Queensland grains research 2017–18

Regional agronomy

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Queensland Government

This publication has been compiled by Jayne Gentry and Tonia Grundy on behalf of the Regional Agronomy Team of Crop and Food Science, Department of Agriculture and Fisheries (DAF).

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Foreword

Queensland Department of Agriculture and Fisheries (DAF), through its recently released 'Queensland Agriculture and Food Research, Development and Extension 10-Year Roadmap and Action Plan' remains strongly committed to grains research and development (R&D) and supporting grain growers to innovate within their businesses based on the results of the DAF R&D. Our three regional agronomy teams based in Goondiwindi, Toowoomba and Emerald, continue to undertake regional testing and validation of a broad range of contemporary grain production techniques and systems. Their purpose remains to provide growers and advisors with best practice guidance to apply to their farming enterprises and encourage innovation in response to climate change, climate variability and other sustainability issues.

This is the third edition of *Queensland grains research* and it continues to communicate many of the key questions, underlying methodology and findings of the research achieved by our agronomists. Awareness of the regional research being carried out, accessibility of results and acknowledgement of the researchers who are leading the research, are key communication objectives of this publication.

Regional validation of modern cropping technologies and farm management strategies to deliver optimum farm enterprise returns remains a strong focus. Exploring options that generate farm financial viability within the constraints of environmental stewardship, market requirements, resource sustainability and workplace health and safety challenge our regional agronomy team in their trial program each season. With an added overlay of scientific integrity in all the teams’ trial work and professional collaboration with other research teams both within Queensland and nationally across Australia, I am proud of the DAF team whose efforts have made this edition such a valuable resource to the grains industry.

We fully acknowledge and sincerely thank producers, advisers and agricultural supply chain businesses who have contributed to the success of these trials. This research is also co-funded by the GRDC, who with their continuous investment cycle and significant corporate footprint within Queensland, help to provide valuable guidance on DAF's strategic investments in grains R&D.

Garry Fullelove
General Manager, Crop and Food Science
Department of Agriculture and Fisheries, Queensland

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The Grains Research and Development Corporation (GRDC) plays a vital role investing in research, development and extension to create enduring profitability for Australian grain growers with a focus on the key profit drivers of yield, price, cost (on-farm and post-farm gate) and the effective management of risk.

The GRDC is committed to collaborating with specialist teams to develop best practice, adoptable information for growers, including guidelines for cost-effective agronomy, nutrition and the management and control of pests and disease threats.

In partnership with the Queensland Department of Agriculture and Fisheries (DAF) the GRDC has invested in a significant regional agronomy program, which has produced this *Queensland grains research 2017-18* regional agronomy publication.

This publication offers growers and advisors the latest regional trial results, as well as valuable information to guide on-farm decision making in response to ongoing and emerging farm management challenges.

Jan Edwards
Senior Regional Manager, North
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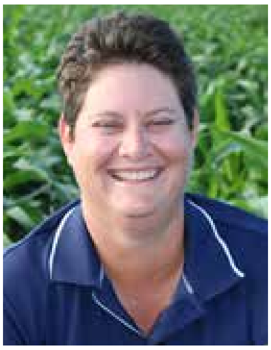
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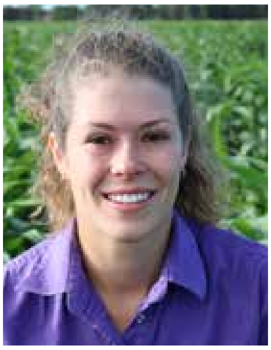
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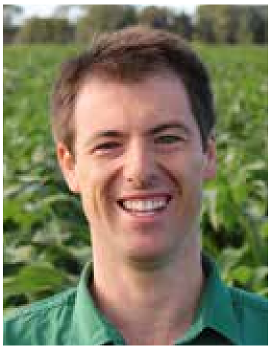
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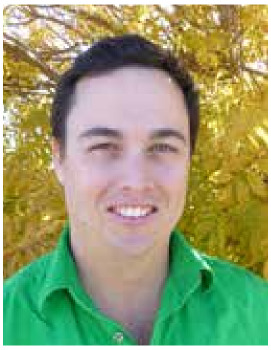
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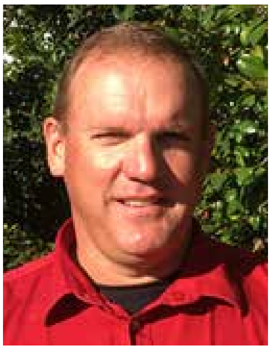
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Research facilities

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 Queensland Agricultural Training College (Emerald) for their operation of heavy plant and research machinery.

