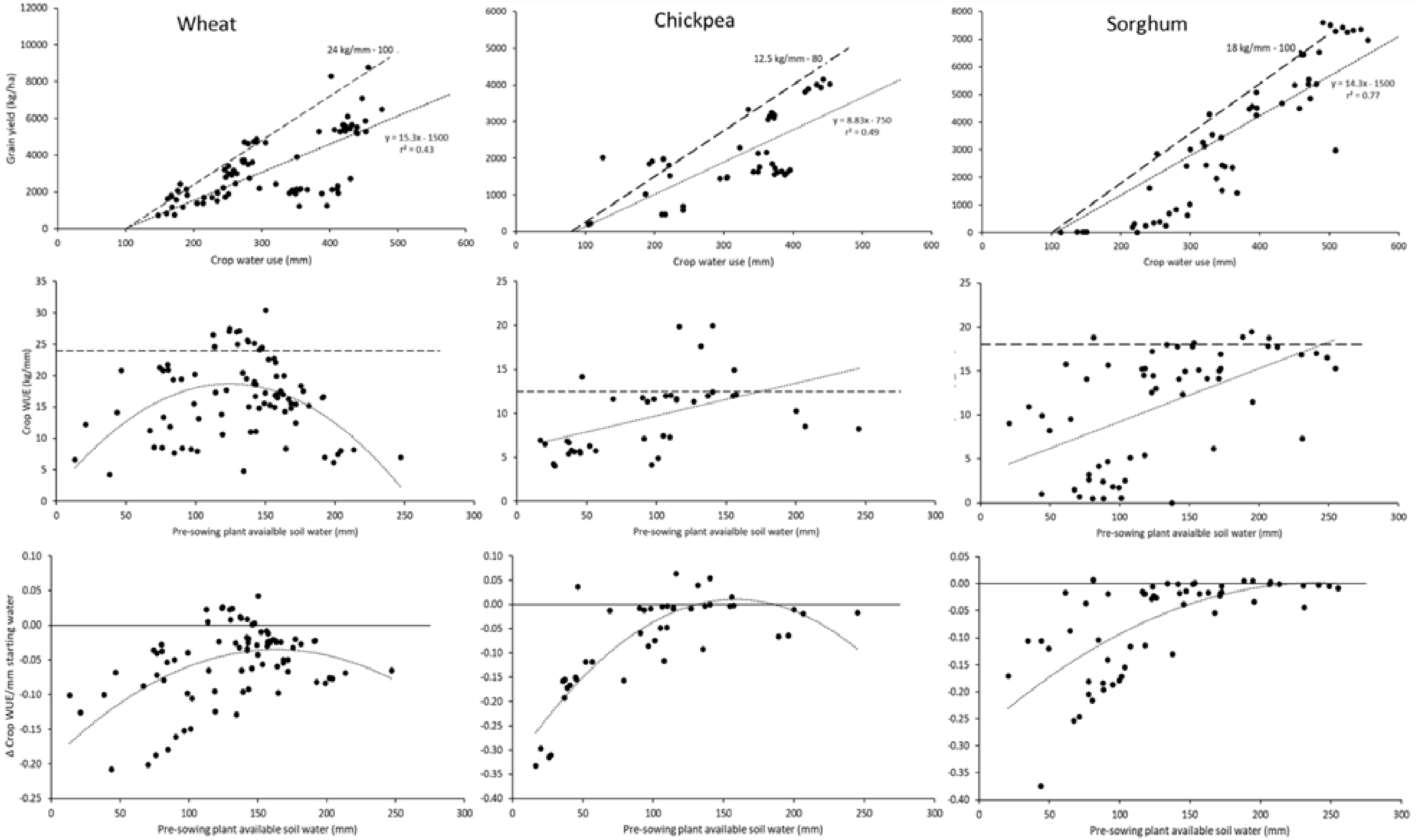

Figure 6. Relationships between water availability and crop yield and water use efficiency (WUE) in wheat, chickpea and grain sorghum collated from data collected across farming systems research sites.

TOP: Crop water use (change in soil water plus rainfall) vs. grain yield, showing the maximum potential (dashed line) and the average across the dataset (dotted line);

MIDDLE: Plant available soil water prior to planting vs. crop WUE (as calculated above); and

BOTTOM: Plant available soil water prior to planting vs. the difference between the measured crop WUE and the potential WUE per mm of additional water available (dashed lines in above figures).

Table 2. Comparison of efficiencies of fallow water accumulation (i.e. change in soil water/fallow rainfall) following different crops (n. = number of crops).

Previous crop	All fallows	n.	Short fallow (<8 months)	n.	Long fallows (> 8 months)	n.
Winter cereals (wheat, durum, barley)	30%	81	34%	54	21%	27
Winter pulses (chickpea, fababean, field pea)	20%	36	25%	20	15%	16
Sorghum	22%	23	28%	7	19%	16
Canola	26%	5	31%	4	6%	1
Cotton	16%	3			16%	3

Data are an average of fallows monitored across the farming systems experiments in northern NSW and southern Qld between 2015 and 2019. Only fallows receiving more than 80 mm of rain are included.

at higher PAW the FE is lower, as is the potential to improve WUE with more stored water.

Crop effects on efficiency of subsequent fallows

Fallow efficiency data following 148 crops was collated to compare how different crop types impact on subsequent fallow efficiencies (Table 2). Fallows with little rain (<80 mm) were removed as this distorts the FE values.

The data shows clear crop effects on subsequent fallow efficiencies; typically related to the ground cover provided and stubble persistence. Winter cereal crops provided the highest fallow efficiencies while the lower cover after winter pulses resulted in lower fallow efficiencies. Based on less data, fallow efficiencies after canola were intermediate between the winter pulses and winter cereals. Sorghum was also intermediate and cotton produced much lower fallow efficiencies in its subsequent long fallows. The data also clearly shows that short-fallows are more efficient than longer fallows. Late in a long fallow, the cover levels will be lower and the soil wetter, so there is less scope for infiltration and more evaporation.

The impacts of particular crops on the accumulation of soil water in the following fallow should be considered in the cropping sequence. For example, a fallow receiving 400 mm of rain after a winter cereal may accumulate 120 mm on average, while the same fallow after a grain legume may only accumulated 80 mm. This difference could impact on planting opportunities and the subsequent yields and gross margins of following crops in the cropping sequence.

Implications for growers

In a northern farming system, grain yield is highly dependent on how much water is stored in the profile during the preceding fallow. The efficiency of this fallow storage is driven by the stubble left by the previous crop and the duration of the fallow period.

Crop type also influences how efficiently crop water use is converted to grain. This research suggests storing more than 80 mm, 100 mm or 120 mm PAW prior to planting chickpea, wheat or sorghum (respectively) increases the likelihood of optimising crop WUE.

Increasing cropping intensity and planting with less stored moisture reduces the potential to recharge deep soils, and may reduce the crop's ability to extract nutrients from dry soil deeper in the profile.

Crop choice can dictate the next planting opportunity through the different residual water levels at harvest and fallow efficiency of the stubble left behind. This opportunity may be quite different in soils with and without soil constraints that can limit the effective depth of a soil and the PAW of individual crops.

Acknowledgements

The research undertaken as part of this project (CSA00050, DAQ00192) is made possible by the significant contributions of growers through both trial cooperation and the support of the Grains Research Development Corporation. Thanks to all the farm and field staff contributing to the implementation and management of these experiments, the trial cooperators and host farmers.

Farming systems: Profitability and impacts of commodity price risk

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RESEARCH QUESTIONS: *Can systems performance be improved by modifying farming systems in the northern grains region? Does commodity price variability affect the economic ranking of these systems?*

Key findings

1. Large gaps in profitability are possible between the best and worst systems: differences of $92-$494/ha/year were found between systems at each site.
2. Intensity is the major factor driving economic performance of the farming system; more so than crop choice. Matching intensity to environmental potential is an important driver to maximise farming system profitability.
3. Systems growing crops with higher price variability (e.g. pulses, cotton) had limited downside risk but increased upside opportunities of higher economic returns.
4. The relative profitability ranking of systems rarely changed when analyses used recent or long-term grain prices. Maximising farming system productivity and resilience is more important than responding to current commodity prices.

Background

Leading farmers in the Australian northern grains region (NGR) perform well in terms of achieving the yield potential of individual crops. However, the performance of the overall system is harder to measure and less frequently well considered. Key factors occurring across the crop sequence include poor weed management, disease and pest losses, sub-optimal fallow management, and cropping frequency.

Research was initiated in 2015 to identify the key limitations, consequences and economic drivers of farming systems in the NGR. The aim was to assess the impacts of modifying farming systems on multiple attributes, such as nutrients, water, pathogens, soil health, and economics, across multiple sites. Experiments were established at seven locations: the core experimental site at Pampas near Toowoomba and six regional centres across Queensland (Emerald, Billa Billa, Mungindi) and northern NSW (Spring Ridge, Narrabri, and Trangie). Sites were selected to represent a range of climatic conditions, soil types, nutritional status, and paddock history.

What was done

Systems with current best-commercial practices (*Baseline*) at each location were compared to alternative systems: *Higher crop intensity*, *Lower crop intensity*, *Higher crop diversity*, *Higher legume*, and *Higher nutrient supply*. Additional systems were investigated at some sites; *Higher soil fertility* and *Integrated Weed Management* (IWM). At Pampas these systems were implemented in a factorial format across summer-dominant, winter-dominant and mixed opportunity cropping systems. This report examines the economic performance of different system modifications in combination with commodity price risk, to help quantify the costs or benefits of different long-term cropping strategies.

The key metric of 'total gross margin' was used to compare profitability between systems and across environments over the experimental period, i.e. 4.5 years, April 2015 to November 2019. These gross margins (GM) are the income minus variable costs and do not include fixed costs, which may vary across different farms, regions and possibly farming systems.

Collected data included crop grain yields (corrected to 12% moisture), machinery operations, and inputs of fertilisers, seed and pesticides for each cropping sequence. Farm-gate commodity prices were based on 10-year median port price for the period 2008-2017 adjusted for inflation, transportation, grading and bagging (Table 1). The same commodity and input prices were used to calculate the accumulated income (sum of grain yield x price for all crops in the sequence) and GM for each of the cropping systems at each location to help identify agronomic differences across trials (Table 2, Table 3).

The effect of commodity price variability on the relative profitability of different systems was also analysed. Gross margins for each farming system were calculated using the range of different prices received for each commodity over the last 10 years, which provided a distribution of possible economic returns based on these different price assumptions. This was then compared with the 10-year median prices and the prices received in the last 3 years (2016-2018).

Table 1. Market commodity prices and farm gate prices used for calculating system gross margins for each crop.

	Port prices ($/t) 10-yr median	Farm-gate prices† ($/t)	
		10-yr median	2016-18 average
Barley	258	218	214
Wheat (APH)	309	269	247
Wheat (Durum)	339	299	277
Canola	543	503	478
Chickpea	544	504	791
Faba bean	422	382	379
Field pea	375	335	324
Sorghum	261	221	215
Maize	321	281	285
Mungbean	950	667	869
Sunflower	749	709	865
Cotton (Lint + seed – 40% turnout)	1267	1090	1066

† Farm gate prices were adjusted to allow for transport, grading or bagging costs or losses.

Results

System modification effects on profitability

Total income and gross margins varied substantially across all sites due to differences in rainfall, site fertility and production input costs (Table 2, Table 3). For this reason, it was best to compare the economic outcomes of systems at the same site.