Biometry support

The DAF biometry team has provided the statistical analysis of the data presented in this report.

Cereals research

Cereal agronomy trials conducted by the Department of Agriculture and Fisheries research agronomy team in Queensland over the past 12 months have significantly moved away from basic varietal yield trials, to in-depth phenology-based research. The trials reported in the following section focus on growth stage characteristics of the varieties used, and how manipulation of agronomic practices such as time of sowing, population, or row spacing can alter how different genotypes will react to a given situation. In turn, how the plant reacts can have not only significant yield ramifications, but can also impact on grain quality.

Working with our project lead partners, New South Wales Department of Primary Industries (NSW DPI) for the 'Optimising grain yield potential of winter cereals in the Northern Grains Region' (BLG104), the focus of the work has honed in on when each of the varieties are hitting targeted growth stages during the life 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 very diverse growing climates with the data from the first year of trials reflecting this difference.

Wheat planted in Emerald was actually no quicker than the Wellcamp site to achieve GS30 (first node) however it was the period from GS30 to GS65 (50% flowering) where the Emerald crop accelerated, achieving GS65 on average 21 days quicker than the southern site. This rapid progress to GS65 meant less total biomass production, however the relationship between yield and final biomass may be less significant than first thought, particularly for some varieties better suited to Central Queensland conditions.

The team has also been working with Daniel Rodriguez and his team from Queensland Alliance for Agriculture and Food Innovation (QAAFI - an institute in The University of Queensland jointly supported by the Queensland Government) on project UQ000075 'Tactical agronomy for sorghum and maize in Central Queensland'. This research has focused on assessing if agronomic triggers such as row spacing, population and hybrid type can alter how and where yield is produced on the plant and what effect this can have on attributes such as grain size and yield potential.

Both sorghum and maize trials were planted in 2017 with quite different results in terms of row configurations, but also target plant density. With the maize, the wider row spacing configuration of 1.5 m comfortably outperformed the solid configurations across all three plant densities tested. A fact that was also confirmed by the water use efficiency of the different treatments. In the sorghum, the narrow 1 m solid configuration performed best, with the high population density outweighing the average yields. When grain quality was tested, it became apparent that high screenings were present, particularly in the higher population, 1 m solid configurations. There were some significant differences between population densities and hybrids and how the hybrids generated the screenings that made the original yield observation much more complex than first thought.

In 2018, the research agronomy team will continue its work with partners, NSW DPI, QAAFI and the Grains Research and Development Corporation to build on the work done in 2017. We will be repeating the trial work done on winter cereals in 2017, while for summer cereals there are some interesting proposals currently under consideration around the effect of early planting dates and how to minimise heat stress at flowing and grain fill. Also we are hoping to look a bit deeper into the effect of population, nutrition, planting precision, and variety on grain development between the main stem and tiller shoots.

Optimising the phenology and grain yield of wheat genotypes—Emerald and Wellcamp

Darren Aisthorpe
Department of Agriculture and Fisheries

RESEARCH QUESTION: *How adapted are different wheat genotypes' phenology and grain yield responses to different sowing dates under Queensland conditions?*

Key findings

1. Yields are maximised by timing flowering and grain fill to avoid frost and heat stress periods.
2. The speed of crop development showed significant similarities for both sites at early growth stages (emergence to GS30) however, significant differences of up to 20 days were observed from first node (GS30) to flowering (GS65).
3. There were biomass variations between varieties, typically related to how quickly the variety reached flowering (GS65).
4. Heat or water stress during flowering and grain fill appeared to override any possible yield benefits achieved from increased biomass.

Background

In 2017, field experiments were conducted across eight sites in the Northern Grain Region (NGR) in central and southern Queensland, and northern and southern New South Wales to determine optimal grain yield potential of wheat genotypes in this region. This paper presents results from the Emerald site (central Queensland) and Wellcamp (southern Queensland) and discusses the influence of sowing date on the phenology and grain yield responses of a core set of 30 wheat genotypes.

The genotypes evaluated were commercial or near-release varieties, varying in phenology responses to vernalisation (exposure to temperatures below a certain level for a required period), photoperiod and basic vegetative phase. Typically, longer season varieties tend to have a greater vernalisation requirement within the genetic makeup than quick season varieties.

Varieties also potentially differ in canopy structure, biomass accumulation and yield formation.

Optimum grain yield is achieved when genotypes are matched with sowing date to ensure flowering occurs at an appropriate time. In central Queensland (CQ), this response is commonly driven by the high risk of heat and moisture stress, whilst in southern Queensland (SQ) there is an increased risk associated with early frost damage. Generally, the genotype and sowing date combinations that flower in temperatures below 30°C and above 2°C will respond the best. Yields will be optimised with flowering as early as mid to late June, which allows grain fill to be completed before daily maximum temperatures can induce heat and moisture stress conditions. These can take affect as early as late July to early August.

Wellcamp has a much more defined temperature threshold window because of the significant frost risk and then the quick transition to +30°C in spring. Ideally, a medium to longer season variety planted no earlier than mid-May would be recommended to target flowering in the first to second week in September.

What was done

Thirty core genotypes varying in maturity (Table 1) were sown at three target sowing dates at each site in 2017: 20 April (TOS1), 5 May (TOS2) and 20 May (TOS3). The third sowing time at Emerald was sown three days earlier (17 May), ahead of an expected rain front.

Trials were soil sampled prior to planting to ensure adequate nutrition to maximise yield potential. In preparation for the trial both sites had water applied to ensure a good planting profile of at least 170 mm of plant available

Table 1. Expected phenology responses of genotypes sown at the Emerald and Wellcamp sites in 2017

Phenology type	2017 Variety list	Time to flowering
Spring wheats *Development has a greater reliance on photoperiod than vernalisation to progress to flowering and grain yield.*	LongReach Dartᶲ	Quick
	LongReach Mustangᶲ	
	TenFourᶲ	
	Condoᶲ	
	LongReach Spitfireᶲ	
	Corackᶲ	
	Maceᶲ	
	Suntopᶲ	
	Beckomᶲ	Medium
	Janz	
	Scepterᶲ	
	Mitchᶲ	
	LongReach Trojanᶲ	
	Sunvale	
	Kioraᶲ	
	LongReach Reliantᶲ	
	DS Pascalᶲ	
	LongReach Lancerᶲ	Medium-Slow
	Suntimeᶲ	
	EGA Gregoryᶲ	
	Cutlassᶲ	
	Coolahᶲ	
	Sunmaxᶲ	Slow
	EGA Eaglehawkᶲ	
	Sunlambᶲ	
Winter wheats *Require a minimum vernalisation period to progress to maturity.*	LongReach Kittyhawkᶲ	
	Longswordᶲ	
	EGA Wedgetailᶲ	
	RGT Accrocᶲ	
	Manningᶲ	

water (PAW) across the three TOS dates. In-crop rainfall for both sites was minimal (Emerald 61 mm and Wellcamp 251 mm (of which 160 mm fell post grain fill)).

Trials were planted with cone planters aiming for target populations of 90-100 plants/m², and were 12 m plots with 50 cm spacing at Emerald, and 6 m plots with 25 cm spacing at Wellcamp.

Detailed phenology measurements were undertaken including timing of commencement of stem elongation (GS30), heading (GS55), flowering (GS65) and physiological maturity (GS90). Other measurements included: plant establishment, biomass at key growth stages (GS30, 65, 90), spike density, harvest index, grain yield and quality parameters.

Results

Plant establishment

Both sites achieved good establishment—greater than 98% of the target, (Figure 1), as an average across all three sowing dates. There was a difference between establishment rates at the two sites, with plant densities at the Emerald site on average 11% lower than the Wellcamp site across all genotypes. The largest differences were seen in LongReach Dartᶲ (29%), LongReach Lancerᶲ (19%) and LongReach Mustangᶲ (19%).

Phenology

Figure 8 illustrates how significant an effect frost had in 2017 and also how quickly the risk of temperatures exceeding +30°C tends to be.

There is variation in the development responses among the 30 genotypes, as such there were differences in the phase duration of genotypes