The gap between the 'best' and the 'worst' cropping-system performance ranged from $92-494/ha/year across the different sites (Table 2, Table 3). The difference between the highest and lowest grossing system in $/ha/yr over the 4.5 experimental years was $410 at Billa Billa, $360 at Emerald, $270 at Mungindi, $300 at Narrabri, $180 at Spring Ridge, $170 at Trangie on red soil and $230 on Trangie grey soil. At Pampas, it was $290 for the mixed, $330 for summer-dominant, and $490 for winter-dominant cropping systems. At several sites the *Baseline* system performed the best or as well as any altered system. Across all comparisons, the cropping intensity systems produced the lowest GMs. This means it is important to match cropping intensity to your environment for optimal system performance.

The economic impact of the different farming systems strategies compared to the *Baseline* at each site was assessed by calculating the system total GM ($/ha; Figure 1) and the return on variable costs ratio (ROVC; Figure 2) as a proportion of that achieved by the *Baseline*. Hence, the *Baseline* value is 1.0, and systems achieving say 0.8 have a 20% lower economic value whereas achieving 1.2 is 20% higher than the *Baseline*. Across the sites there were both variable and consistent results in terms of the relative economic performance of the farming systems.

The *Higher nutrient supply* strategy budgeted nitrogen fertiliser for 90% crop yield potential, compared to median yield potential in the *Baseline*. This increased the cost of fertiliser inputs by $18-$136 /ha/yr (Table 2, Table 3). However, only two crops had a yield increase from the higher fertiliser application, hence a lower total GM was achieved in 8 of 10 comparisons (Figure 1). Emerald and Trangie (Red soil) had an increase in yield from the additional nutrient supply, so they were the only locations where system GM in *Higher nutrient supply* was higher than the *Baseline*.

Table 2. Economic indicators* for the treatments at each regional centre.

Site	System	Total income ($/ha)	Total costs ($/ha)	Total GM ($/ha)	Gap from best ($/ha/yr)	ROVC	Max. cash outlay ($/ha)
Billa Billa	*Baseline*	**3901**	**839**	**3062**	**0**	**4.7**	**-317**
	Higher nutrient supply	3872	1055	2817	-54	3.7	-326
	Higher soil fertility	3590	1003	2587	-106	3.6	-321
	Higher legume	3597	1017	2581	-107	3.5	-306
	Higher crop diversity	3010	923	2087	-217	3.3	-352
	Higher crop intensity	2360	1144	1217	-410	2.1	-513
	Lower crop intensity	2305	852	1453	-358	2.7	-341
Emerald	*Baseline*	**3787**	**1492**	**2295**	**-118**	**2.5**	**-417**
	Higher nutrient supply	4090	1534	2556	-60	2.7	-422
	Higher soil fertility	4352	1528	2824	0	2.8	-417
	Higher legume	4115	1512	2603	-49	2.7	-395
	Higher crop intensity	2913	1706	1207	-359	1.7	-395
	IWM	4031	1972	2059	-170	2.0	-532
Mungindi	*Baseline*	**1590**	**643**	**947**	**0**	**2.5**	**-290**
	Higher nutrient supply	1504	909	595	-78	1.7	-313
	Higher legume	1495	727	768	-40	2.1	-290
	Higher crop diversity	669	537	132	-181	1.2	-351
	Lower crop intensity (cotton)	1297	752	545	-89	1.7	-297
	Lower crop intensity (grain)	375	638	-263	-269	0.6	-310
Narrabri	*Baseline*	**2569**	**1023**	**1546**	**0**	**2.5**	**-354**
	Higher nutrient supply	2265	1329	936	-136	1.7	-486
	Higher legume	2049	928	1121	-94	2.2	-354
	Higher crop diversity	1439	1227	212	-296	1.2	-633
	Higher crop intensity	2687	1177	1510	-8	2.3	-507
	Lower crop intensity	1707	797	910	-141	2.1	-451
Spring Ridge	*Baseline*	**3294**	**2166**	**1128**	**-60**	**1.5**	**-593**
	Higher nutrient	3363	2730	633	-170	1.2	-974
	Higher legume	3403	2006	1398	0	1.7	-712
	Higher crop diversity	2992	2160	832	-126	1.4	-593
	Higher crop intensity	2563	1960	604	-176	1.3	-731
	Lower crop intensity	2525	1480	1045	-78	1.7	-827
Trangie (Red)	*Baseline*	**1845**	**1021**	**824**	**-16**	**1.8**	**-324**
	Higher nutrient supply	2337	1444	894	0	1.6	-426
	Higher legume	1853	1049	804	-20	1.8	-363
	Higher crop diversity	1431	1049	382	-114	1.4	-363
	Lower crop intensity	1605	737	868	-6	2.2	-442
Trangie (Grey)	*Baseline*	**1217**	**713**	**504**	**0**	**1.7**	**-251**
	Higher nutrient supply	963	873	91	-92	1.1	-380
	Higher legume	1119	821	299	-46	1.4	-302
	Higher crop diversity	953	816	137	-82	1.2	-302
	Lower crop intensity	761	567	195	-69	1.3	-289

*** Figures provided include total revenue generated, costs of production (fertilisers, seed, operations, chemicals), gross margins (GM), the average annual gap bewteen the highest and lowest GM per site, returns on variable costs (ROVC, ratio of income to costs), and the maximum cash outlay calculated using 4.5 years of experimental data.**

The ROVC ratios were 20-30% lower than the *Baseline* system at all sites except Emerald (Figure 2). At Mungindi the additional nutrient reduced grain yield in one year and added significant costs to this system. With better seasonal conditions it might be expected to realise the benefits of the high nutrient strategy, but this potential has not be realised with below-average rainfall over the years experienced so far.

The *Higher legume* frequency strategy grew at least 50% of crops as legumes. This increased the variable costs of production in most cases, mainly due to higher pesticide costs. Treatments at Emerald and Spring Ridge had higher GMs ($60-68/ha/yr) than the *Baseline* systems, but their higher costs resulted in lower return on variable costs (ROVC) (Table 2, Table 3, Figure 2). Increasing legume frequency achieved 20-40% lower total GMs than the *Baseline* at Billa Billa, Mungindi, Narrabri, and Trangie grey-soil (Figure 1). At all other sites, GMs were similar to the *Baseline* system.

The *Higher crop diversity* strategy aims to manage soil-borne diseases and diversify herbicide use through crop rotation. No more than 50% of crops grown are susceptible to root lesion nematodes (*Pratylenchus thornei*) and each crop must be followed by two alternatives before it can be grown again to reduce the risk of herbicide resistance. This strategy did not significantly alter the costs of production in most cases, though there were some notable site differences (Table 2, Table 3). Across the regional sites, total GMs were 20-80% ($66-296/ha/yr) lower than the *Baseline* system (Figure 1).

Table 3. Economic indicators* for the treatments at the core experimental site at Pampas.

	System modification	Total income ($/ha)	Total costs ($/ha)	Total GM ($/ha)	Gap from best ($/ha/yr)	ROVC	Max. cash outlay ($/ha)
Mixed opportunity	*Baseline*	**4409**	**885**	**3524**	**-31**	**5.0**	**-326**
	Higher nutrient supply	4623	1223	3400	-58	3.8	-418
	Higher legume	4678	1032	3647	-3	4.5	-358
	Higher crop diversity	4665	1003	3662	0	4.7	-314
	Crop div. + nutrient	4371	1394	2977	-152	3.1	-491
	Higher leg. + diversity	4398	978	3420	-54	4.5	-346
	Lower crop intensity	3382	1002	2380	-285	3.4	-632
Higher intensity	*Baseline*	**4266**	**1218**	**3049**	**-9**	**3.5**	**-308**
	Higher nutrient supply	4358	1608	2750	-75	2.7	-358
	Higher legume	4105	1332	2773	-70	3.1	-334
	Higher crop diversity	4085	1081	3004	-19	3.8	-296
	Crop div. + nutrient	3977	1665	2312	-172	2.4	-471
	Higher leg. + diversity	4222	1134	3088	0	3.7	-328
Summer	*Baseline*	**3196**	**724**	**2472**	**-261**	**4.4**	**-382**
	Higher nutrient supply	3329	938	2392	-278	3.6	-426
	Higher legume	3073	921	2152	-332	3.3	-441
	Higher crop diversity	4170	906	3264	-85	4.6	-578
	Crop div. + nutrient	4197	1227	2970	-150	3.4	-650
	Higher leg. + diversity	4206	1048	3158	-108	4.0	-593
	Lower crop intensity	4351	705	3645	0	6.2	-317
Winter	*Baseline*	**3775**	**863**	**2913**	**-219**	**4.4**	**-445**
	Higher nutrient supply	3570	1064	2506	-310	3.4	-479
	Higher legume	4323	815	3508	-87	5.3	-237
	Higher crop diversity	4598	698	3900	0	6.6	-237
	Crop div. + nutrient	4252	1162	3090	-180	3.7	-430
	Higher leg. + diversity	4420	739	3680	-49	6.0	-220
	Lower crop intensity	2444	767	1678	-494	3.2	-441

*** Figures provided include total revenue generated, costs of production (fertilisers, seed, operations, chemicals), gross margins (GM), the average annual gap bewteen the highest and lowest GM per site, returns on variable costs (ROVC, ratio of income to costs), and the maximum cash outlay calculated using 4.5 years of experimental data.**

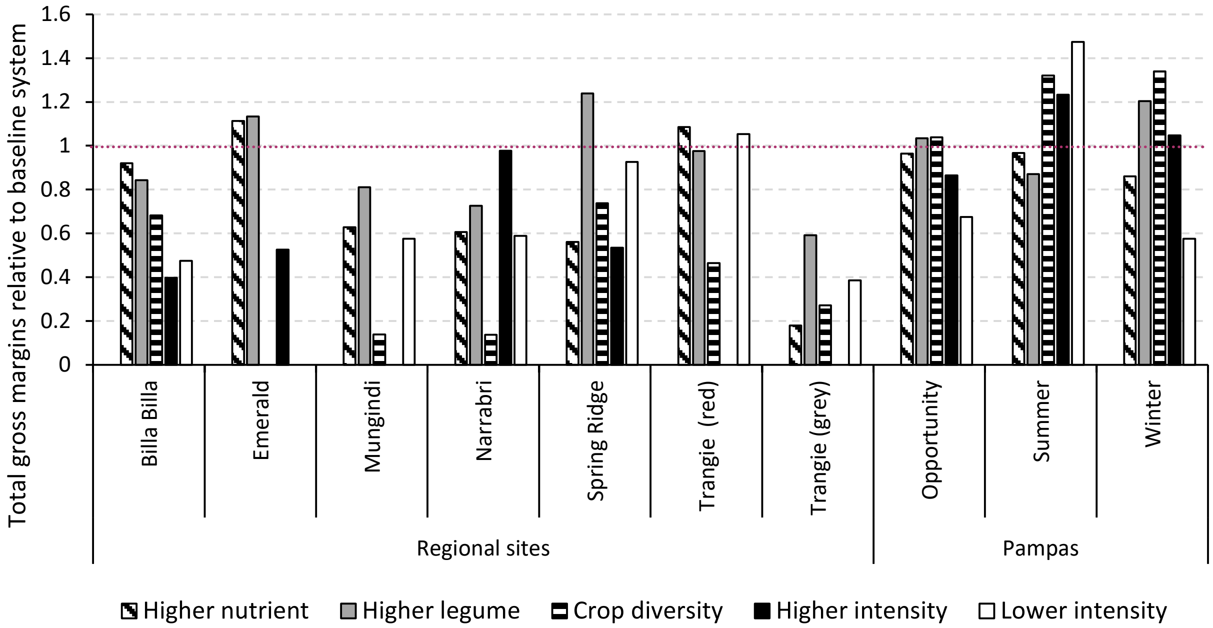

Figure 1. Relative total gross margin of different farming systems as a ratio of the *Baseline* system (i.e. 1 equals the *Baseline*, higher is better and lower is worse) at seven regional sites and under three different seasonal crops at the core site (Pampas).