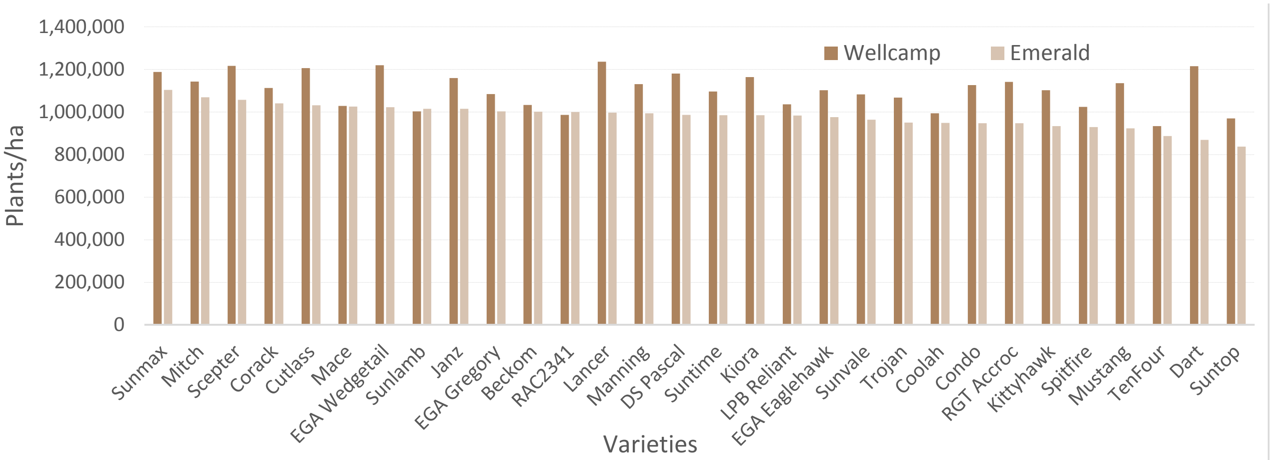


Figure 1. Mean plant establishment (plants/ha) for genotypes across three sowing dates

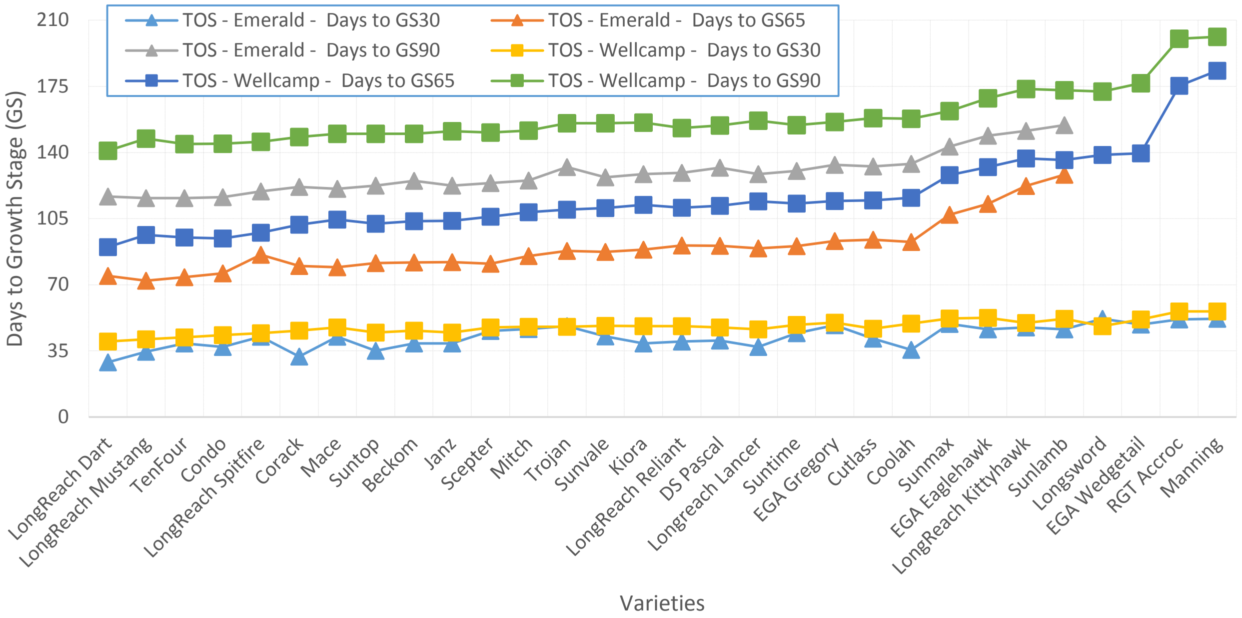


Figure 2. Days to GS65 (50% flowering) at Emerald
lsd was 2.79 days across varieties and TOS dates; P(0.05)

Figure 3. Average days to crop growth stage GS65 (50% flowering) for Emerald and Wellcamp sites