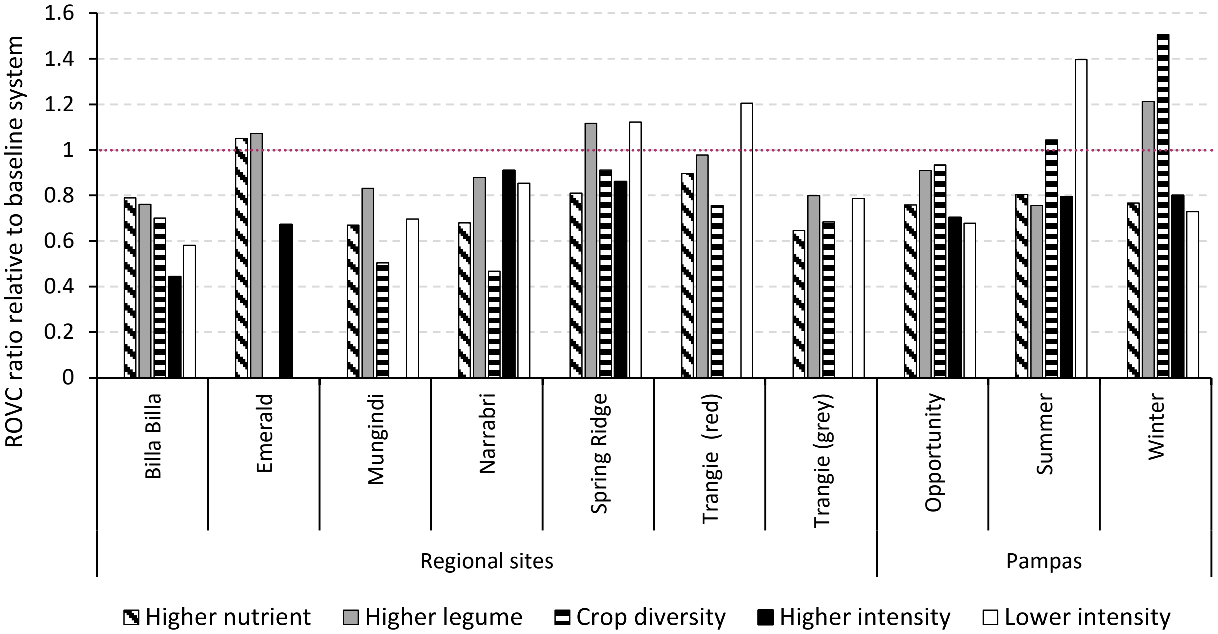

Figure 2. Relative the return on variable costs (ROVC) of different farming systems as a ratio of the *Baseline* system (i.e. 1 equals the *Baseline*, higher is better and lower is worse) at seven regional sites and under three different seasonal crops at the core site (Pampas).

On the other hand, diversifying the cropping system at Pampas has consistently exceeded the *Baseline* crop sequence total GM by 32% ($31-219/ha/yr). It is worth noting that while this system strategy aimed to managed disease and weed threats, few sites had significant disease loads for rotational benefits to be clearly observed.

The *Higher crop intensity* systems sowed crops on a 30% full soil profile to increase the proportion of rainfall transpired and carbon inputs into the system. This did not increase total crop income at any of the sites and typically brought about an increase planting and harvesting in costs, so the GMs were generally lower and the ROVC was dramatically lower than the *Baseline* system (Figure 1, Figure 2).

This highlights the risks associated with relying on in-crop rainfall in the NGR. These systems were working harder but not smarter than a more conservative cropping system. The *Higher crop intensity* systems were up to $410/ha behind the *Baseline* system at Billa Billa (Table 2). Even at the higher rainfall sites (Pampas, Spring Ridge, and Emerald), the GMs were below the *Baseline* system (Figure 1).

The *Lower crop intensity* systems waited until the soil profile was near full before sowing crops and seeking higher value crops. This generally incurred lower costs, but was not universal across all sites; 5 of the 8 *Lower crop intensity* systems had lower costs than the *Baseline*. This strategy achieved 40-70% lower total GM than the *Baseline* system over the 4.5 years at most locations (Figure 1). However, the system did result in 47% higher GM and 40% higher ROVC ratio in the summer-dominant system at Pampas compared to the *Baseline* system. The Spring Ridge and Trangie red-soil GM were similar to the *Baseline* system; however, the ROVC ratios were better than the *Baseline* system.

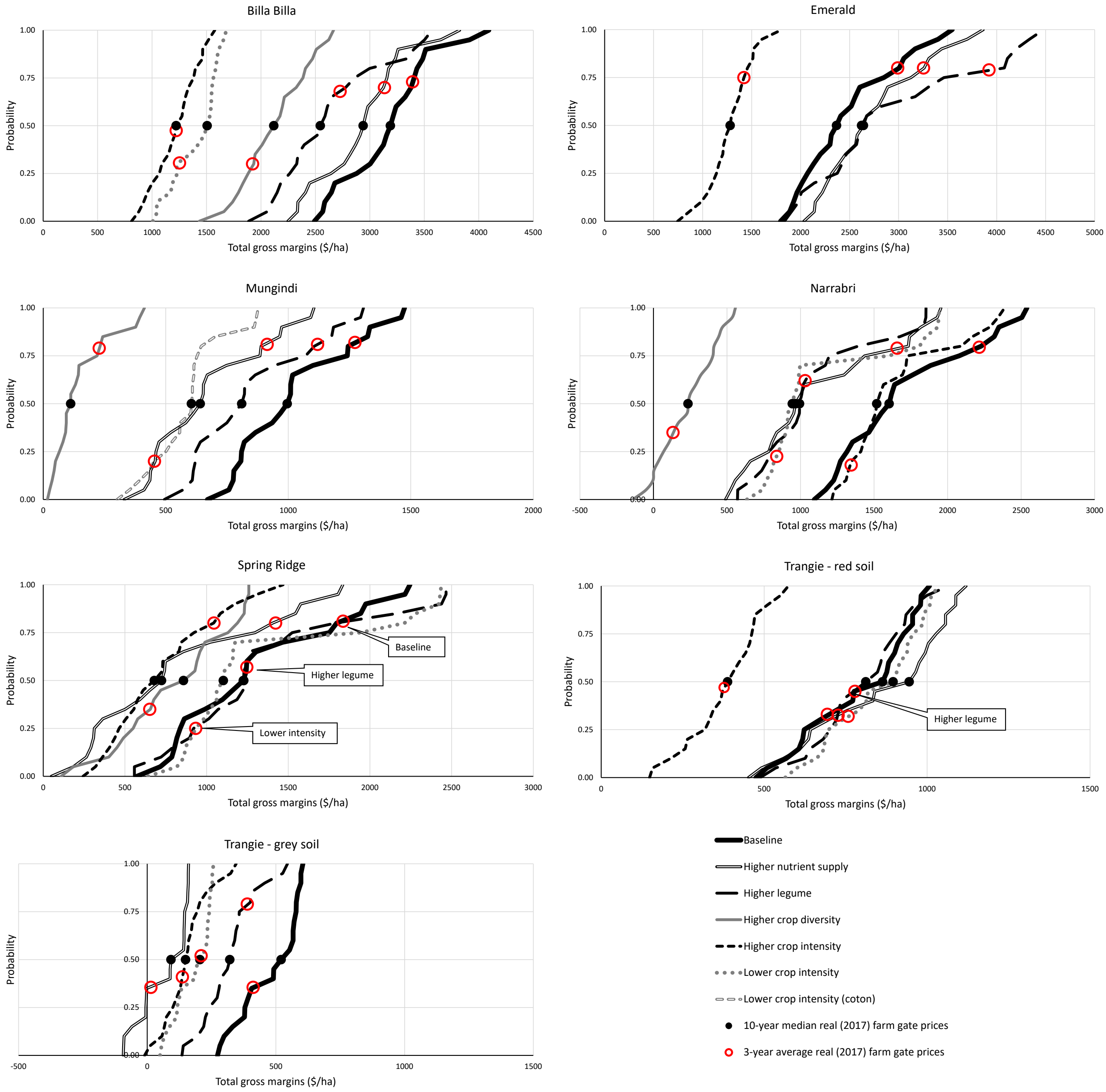

Figure 3. The distribution of total gross margins (GM) of systems at the seven regional farming systems sites, calculated using the range of commodity prices from the last 10 years.

The total GM with the lowest set of grain prices are shown where P=0 and the highest combination of grain prices is shown where P=1.

Impact of commodity price variability on system profitability

Calculations in the previous section used the 10-year median commodity prices for each crop grown. However, we know that prices can vary greatly from year-to-year and introduce variability in the economic outcomes. Therefore, the possible range of total GMs for each cropping system and location were also calculated using different combinations of crop grain prices (Figure 3, Figure 4). Sorghum, wheat, and maize had lower prices and price variance (the difference between the lowest and highest farm-gate price divided by the median price of each commodity) over the ten years; 26-40%. The chickpea, mungbean, sunflower and cotton had higher price variance (61-94%). So, how would the economic outcomes change if recent prices were used during the experimental period, and would this change the economic ranking of cropping systems?

At Billa Billa, the *Baseline* system's total GM was \$3062/ha (Figure 3, black dots) using the 10-year median commodity price. However, the total GM could be as low as \$2490/ha when all commodity prices of that system are low, and as high as \$4092/ha when all commodity prices are high. Based on the last 3-year average price, the total GM of this *Baseline* system at Billa Billa would have increased by 11% to \$3393/ha (Figure 3, red circles). Overall, there was a 73% chance of getting lower GM; and 27% chance of higher GM based on historical commodity prices. This system included wheat, barley and chickpea crops and was affected more by the higher chickpea price than the lower price received from the wheat and barley over this period.

The greatest difference in the total GM (\$/ha) between the 10-year median and the 3-year average commodity prices over the 4.5 experimental years varied with each site; \$331 at Billa Billa, \$1319 at Emerald, \$352 at Mungindi, \$721 at Narrabri, \$790 at Spring Ridge, -\$5 at Trangie (Red soil) and \$90 at Trangie (Grey soil) (Figure 3). At Pampas, it was \$314 for the mixed opportunity cropping systems, \$1024 for higher crop intensity systems, \$282 summer-dominant systems, and \$838 for winter-dominant systems (Figure 4).

Importantly, changing commodity prices did not change the ranking of many systems across the sites. For example at Billa Billa, the best performing cropping system was consistent using both the 10-year median and the 3-year average commodity prices; *Baseline* > *Higher nutrient supply* >*Higher legume* > *Higher crop diversity* > *Lower crop intensity* and *Higher crop intensity* (Figure 3, Figure 4).

When the ranking of systems did change at some sites, there was little economic gain. Naturally, the systems involving higher frequencies of chickpea or mungbean in the rotation (e.g. *Higher legume* frequency systems) benefited more using the recent higher prices than the long-term median.