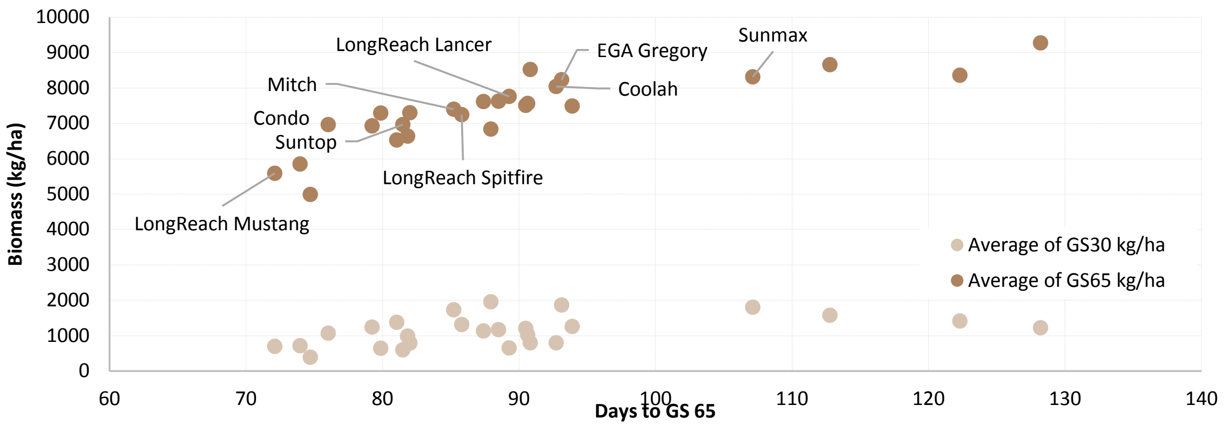


Figure 4. Average biomass accumulation at GS30 (elongation) and GS65 (50% flowering) at Emerald, relative to days to GS65

in response to sowing date and between the two sites (Figure 2). At the CQ site, (Figure 3), days to flowering ranged from 70 days for Mustang[⏀] in TOS3, right up to 143 days for Sunlamb⏀ in TOS1. Winter varieties like RGT Accroc⏀, Manning⏀, EGA Wedgetail⏀ and Longsword⏀ were not able to achieve GS65, due to insufficient cooling period to meet vernalisation requirements.

Mean time to stem elongation (GS30) across all genotypes was similar for both sites, despite different seasonal conditions in 2017 for both spring and winter wheat types. Days to 50% flowering (GS65) at Emerald was recorded on average 21 days faster than the Wellcamp site, and the grain-filling phase (flowering to physiological maturity (GS90)) was recorded five days faster at the Emerald site.

Biomass accumulation

Generally, biomass accumulation was greater in genotypes with long growth development periods to GS30 and GS65 (Figure 4). However this trend tends to flatten for the longer season varieties like Sunmax⏀. When you compare biomass accumulation between TOS dates, typically there was not a significant difference between them for either GS65 or GS90 biomass cuts.

Sunmax⏀ for both GS65 and to a lesser extent for GS90, and Mitch⏀ at GS90 for Wellcamp stand out as exceptions, showing significant differences between times of sowings for possibly very different reasons.

Figures 5 and 6 show biomass accumulation, for GS65 and 90 respectively, per hectare at both sites for all three times of sowing, for