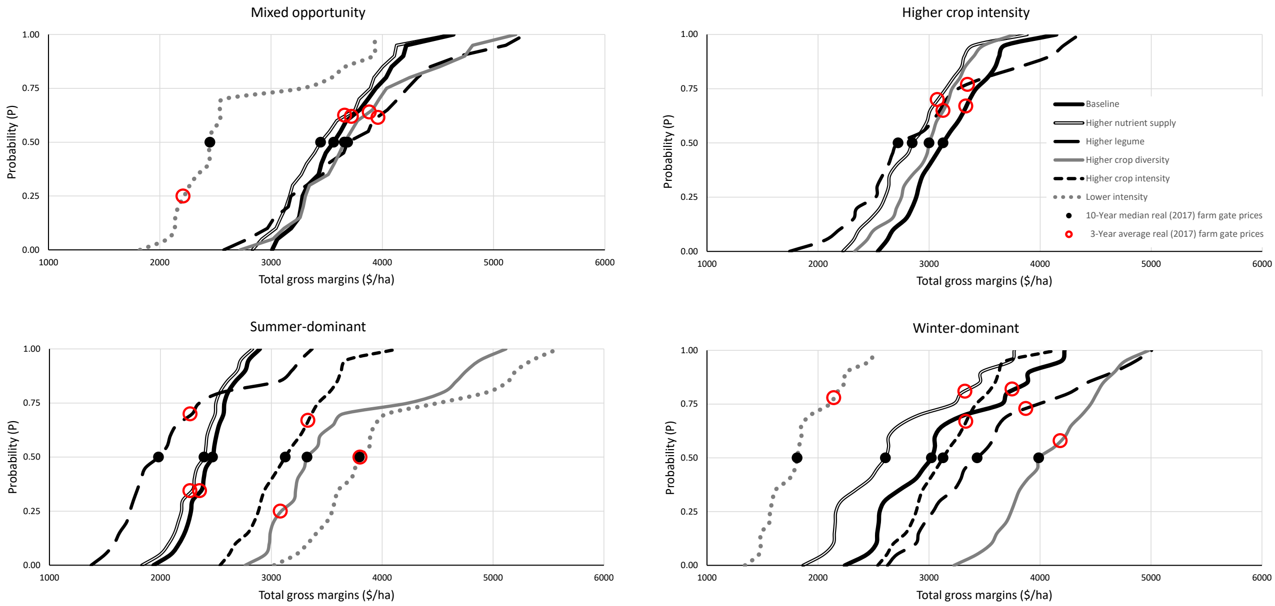

Figure 4. The distribution of total gross margins (GM) for each farming system at the core site (Pampas), calculated using the range of commodity prices from the last 10 years.

The total GM with the lowest set of grain prices are shown where P=0 and the highest combination of grain prices at P=1.

Implications for growers

This research provides a greater understanding of the combined impacts of production and commodity-price risk on the profitability of different systems within the northern grains region. System selection resulted in large profitability gaps, with differences of $92-$494/ha/yr found between the best and worst system at each site.

Cropping intensity is a major economic driver of system performance. Increasing and decreasing intensity relative to the *Baseline* system resulted in lower GMs at most sites, due to increased machinery input costs in *Higher crop intensity* or the loss of income from fewer crops and missed opportunities in *Lower crop intensity* systems. Nonetheless, this data demonstrates that matching planting decision to environmental potential is an important driver in maximising system profitability.

The analysis also shows that including more crop diversity into a rotation can help reduce commodity price risk and may increase GM when prices are high for higher-value crops, like chickpea, mungbean and cotton. The most significant outcome was that the ranking of systems based on total GM rarely changed when using either the 10-year median commodity price or the average price over the last 3 years (2015 to 2017). Therefore, maximising long-term farming system productivity and resilience is more important than responding to current commodity prices.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial host farmers and the support of the Grains Research and Development Corporation, Department of Agriculture and Fisheries, New South Wales Department of Primary Industries and CSIRO (CSA00050, DAQ00192).

Cover crops: Soil water was not reduced on a long fallow during a drought—Yagaburne

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

Research Questions: *Can summer cover crops increase the net water accumulation in dryland systems with low ground cover (<30%) in the northern region?*

- *What is the net water cost to grow summer cover crops?*
- *What is the net water gain to subsequent grain crops (fallow and early growth periods)?*
- *What is the impact on the yield of the grain crops?*

Key findings

1. Cover crops continue to provide soil and water security in the Goondiwindi district with little if any downside risk of losing stored moisture across long fallows.
2. The net water deficit of both mid-terminated summer and winter cover crops was approximately 40 mm; in-line with all past experiments in this project.
3. Despite a record dry season, all cover crop treatments recovered to within +/- 10 mm plant available water by the end of the fallow.
4. Ground cover from the cover crops created a planting opportunity in 2019 that was not available where cover crops were not used; a valuable opportunity in most seasons.

Background

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

Grains Research and Development Corporation (GRDC) funded farming systems projects (DAQ00192/CSA00050) are assessing ways to improve this system water use, and to achieve 80% of the water and nitrogen limited yield potential in our cropping systems. GRDC's Eastern Farming Systems project and Northern Growers Alliance trials both suggested that cover crops and increased stubble loads can reduce evaporation, increase infiltration and provide net gains in plant available water (PAW) over traditional fallow periods. Consequently, cover crops may be a key part of improved farming systems; providing increased productivity, enhanced profitability and better sustainability.

The project has previously demonstrated at Bungunya that it is possible to recoup PAW used by a cover crop in a long fallow between sorghum and wheat, and even increase total water storage in some treatments. Reported in *Queensland grains research 2018-19*, the trial subsequently established a more even wheat population after cover crops, extracted more water at harvest, and increased wheat grain yield by 30%.

Scientific rationale

Stubble and evaporation

Retained stubble provides ground cover, protects the soil from rainfall impacts and so improves infiltration to store more water in the soil. Conventional wisdom is that increased stubble loads can slow down the initial rate of evaporation, but that these gains are short-lived and lost from accumulated evaporation after about three weeks. However, further rain within this period, and the manipulation of stubble to concentrate stubble loads in specific areas, provide an opportunity to reduce total evaporation and to accumulate more plant available water (Photo 1).

Photo 1. The stubble effect visible three days after ~30 mm of rain. The theory is that stubble reduces evaporation and keeps the soil surface wetter for ~21 days, so if more rain falls within that time, more water will be stored.

Dryland grain systems

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

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

What was done

The Yagaburne experiment was in a long-fallow zero-till paddock following skip-row sorghum. The sorghum harvest was in early February 2018 and the paddock was left with standing sorghum rows and some wheat stubble in the interrow.

The site was on a poplar box soil that is prone to setting hard in the absence of good ground cover.

There were two times of planting for cover crops and five replications. Winter cover crops were planted on 18 July 2018 with ~70 mm of PAW, with five different cover crop treatments and an undisturbed control (Photo 2).

Photo 2. Residual stubble at emergence of the winter cover crop (and undisturbed on the right).

A further six spring cover crop treatments were planted on 9 October 2018 with ~90 mm PAW. The rest of the paddock was sown to a White French millet cover crop by the cooperator. Cover crop treatments are provided in Table 1.

There were three planned termination times matching key growth stages: Early-termination (sprayout) at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production. All cover crops were terminated to their growth stage. All treatments were monitored for ground cover, dry matter production and soil water until the subsequent grain wheat crop was planted in May 2019.

Soil water was estimated using soil cores to measure gravimetric soil water at key times across the fallow and the subsequent wheat, along with regular neutron moisture meters (NMM) and EM38 readings in each plot.

Table 1. Cover treatments applied at the Yagaburne site prior to planting wheat, biomass* at termination of each cover crop and percentage ground cover at the last termination date and at the end of the fallow period.

Trt#	Cover crop	Planting rate (plants/m² targeted)	Termination (sprayout)	Biomass grown (kg/ha)	Ground cover %	
					5/12/19	2/05/19
1.	Bare (control)			0	8	8
2.	Wheat	100	Early	86	12	11
3.	Wheat	100	Mid	410	26	24
4.	Wheat	100	Late	697	45	42
5.	Wheat	100	Late + roll	718	50	45
6.	Winter multi-species (wheat, vetch, radish)	50, 30, 20	Mid	538	38	31
7.	Millet	100	Early	527	62	37
8.	Millet	100	Mid	1412	89	80
9.	Millet	100	Late	2043	94	87
10.	Millet	100	Late + roll	1945	97	84
11.	Sorghum (sudan hybrid)	65	Mid	2551	96	93
12.	Summer multi-species (millet, lablab, radish)	50, 30, 20	Mid	1117	65	46

*** (does not include the 1700 kg/ha of residual stubble, centred mostly on the sorghum row, in all treatments including the 'bare control')**

These NMM and EM38 readings and the percentage ground cover were recorded every 2–4 weeks while the cover crops were growing, and every four weeks in the fallow once all cover crops were terminated. These soil water measurements continued every four weeks in the growing crop and a final soil water measure at harvest.

The subsequent wheat crop was planted on 27 May 2019 and harvested in October 2019. With no planting opportunity and no rain predicted, the site was dry planted using the grower's single disc planter (33⅓ cm row spacing) and ~8 mm trickle irrigation applied for crop establishment. While several of the cover crop plots retained better surface moisture and could have been planted earlier in the season, the treatments with little cover could not. So, planting was held off for rain then resorted to irrigation at the end of May to ensure any underlying treatment impacts on the grain yield of the wheat crop could be compared.

Results

Biomass and ground cover

The late planting date of the winter cover crops and the relatively dry conditions restricted dry matter production (biomass) and ground cover. The Early-terminated wheat grew only 86 kg/ha of biomass before termination and did not provide useful levels of cover (Table 1), whereas past trials had early termination biomass levels in cereal cover crop of over 1000 kg/ha and ground cover levels over 50%; equal to the best cover levels from the winter cover cops in this experiment at Yagaburne.

The summer cover crop fared much better. While still relatively low, the millet treatments produced ~500, 1400 and 2000 kg/ha for Early, Mid and Late-termination respectively (Table 1). The Mid-terminated sorghum cover crop was sprayed out on the same day as the Late-terminated millet, used the same water and grew similar biomass.

Soil water

The mid-terminated wheat cover crop had 36 mm less PAW at termination than planting for 400 kg/ha biomass (Figure 1, Figure 2). With 50 mm rainfall in October, the late-terminated wheat was 5 mm drier than at planting with 700 kg/ha of resilient straw. Critically, all winter cover crops had recovered to similar PAW as the control when the summer cover crops were planted.

With an extra 90 days and 75 mm rain in fallow, the summer cover crop had 26 mm more PAW in the soil than when the winter cover crop was planted. The Early, Mid and Late-terminated millet cover crops were 25 mm, 46 mm and 80 mm drier at termination than when they were planted (Figure 1, Figure 2; the balance of water used by the cover crop and the water captured and stored from rainfall).

The subsequent wheat crop

With the dry autumn of 2019, the paddock was assessed on 14 May for the potential to plant wheat across the trial. At ten days after 8 mm rain and 45 days since the last significant rainfall, the conclusion was that only the plots with the highest levels of cover (those above 40%) had enough surface moisture to allow an even establishment of wheat; soil moisture across the plots clearly reflected their cover levels. The four treatments with the best cover (Treatments 8-11; Table 1) had good moisture for planting; three treatments were too dry (Treatments 1-3; Table 1), and the other five treatments were marginal.

With no rain received by the end of May and no forecast rain, it was decided to dry plant and apply trickle irrigation to the seed row for crop establishment.

When the wheat 'cash crop' was planted, the bare control treatment had approximately the same PAW that it had 11 months earlier at the start of the fallow; it was a dry season but there was no net water storage after 240 mm of rain (average annual rainfall for the area is 580 mm). Previous trials have shown variability in sampling of +/- 10 mm, so there was no real difference in PAW at this time with the best cover crop treatments having only 10 mm more and the worst 10 mm less PAW than the control.