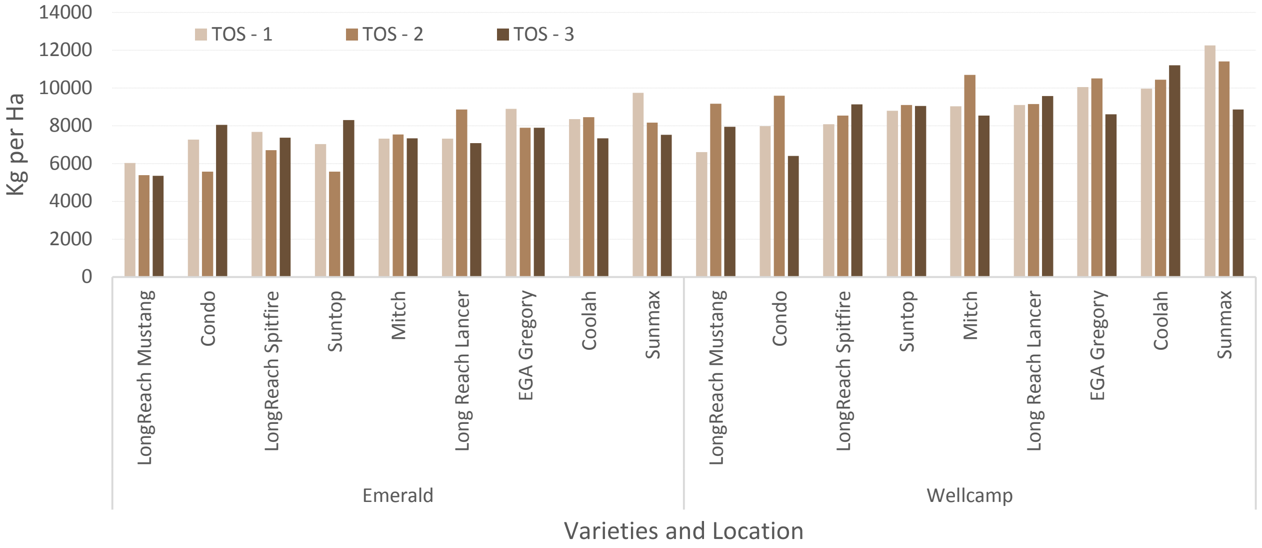


Figure 5. GS65 biomass accumulation for Emerald and Wellcamp sites across all three times of sowing
lsd for Wellcamp was 1290 kg/ha; lsd for Emerald was 1568 kg/ha; P(0.05)

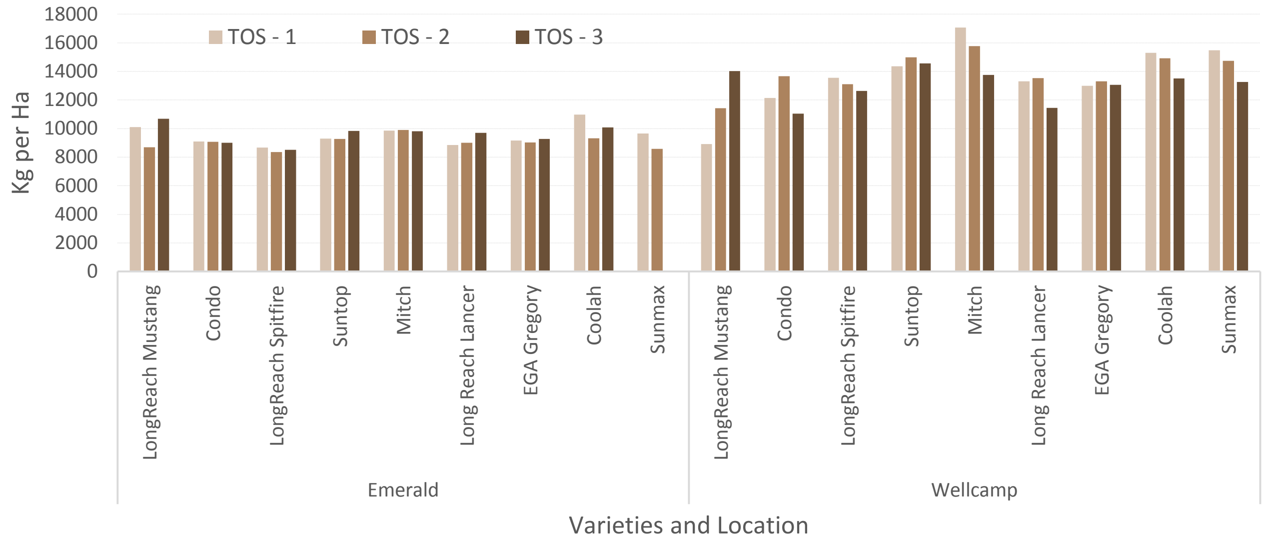


Figure 6. GS90 biomass accumulation for Emerald and Wellcamp sites across all three times of sowing dates
lsd for Wellcamp was 1337 kg/ha; lsd for Emerald was 1430 kg/ha; P(0.05)

nine of the varieties used in the trials. For the slow, long season wheats (Table 1) such as Sunmax$^{\phi}$, biomass was driven by a combination of vernalisation time and photoperiod, whereas with Mitch$^{\phi}$ it's about photoperiod accumulation before flowering and as planting dates got later, that time reduced.

LongReach Mustang$^{\phi}$ and to a lesser extent Condo$^{\phi}$ are the other obvious stand outs in biomass accumulation, however this time it's the effect of photoperiod combined with significant frost damage experienced, particularly during TOS1 and 2.

When the data in Figure 6 is compared for GS90 biomass accumulation between sites and times of sowing, it is interesting to note that there is no significant difference in biomass at all for Emerald between varieties, yet for Wellcamp there is still a trend towards higher biomass accumulation for longer season varieties. This could be strongly related to climatic conditions at both sites during flowering and grain fill and it was unfortunate that the Wellcamp site was so significantly affected by hail and frost, that we didn't see if this trend would continue into yield.