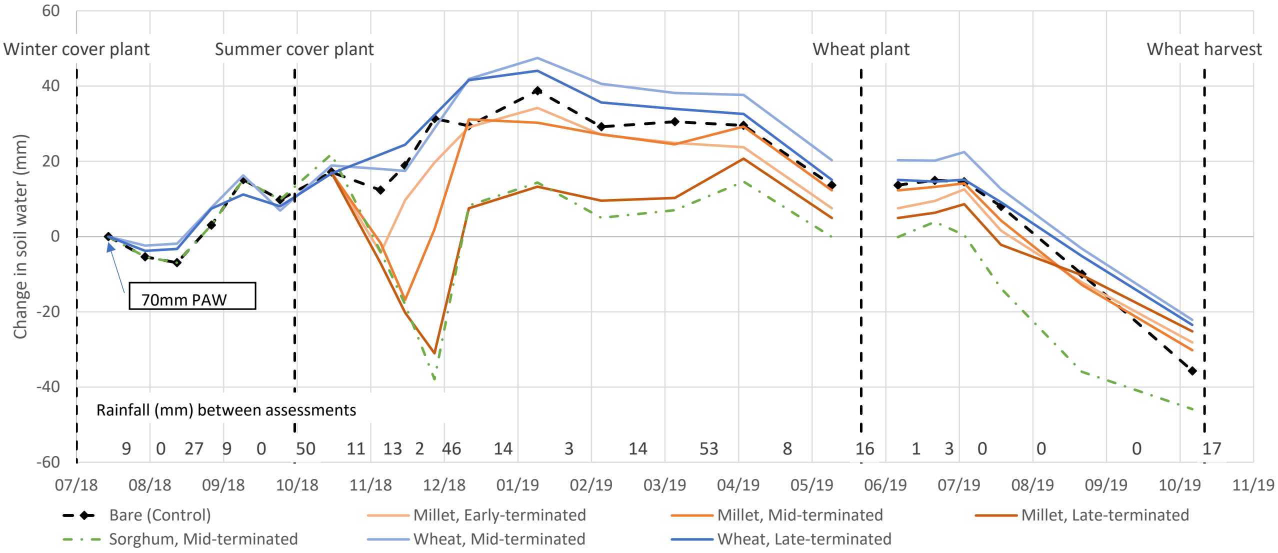

Figure 1. Change in plant available water for a range of cover crops, measured with a neutron moisture meter to 150 cm depth. Grids represent each month and numbers in the bottom row are mm rainfall for that month.

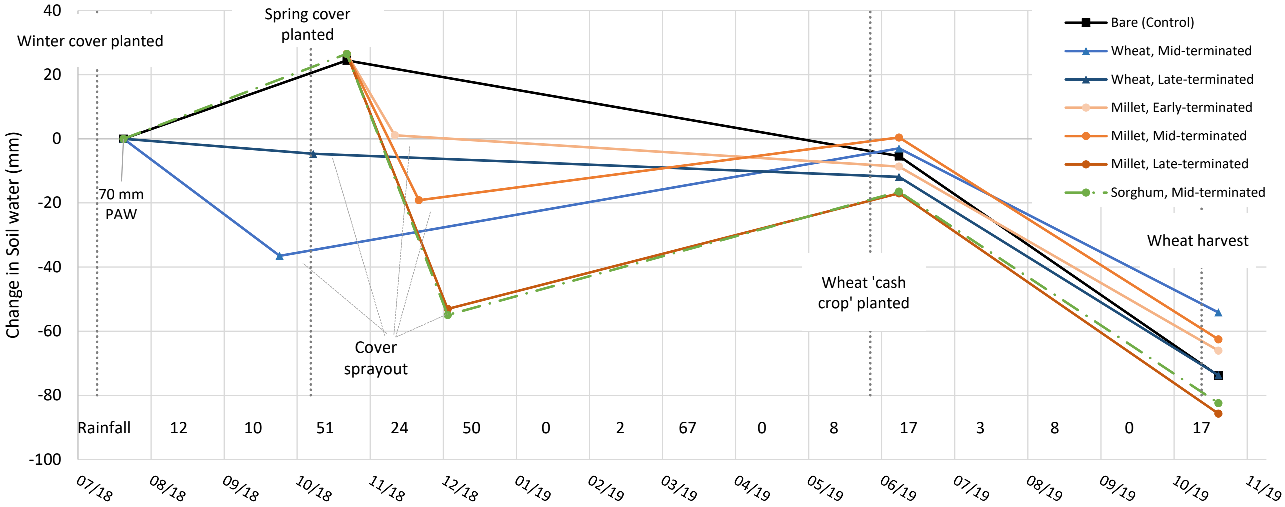

Figure 2. Change in plant available water for a range of cover crops, measured with soil cores (gravimetric) to 150 cm depth at key crop growth stages. Grids represent each month and numbers in the bottom row are mm rainfall for that month.

Volumetric soil water measured post-harvest of the wheat crop had a similar spread as the wheat. The crop extracted an average of 61 mm (net) of PAW from the profile, and with only 17 mm of in-crop rain the wheat yielded 570 kg/ha. There was no treatment effect observed from the cover crop treatments, reflecting the similar soil moisture levels they had at planting.

However, there was a consistent yield increase from the crop over the old sorghum rows, compared to the crop growing in the original 'skip-row' from the previous sorghum crop. After noticing lower EM38 readings in the previous sorghum skips, two plot header runs were taken for each plot: one over the previous sorghum rows and the other over the skip (Figure 1). Across all plots, there was an extra 126 kg/ha yield (25%) measured on the old sorghum rows versus the skip (632 kg/ha vs 506 kg/ha), reinforcing the original rationale for cover crops in the Goondiwindi district; to protect the bare skip-rows from erosion by encouraging infiltration rather than runoff, especially on harder setting and sloping sites.

Implications for agronomists and growers

The trial has provided some clear insights despite the extremely dry season, with its low yields for both the cover crops and the subsequent wheat.

The net water deficit of both the Mid-terminated summer and winter cover crops was approximately 40 mm; in line with all past experiments in this project.

Again in an extremely dry season, by the time the subsequent wheat crop was planted for grain, the water in all treatments had recovered to within +/- 10 mm PAW.

Furthermore, the only plots that had enough surface moisture to be planted (without the aid of trickle tape) were those in which cover crops had increased, and then maintained, at least 40% cover by the end of the fallow. The opportunity for an extra crop could be incredibly valuable in many seasons.

This was a real test for cover crops with a large expected downside risk. However, the results suggest that even in these very dry times, cover crops can be used to protect the soil and maximise the opportunity to capture as much rain as possible, with no significant loss of water across the fallow. Growing the cover crops is an additional cost, however, this cost will be off-set in more normal seasons when infiltration, runoff and erosion are more likely to be problems. In short, cover crops have an understandable role to play when cover levels are low and growers are struggling to get water back into their paddocks.

Acknowledgements

We very much appreciate the support of the trial cooperator and consultants for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical 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).

Trial details

Location:	Yagaburne
Crop:	Wheat long fallowed from skip-row sorghum with wheat or White French millet and other cover crops
Soil type:	Poplar Box Chromosol
Rainfall:	269 mm (224 mm cover/fallow and 45 mm in wheat)


Taking monthly neutron moisture meter readings.

Cover crops: Soil water was not reduced on a long fallow during a drought—Goondiwindi

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

Research Questions: *Can cover crops increase infiltration and net water accumulation in lateral-irrigated cotton systems with low ground cover (<30%)?*

- *What is the net water cost to grow winter cover crops?*
- *What is the net water gain to subsequent cotton crops?*
- *What is the impact on the yield of the subsequent cotton crops?*

Key findings

1. Cover crops can improve ground cover in fallows without costing plant available water for the next crop.
2. The Early-terminated treatment was the best cover crop for storing water over the short fallow in this study where cover did not have to last very long. However, the extra cover in the Mid and Late-terminated treatments continued to boost infiltration later in the fallow.

Background

Approximately 60% of rainfall in northern farming systems is lost to evaporation, with transpiration through plants typically only 20-40%. Cover crops protect the soil from erosion, build soil organic matter and maintain soil biological activity. However, not being harvested for grain or fibre, they are considered 'wasteful' of rainfall; widely seen to be our most limited resource in dryland farming systems.

Recent research now suggests that cover crops may provide benefits with little or no loss of this plant available water (PAW). Therefore, there is renewed interest in cover cropping to use some of this 'lost' water and help develop systems that are more productive, profitable and sustainable. For example, we know that cotton crops can leave the soil dry and unprotected with low groundcover after picking, reducing infiltration and making it difficult to rebuild soil water levels for the next crop. Consequently, dryland growers plant winter cereals to get cover back on the ground and protect the soil; the crops may be harvested in good seasons, or be sprayed out after 6-10 weeks to provide the necessary ground cover to maintain infiltration.

However, efficient water use is also important for irrigated cotton growers, especially overhead irrigators who are interested in cover to maximise infiltration when they are watering-up and during the early growth stages of the cotton when they may have trouble getting enough water into the soil to keep up with later crop demand. Stubble will also protect young cotton plants from hot summer winds after planting.

This project has intensively monitored crop experiments from Goondiwindi (Qld) to Yanco (NSW) to quantify the impact of cover crops on fallow water storage and crop growth. That is, how much water is required to grow cover crops with sufficient stubble, how will these stubble loads affect accumulation of rainfall, the net water gain/loss for following crops and the subsequent impacts on crop growth and yield. This paper reports on an irrigated cotton paddock north-west of Goondiwindi.

What was done

The Goondiwindi experiment was on a lateral-irrigated paddock that grew chickpea in 2017. Chickpeas were harvested in December and cover crops were planted on the first significant rainfall event after harvest. Nine cover treatments with five replicates were planted in February 2018, and a further two (winter) cover crops in June (Table 1). The commercial area was planted to a wheat cover crop with the aim of growing cotton in 2018/19.

This site had 12 m wide plots with the plan to plant half (6 m) to winter crop after a cover crop in a short fallow and keep the other half for long fallow into cotton.

Table 1. Cover treatments applied in 2018.

Trt#	Cover crop	Termination timing	Planted	Terminated	Termination stage
1	Control (bare)				
2	Sorghum	Early	6 February	15 March	First node (Z31)
3	Sorghum	Mid	6 February	5 April	Flag leaf emergence (Z41)
4	Sorghum	Mid and rolled	6 February	5 April	Flag leaf emergence (Z41)
5	Sorghum	Late	6 February	14 May	Anthesis (Z65)
6	Sorghum	Late and rolled	6 February	14 May	Anthesis (Z65)
7	Millet	Mid	6 February	5 April	
8	Millet & lablab	Mid	6 February	5 April	
9	Millet & lablab	Mid (incorporated not sprayed)	6 February	16 April	
10	Multispecies	Mid	6 February	5 April	
11	Wheat	Mid	7 June	3 September	Booting (Z53)
12	Wheat	Late	7 June	17 September	Milky-dough

Sorghum termination times matched key growth stages: Early-termination when the crop begins stem development; Mid-termination when the reproductive phase begins; and Late-termination at anthesis for peak biomass production. The wheat cover crops were planned for termination at ‘mid’ and ‘late’ phenological stages.

The incorporated millet/lablab was not sprayed out, but ploughed with offsets. Sorghum development slowed after Mid-termination with Late-termination occuring 14 weeks post-planting. Mid-termination for the wheat cover crop was at booting (10 days later than planned), and Late-termination two weeks later when the wheat was at milky-dough stage.

The dry spring in 2017 meant the summer cover crop were planted late, and with a dry autumn the Late-termination didn’t occur until winter crop planting time. Consequently, the plan to split all plots and plant wheat was not progressed, and the larger plots were maintained to plant cotton in spring 2018. Due to the ongoing dry winter, the farm used the last of their water to grow their cover crop through to yield and did not grow cotton that year.

Soil water was estimated using soil cores to measure gravimetric soil water at key times, along with regular neutron moisture meters (NMM) and EM38 readings in each plot. These readings and the percentage of ground cover were recorded every 2–4 weeks. NMM water monitoring continued until 14 August 2019.

Results

Biomass and ground cover

The millet established very poorly, providing an ineffective cover crop, so the millet and multispecies treatments will not be discussed in any detail.

Biomass of the sorghum cover crops ranged from 2072 kg dry matter (DM)/ha for the Early-termination, up to 3650 kg DM/ha for the Mid and Late-terminated sorghum (Figure 1). The millet established poorly and produced much less biomass than the sorghum, despite being at anthesis (peak biomass) when sprayed. There was very little millet in the millet/lablab cover crops, so these treatments produced considerably less biomass than the sorghum.