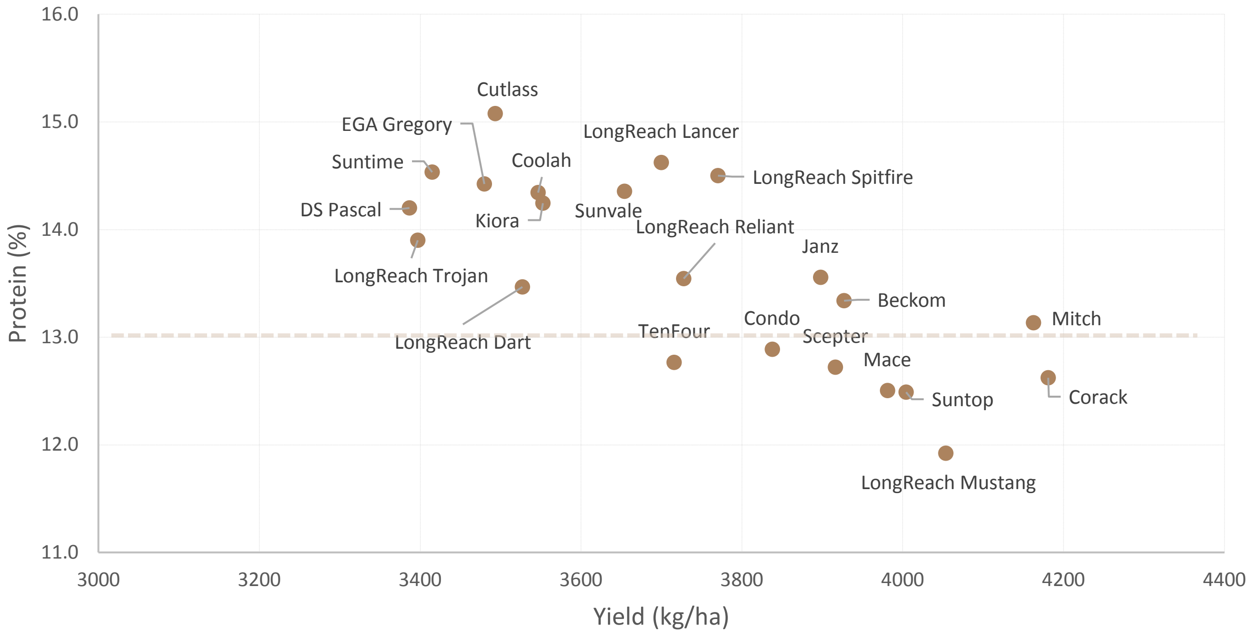


Figure 7. Grain yield and variety effect on grain protein; shows the relationship between variety, yield and grain protein (%) for the Emerald site
All varieties mentioned are covered by p; lsd = 355 kg; P(0.05)