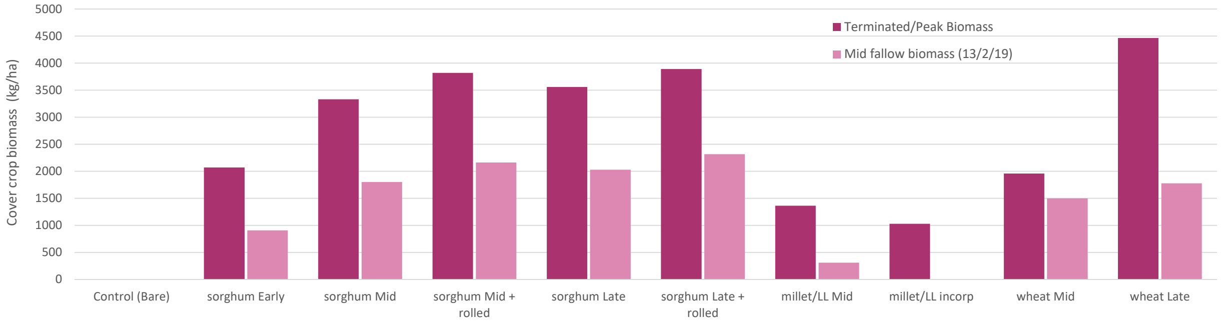

Figure 1. Above ground biomass accumulation for each cover crop treatment (excluding old cotton stubble).

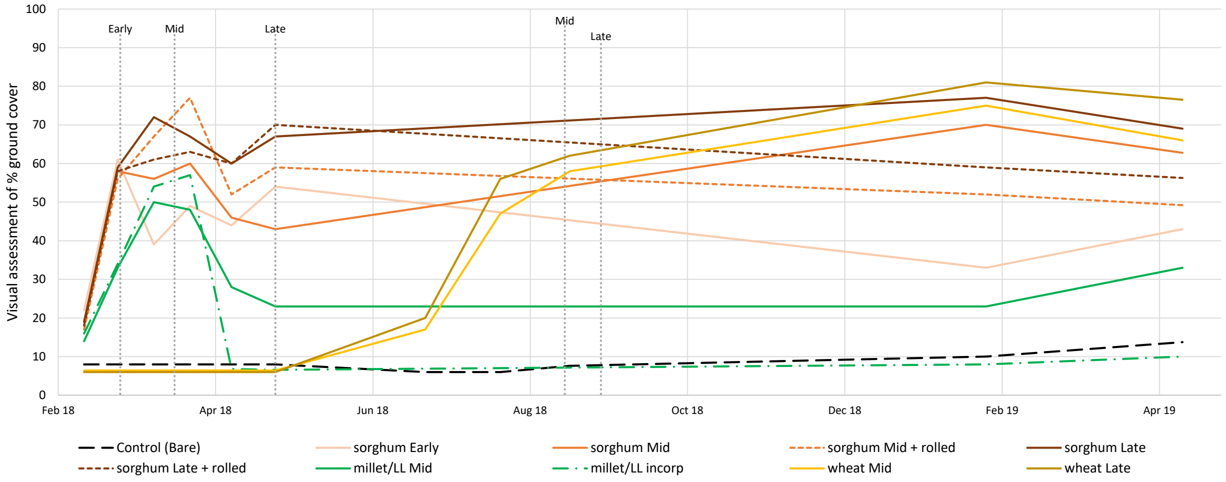

Figure 2. Visual assessments of ground cover for each cover crop treatment over time.

The wheat cover crop produced 1959 kg DM/ha at the Mid-termination, and increased to 4465 kg DM/ha at Late-termination. The change in biomass to February 2019 suggests about 2 t/ha of this increase was grain production.

Ground cover increased rapidly in line with biomass as the cover crops grew. However, the Early-terminated sorghum collapsed across the rows shortly after termination, and increased its initial ground cover to a level higher than the Mid-terminated sorghum. The Mid and Late-terminated sorghum developed stronger stems so remained standing, but rolling the Mid and Late-terminated sorghum had a similar effect in increasing initial ground cover. Early termination and rolling increased the rate of stubble breakdown and overall loss of ground cover for these treatments (Figure 2).

Soil water

The chickpea crop prior to the experiment left the soil profile wet below 90 cm, so the results presented here focus on the top 90 cm of soil.

The cover crop was planted after 50 mm of rain with 30 mm PAW. With another 138 mm of rain in the early stages of the cover crop, the Early-terminated sorghum finished with similar soil water to the bare control.

With little rain after Early-termination, the Mid-terminated sorghum had 30 mm less PAW than the control, and this gap increased to 40 mm PAW at Late-termination (Figure 3). The Late-terminated sorghum used all of the PAW in the top 90 cm.

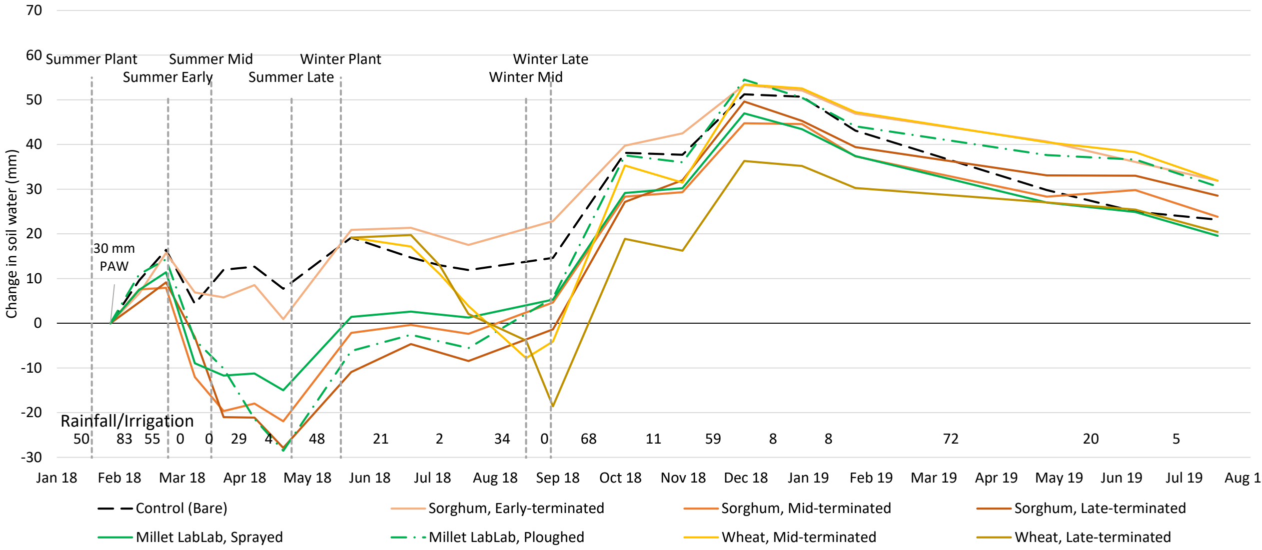

Figure 3. Changes in soil water (mm to 90 cm) from planting of the cover crop treatments to conclusion of monitoring at Goondiwindi. Rainfall and overhead sprinkler irrigation was measured onsite from May 2018, prior values were estimated from a nearby BOM station.

The wheat cover crops had 20 mm more PAW at planting (50 mm). By Mid-termination the wheat was 24 mm drier than the bare control, and 30 mm drier the late-sprayout. The Late-terminated wheat and sorghum were the only treatments to extract water from below 60 cm.

The summer cover crops recovered some of their lost PAW during the winter. However, it was not until after the Late-terminated wheat spray-out and the grower started irrigating the paddock that the treatments recovered the water used to grow the cover crops. By the end of November, most cover crops had recovered PAW differences, only the Late-terminated sorghum and wheat were drier in the 60-90 cm layer.

Rainfall in 2019 was very low, so differences began to emerge and the treatments with low cover dried out in the 0-30 cm layer more than those with more ground cover (i.e. where the lines cross in Figure 3). The exception was the incorporated millet/lablab cover crop, which maintained more surface moisture than the sprayed out millet/lablab, and similar moisture to the sorghum and wheat cover crops that had much higher ground cover. The surface roughness from tillage may have allowed the water to pool and infiltrate over time on this flat site. Closed soil pores then slowed the rate of water loss in the following period.

Implications for growers and agronomists

Terminating the sorghum cover crop early allowed ground cover to be re-established without sacrificing PAW or planting opportunities of the next crop. However, as the crop matured, the later terminations used more water and created a water deficit that took longer to recover in the fallow.

The poor establishment of the millet in the other summer cover crops made them ineffective; they used soil water without producing high levels of ground cover, in a similar fashion to a weedy fallow. These treatments with millet still recovered the soil water used at the same time as the more effective cover crops, but did not provide resilient, long-term ground cover to reduce surface drying in 2019.

All cover crop treatments in this trial recovered their soil water. However, the site was located in an irrigated system that did not have enough water available to grow a subsequent 'cash' crop and assess the impact of the cover crops on their yield.

Acknowledgements

We very much appreciate the support of the trial cooperator and consultants for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical 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).

Trial details

Location:	Goondiwindi
Crop:	Cover crops including sorghum, wheat, millet, lablab and tillage radish.
Soil type:	Alluvial, Grey Vertosol
In-crop rainfall and irrigation:	521 mm (February 2018 to August 2019)

Cover crops: Summer cover crops on a short fallow reduced soil water and wheat yield—Billa Billa

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

Research Questions: *Can summer cover crops increase the net water accumulation in dryland systems with low ground cover (<30%) in the northern region?*

- *What is the net water cost to grow summer cover crops?*
- *What is the net water gain to subsequent grain crops (fallow and early growth periods)?*
- *What is the impact on the yield of the subsequent grain crops?*

Key findings

1. Stubble load and stubble type had no impact on fallow efficiency in this very dry season.
2. Growing cover crops can reduce soil water available at the end of the fallow.
3. Wheat population and evenness of establishment remains critical to maximise water extraction and water use efficiency.

Background

Growers typically use cover crops to protect the soil from erosion in low stubble situations, return biomass that helps maintain soil organic matter and biological activity, and provide additional nitrogen (when legumes are used). However, cover crops also offer an opportunity to increase infiltration and fallow moisture storage for better and more profitable grain and cotton crops across the northern region of New South Wales and Queensland.

Grains Research and Development Corporation (GRDC) funded farming systems projects (DAQ00192/CSA00050) are assessing ways to improve this system water use, and to achieve 80% of the water and nitrogen limited yield potential in our cropping systems. GRDC's Eastern Farming Systems project and Northern Growers Alliance trials both suggest that cover crops and increased stubble loads can reduce evaporation, increase infiltration and provide net gains in plant available water over traditional fallow periods. Consequently, cover crops may be a key part of improved farming systems; providing increased productivity, enhanced profitability and better sustainability.

The 'Cover crop project' (DAQ00211) has 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.

This project has previously demonstrated at Bungunya that it is possible to recoup PAW used by a cover crop in a long fallow between sorghum and wheat, and even increase total water storage in some treatments. Reported in *Queensland grains research 2018-19*, the trial subsequently established a more even wheat population after cover crops, extracted more water at harvest, and increased wheat grain yield by 30%. In the short fallow between two cotton crops, only the earlier termination timings recouped the PAW used by the cover crops. However, all cover crops treatments had improved capture of the overhead irrigation water in early crop development that led to significant cotton yield benefits.

This current report is on research to explore the possibility of improving ground cover in a short fallow following a chickpea crop, without sacrificing the following wheat crop.

What was done

The Billa Billa experiment was established adjacent to the long-term farming systems trial site. The duplex soil has a loam surface that is prone to setting hard in the absence of good ground cover. The experiment compared the use of a cover crop when cover was low following chickpea, compared to different amounts and heights of traditional cereal stubble. The trial was planted to randomised plots of wheat and chickpea in 2018 to establish the different reference stubble types.

At harvest the wheat stubble was cut at two heights; tall - just below the head (50 cm), and short - half the height of tall (25 cm). Half of the tall wheat was later rolled, and half of the short wheat had the chopped straw raked off the plots, creating four wheat stubble treatments; tall standing, tall rolled, short tops spread, short tops removed. In the chickpea plots, sorghum cover crops were planted on the next planting opportunity post-harvest, with one chickpea treatment left as a bare control (Table 1).

All crops were planted on 40 cm row spacing, using the same planter and GPS guidance each time. This allowed us to plant the cover crop on the chickpea stubble row, and the subsequent wheat crop was planted in the inter-row leaving existing stubble standing in all plots.

Five Sudan hybrid forage sorghum cover crop treatments with six replicates were planted on 26 November 2018, to complement the five reference treatments with different stubble treatments.

Three planned termination times matched key growth stages of the main cereal treatments: Early-termination at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production.

With low in-crop rain, the sorghum stopped phenology development at second node, so Mid-termination was sprayed-out three weeks after Early-termination. The Late-termination was delayed until rain was received, so wasn't sprayed until two months after the Mid-termination. There were two treatments sprayed at each of the mid and late spray dates, with the second treatment left a week for herbicide translocation, then crimp rolled.

Soil water was estimated using soil cores for gravimetric soil water at key times across the fallow and the subsequent wheat, along with regular neutron moisture meter (NMM) and EM38 readings in each plot. The NMM and EM38 readings and the percentage ground cover were recorded every 2–4 weeks in the fallow. These soil water measures continued every four weeks in the growing crop until canopy closure, with a final soil water measure at harvest.

The subsequent wheat was dry-planted on 28 June 2019 and irrigated with trickle tape down the seed row, for establishment. Wheat yields were estimated with hand-cuts on 17 October, and mechanical harvesting on 30 October 2019.

Table 1. Cover treatments applied prior to planting wheat in 2019.

Trt#	Initial crop	Cover treatment
1	Chickpea	Bare (Control)
2	Chickpea	Sorghum Early-terminated
3	Chickpea	Sorghum Mid-terminated
4	Chickpea	Sorghum Mid-terminated + Rolled
5	Chickpea	Sorghum Late-terminated
6	Chickpea	Sorghum Late-terminated + Rolled
7	Wheat	Tall stubble, left standing
8	Wheat	Tall stubble, rolled
9	Wheat	Shorter stubble, tops spread
10	Wheat	Shorter stubble, tops removed

Results

Biomass and ground cover

The chickpea stubble provided 20% ground cover at the start of the fallow. Planting a cover crop increased ground cover rapidly to have 65% cover at early-termination (Figure 1) but did not increase with delayed termination.

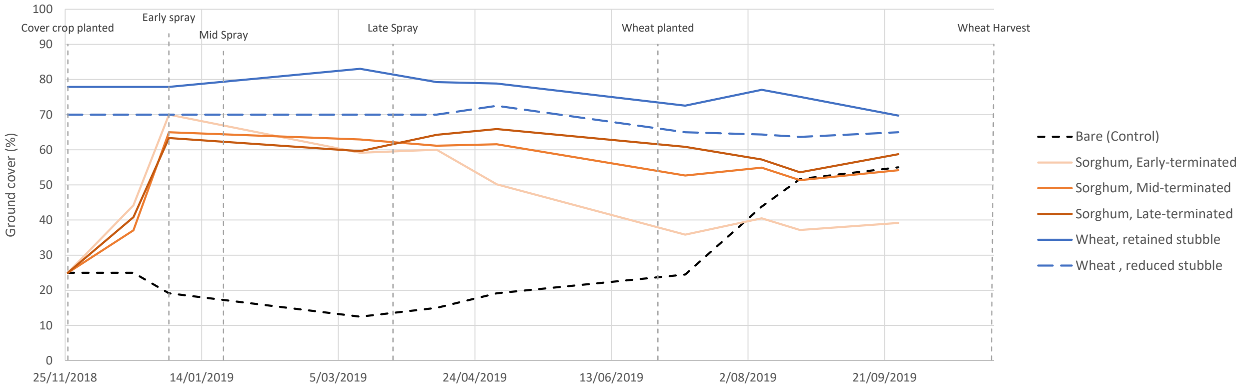

Figure 1. Visual assessment of % ground cover (three retained stubble treatments or +/- rolling were not different, so averaged values are presented).

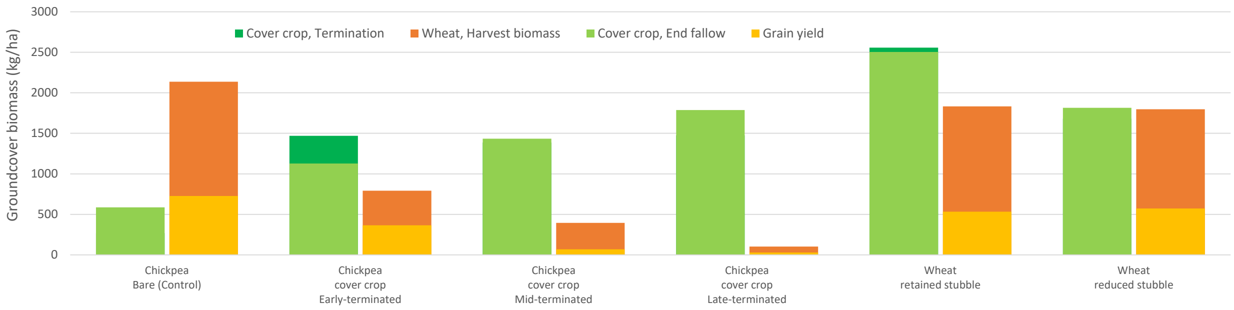

Figure 2. Biomass of ground cover assessed at Late-termination (27 March 2019), overlayed by biomass at the end of the fallow (21 June 2019), and wheat crop biomass overlayed by grain yield.

The three treatments with retained wheat stubble had 80% cover throughout the fallow. Removing the tops of the wheat plant only reduced this cover to 70%.

The chickpea stubble (bare control) provided 0.5 t/ha biomass at the start of the fallow. The sorghum cover crop provided an additional 1.5 t dry matter (DM)/ha at Early-termination, and with no in-crop rain, the sorghum biomass did not increase for the later termination timings. In comparison, there was 2.7 t DM/ha in the tall wheat stubble, while cutting the wheat stubble shorter and removing the tops reduced the biomass to a similar level as the sorghum cover crop (Figure 2).

With the low rainfall received during the fallow period, the wheat and chickpea stubble persisted on the soil surface. Only the Early-terminated cover crop reduced biomass and ground cover over the fallow period, as it was soft and leafy at termination, so broke down with the small rainfall events.

The subsequent wheat crop only increased cover significantly in the bare control. This treatment started from a lower cover level and increased to a similar level to the Mid and Late-terminated cover crops.

The wheat stubble plots started with higher cover levels, so the low yielding wheat crop made little improvement. The subsequent wheat grew poorly following the cover crops, and did not improve the cover in these treatments.

Soil water

The preceding chickpea left 20 mm more plant available water (PAW) on average than the wheat at harvest in 2018. The cover crops were planted on the next rainfall event after harvest with 70 mm plant available water.

At Early-termination, PAW reduced by 40 mm, and by Mid-termination used all of the PAW. The site received 40 mm rainfall in the first half of March, so had 16 mm PAW at Late-termination and received another 43 mm rain in the last week of March (Figure 3).

The rainfall over the fallow period was the lowest on record with rainfall only received in isolated storms. With no follow-up rain, the fallow efficiency was the same for all stubble types and stubble loads. As such the bare control (chickpea stubble) had the most PAW at planting, followed by the wheat stubble (which started the fallow 20 mm drier), and the sorghum cover crops had the least (Figure 3).

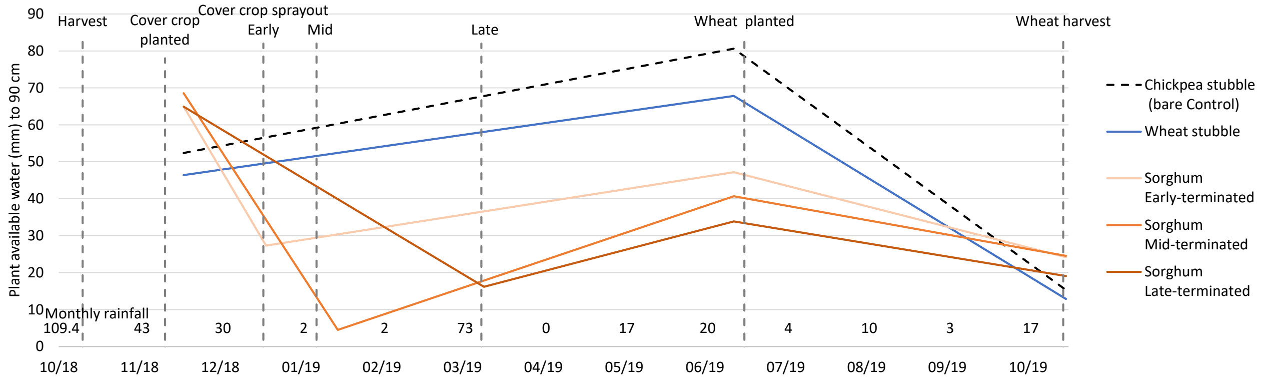

Figure 3. Plant available water measured to 90 cm with gravimetric soil coring at key times. Values on the bottom show the rain received that month. Wheat stubble treatments or +/- rolling Mid and Late-terminated cover crops had no impact on soil water, so averaged values are presented here.

The Early-terminated cover crop had a similar fallow efficiency to the fallowed treatments. The Mid and Late-terminated cover crops had drier soil surface when the site received 73 mm rain in March, which allowed them to capture more of this rainfall and so return a higher post-cover crop fallow efficiency; however, they still had the least PAW when the subsequent wheat crop was planted.

With an even population established in the wheat crop, all treatments dried the profile to a similar level at harvest.

Crop performance

Biomass of the mature crop and grain yield was low across all treatments (Figure 2). Yields were directly related how much soil water was available at planting. Crops across all treatments produced 37 kg/ha biomass or 11.8 kg/ha grain per mm of water over-and-above an initial 44 mm of water required before crops went through to yield (Figure 4).

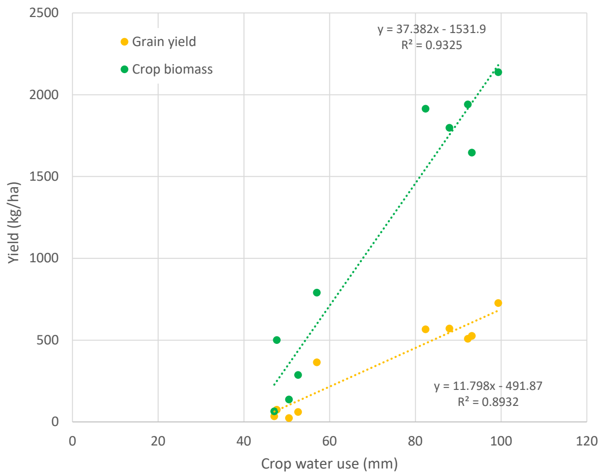

Figure 4. Crop water use and grain yield of the wheat following cover crops at Billa Billa. The point where the lines intercept the x axis is the water use required to produce yield and the slope of the line is the marginal water use efficiency.

Implications for agronomists and growers

This project has previously shown that it is possible to recover the water used by a cover crop, and even accumulate more PAW in a long fallow with little cover. Moreover, the project has measured yield benefits beyond what can be explained by the extra PAW.

However, this experiment showed the opposite. It focused on a shorter fallow period and in a record low rainfall year. Over the fallow, the rain received was in one-off events with no follow-up for up to four weeks. So, it is not surprising that the cover crops did not recover the PAW used to grow them. In this situation stubble loads were of little consequence; any effect extra stubble had on slowing the evaporation of surface moisture had dissipated by the time the next rain fell.

The use of trickle tape irrigation for establishing the wheat crop allowed an even population of 1 million wheat plants per hectare. With this even population the differences in wheat yield was strongly correlated to the soil water at planting that was subsequently used by the crop. From this we can suggest that the PAW left at harvest in the bare control at the Bungunya site (reported in *Queensland grains research 2018-19*) and its associated yield penalty was largely a result of uneven crop establishment.

Acknowledgements

We very much appreciate the support of the trial cooperator and consultants for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical 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).

Trial details

Location:	Billa Billa
Crop:	Wheat short fallowed from wheat or chickpea with sorghum cover crops
Soil type:	Belah, Duplex
Rainfall:	180 mm (145 mm cover/fallow and 35 mm in wheat).

Cover crops: Cover crops though a very dry then very wet fallow—Croppa Creek

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

Research Questions: *Can cover crops increase infiltration and net water accumulation in pivot-irrigated cotton systems with low ground cover (<30%)?*

- *What is the net water cost to grow winter cover crops?*
- *What is the net water gain (and impact on yield) to subsequent cotton crops?*

Key findings

1. Early-terminated cover crops quickly recovered the soil water they used early in the fallow.
2. Cover had no impact in what was a very dry fallow period.
3. Mid and Late-terminated cover crops had more cover and captured more rain in the wet February late in the fallow, resulting in all treatments finishing with similar plant available water.

Background

This site aimed to replicate the 2018-19 Goondiwindi and 2017-18 Yelarbon sites (*Queensland Grains Research 2018-19*), which grew cover crops in preparation for overhead irrigated cotton. Unfortunately, no cotton was planted due to a water shortage, so no crop effects are reported.

What was done

The Croppa Creek experiment was conducted on a newly converted pivot-irrigated paddock that last flood irrigated cotton in 2017. Initially planted to a barley cover crop, the paddock was surveyed using an EM38 before it was pegged and soil sampled (Image 1). Control treatments were established on 12–13 June 2019 by spraying-out the barley at the 3 leaf stage before six cover crop treatments with five replicates were established (Table 1).

Three termination times matched key growth stages of the barley: Early-termination at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production. The terminations were conducted on 5 July, 4 August, and 6 September 2019. Terminated crops were left for a week to translocate herbicides before soil sampling, biomass cuts and rolling (where applicable) at each timing.

Table 1. Cover treatments applied.

Trt#	Cover crop type	Termination
1	Control (Bare)	
2	Barley	Early
3	Barley	Mid
4	Barley	Mid and Rolled
5	Barley	Late
6	Barley	Late and Rolled

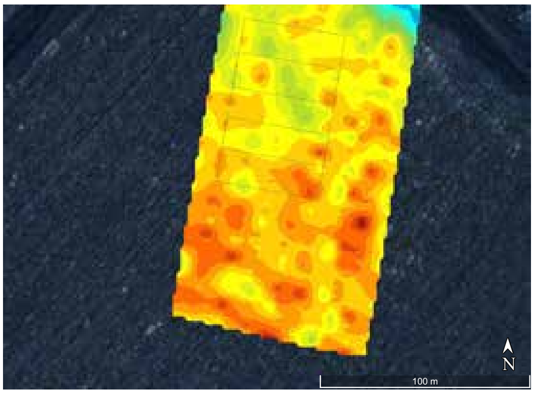

Image 1. EM38 survey (black lines indicate trial area).

Bore water allocations for the district are reviewed mid-year and were reduced for 2019–20. The collaborating grower subsequently decided not to grow cotton but to take the barley cover crop through to grain yield, with 80 mm of irrigation applied in August.

Soil water was estimated using soil cores to measure gravimetric soil water at key times, along with regular neutron moisture meters (NMM) and EM38 readings in each plot. These readings and the percentage ground cover were recorded every 2–4 weeks.

Results

Biomass and ground cover

The Early, Mid and Late-terminated barley cover crops produced 2.6 t/ha, 4.8 t/ha and 10.5 t/ha of dry matter respectively (Figure 1), with peak ground cover levels of 70%, 90% and 100% (Figure 2). Visual assessments of cover continued across the fallow. However, a hail storm on 12 October damaged the stubble and biomass was not reassessed.

Cover in the Early-terminated barley reduced rapidly once sprayed out, and fell below 30% by October 2019.

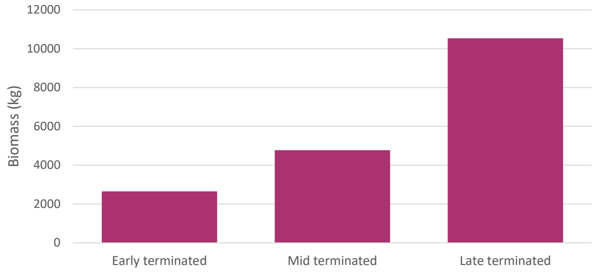

Figure 1. Above ground biomass accumulation for each cover crop treatment (excluding old cotton stubble).

The Mid-terminated barley produced more stubble that was also was more resilient, maintaining 50% cover until March 2020 when the trial concluded. There was no difference between the rolled and standing stubble treatments. Continuing to a Late-termination again produced more stubble that was also more resilient, maintaining 75-85% cover. In previous experiments, rolling stubble has increased stubble breakdown, but with the soil surface remaining dry for most of the trial, both the standing and rolled Late-terminated treatments maintained very high groundcover. The Late-terminated standing barley suffered a 20% cover reduction from a hail storm in October, whereas the rolled barley retained cover in this period (Figure 2).

Soil water

The site had approximately 120 mm of PAW when the trial was established, which remained static in the bare Control until August. The Early-terminated barley had 20 mm less plant available water (PAW) than the bare Control when sprayed-out. This deficit increased to ~50 mm for the Mid-terminated barley and 100 mm for the Late-terminated barley (Figure 3).

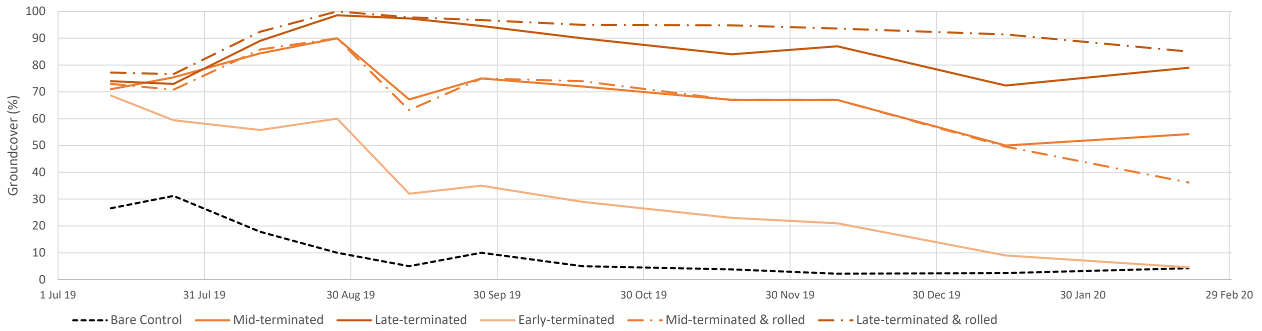

Figure 2. Visual assessments of ground cover for each cover crop treatment over time.

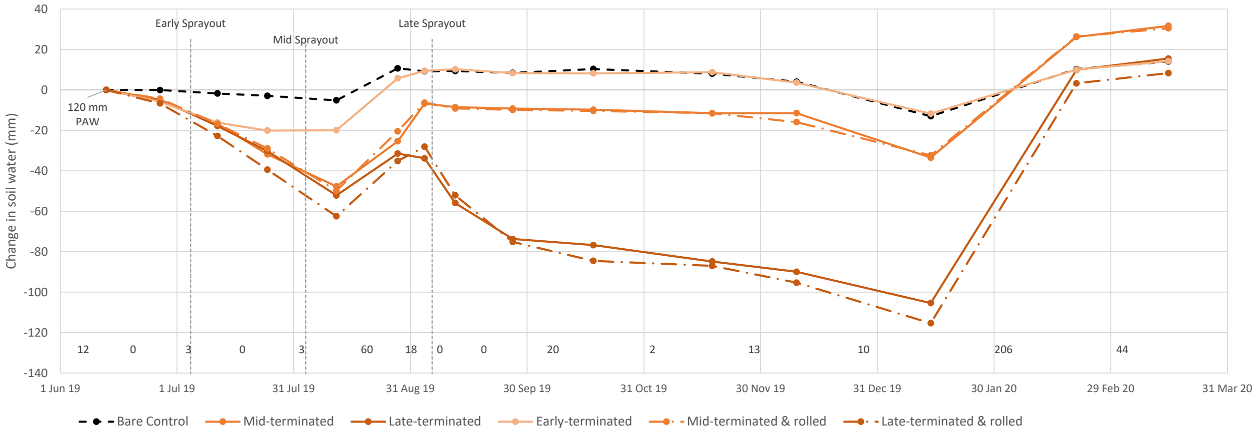

Figure 3. Change in soil water estimated using neutron moisture meters.

The 80 mm of irrigation applied to the paddock in August allowed all treatments to accumulate PAW. The bare Control increased 10 mm, while the Early-terminated cover crop increased by 30 mm to the same PAW as the bare Control. These two treatments maintained the same PAW for the remainder of the trial.

The Mid-terminated crop increased by a similar amount to reach a 20 mm deficit. The late terminated cover crop also recovered ~30 mm during this irrigation, but was still actively growing and continued to use this water. It had a deficit of 100 mm PAW when sprayed out to begin its fallow period.

All treatments maintained PAW at approximately the same levels until December 2019 when they began to decrease. The season changed early in 2020, with 206 mm rainfall in January and February. The bare Control captured 20 mm of this rainfall to have a net storage of 10 mm more PAW than the start of the trial. The Mid-terminated cover crop captured more of this rainfall, and finished with ~20 mm more PAW than the bare Control. Similarly, the Late-terminated cover crops had much higher fallow efficiency during this period and recovered from their 100 mm deficit to finish the trial with a similar PAW to the bare Control.

There was no difference in PAW between the rolled and standing stubble treatments in this trial.

Packing up the soil sampling truck after establishing the trial site.

Implications for growers and agronomists

The impacts of the cover crops on subsequent cotton yields were unable to be measured in this trial when a water shortage prevented the cotton being planted. However, the recovery of the water deficits to grow the cover crops was clear; all treatments finished the fallow with similar soil water levels.

Growers going into fallows with little ground cover can expect that well managed cover crops, sprayed out at the appropriate growth stage for the intended fallow length, can recharge their lost water as long as there is a period of reasonable rainfall at some stage in the fallow. Past research suggests that a deficit of 40-60 mm of soil water can be expected. High fallow efficiencies after a cover crop suggest that 80-120 mm of rain may be needed to recover this deficit for cereal cover crops terminated by the appearance of the flag leaf. Early-terminated cover crops have smaller water deficits, recover their water deficit much faster, and may still protect surface moisture to allow better planting opportunities.

Acknowledgements

The support of the trial cooperator and consultants is greatly appreciated for their effort and contributions to the project, along with our project team members in CSIRO (Neil Huth, Brook Anderson), David Freebairn, and the DAF Biometry, Technical 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).

Trial details

Location:	Croppa Creek
Crop:	Barley cover crop
Soil type:	Grey Vertosol
In-crop rainfall and irrigation:	391 mm (June 2019 to March 2020).

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