Table 2. Grain yield and quality data from Emerald

	Days to GS 65			Yield (kg/ha)			Protein (%)			Screenings (%)		
Variety	TOS 1	TOS 2	TOS 3	TOS 1	TOS 2	TOS 3	TOS 1	TOS 2	TOS 3	TOS 1	TOS 2	TOS 3
LPB Mustang$^{\phi}$	73	72	71	3851	4329	3981	11.6	12.0	12.1	6.16	4.87	5.61
TenFour$^{\phi}$	77	74	71	3463	3991	3694	12.4	12.8	13.0	5.80	6.19	6.56
LPB Dart$^{\phi}$	78	75	72	3611	3542	3428	13.0	13.8	13.6	10.06	9.29	7.89
Condo$^{\phi}$	79	76	74	3738	3932	3844	12.4	13.3	13.0	6.11	5.39	5.06
Corack$^{\phi}$	86	78	75	4106	4317	4119	12.4	12.8	12.6	4.83	4.66	5.69
Mace$^{\phi}$	83	79	76	4132	3936	3875	12.3	12.6	12.5	6.86	7.11	6.36
LPB Spitfire$^{\phi}$	93	79	86	3902	3719	3689	13.7	14.9	14.9	4.22	4.95	5.56
Janz	86	80	80	3958	3864	3871	13.1	13.6	14.0	3.75	2.96	3.79
Suntop$^{\phi}$	82	80	79	4021	3999	3992	12.3	12.8	12.4	4.36	5.98	6.76
Scepter$^{\phi}$	83	80	80	4010	3727	4011	12.4	13.0	12.8	7.24	8.53	7.25
Beckom$^{\phi}$	84	82	79	3831	4073	3877	13.0	13.3	13.6	5.43	4.69	7.07
Mitch$^{\phi}$	88	85	82	4831	4094	3563	12.5	13.0	13.9	7.08	6.63	10.19
LPB Trojan$^{\phi}$	91	88	84	3499	3359	3334	13.7	14.1	13.9	4.40	4.81	7.64
Kiora$^{\phi}$	92	89	85	3662	3610	3386	13.8	14.3	14.6	5.01	5.28	9.79
Sunvale	88	90	84	3725	3798	3439	14.1	14.3	14.6	2.94	2.23	4.70
Suntime$^{\phi}$	94	91	87	3575	3453	3217	14.1	14.5	15.1	6.05	5.99	9.24
DS Pascal$^{\phi}$	94	91	86	3798	3172	3189	13.2	14.7	14.7	6.05	7.15	7.95
LPB Lancer$^{\phi}$	91	92	85	3899	3557	3643	14.4	14.8	14.7	3.15	3.72	4.07
LPB Reliant$^{\phi}$	95	92	86	3640	3845	3697	13.4	13.6	13.6	4.43	3.26	4.95
Coolah$^{\phi}$	96	93	90	3932	3476	3231	13.7	14.5	14.8	4.51	5.65	10.69
EGA Gregory$^{\phi}$	97	93	89	3659	3476	3305	13.9	14.5	14.9	4.30	4.61	7.82
Cutlass$^{\phi}$	94	95	92	3775	3610	3095	14.1	14.9	16.3	5.39	5.91	12.44
Sunmax$^{\phi}$	113	107	102	2936	2420	2167	16.7	17.6	19.1	5.28	7.07	14.85
EGA Eaglehawk$^{\phi}$	118	112	109	2837	2311	2221	16.2	17.3	17.3	7.08	10.57	17.21
LPB Kittyhawk$^{\phi}$	129	124	114	1116	364	780	18.4	17.8	17.7	2.52	3.33	3.68
Sunlamb$^{\phi}$	144	129	116	495	592	925	18.4	18.0	17.0	3.55	3.56	4.77
EGA Wedgetail$^{\phi}$	*	*	*	*	*	*	*	*	*	*	*	*
Manning$^{\phi}$	*	*	*	*	*	*	*	*	*	*	*	*
Longsword$^{\phi}$	*	*	*	*	*	*	*	*	*	*	*	*
RGT Accroc$^{\phi}$	*	*	*	*	*	*	*	*	*	*	*	*
TOS average	**93**	**89**	**86**	**3539**	**3406**	**3291**	**13.82**	**14.35**	**14.49**	**5.25**	**5.55**	**7.60**
lsd within TOS	**2.81**	**2.76**	**2.76**	**363**	**366**	**366**	**0.49**	**0.49**	**0.49**	**0.19**	**0.19**	**0.19**
lsd between TOS		**2.79**			**355**			**0.48**			**0.19**	

*** Did not reach growth stage**
lsd for Emerald was 355 kg/ha between times of sowing. As an overall average in 2017 there was no statistical difference in yield between all three sowing dates; P(0.05)

Overall average yield was significantly higher at the Emerald site (Table 2) compared to the Wellcamp site (Table 3) despite similar starting PAW, excellent establishment and crop development during the season. Local climate played a significant role with severe frosts and mid-October hail storms affecting the the Wellcamp yield data.

Starting soil available nitrogen (N) levels at the Emerald site were high (greater than 300 kg/ha), however there is a significant range in average protein spread across the genotypes in the trial, with average protein dropping below the 13% Prime Hard (APH) threshold for some. Figure 7 indicates the wide range of proteins recorded in 2017, despite a starting N in excess of 300 kg/ha. In comparison, the proteins obtained at Wellcamp were rarely below 13%.

Table 3. Grain yield and quality data from Wellcamp

	Days to GS65			Yield (kg/ha)			Protein (%)			Screenings (%)		
Variety	TOS 1	TOS 2	TOS 3	TOS 1	TOS 2	TOS 3	TOS 1	TOS 2	TOS 3	TOS 1	TOS 2	TOS 3
LPB Dartᶲ	80	94	96	271	1472	1962	15.1	15.1	13.7	3.3	1.8	3.0
Condoᶲ	87	101	96	157	795	1031	13.9	14.3	13.5	2.6	2.2	2.5
TenFourᶲ	84	101	100	250	1033	1767	14.5	14.6	12.7	1.9	1.4	3.0
LPB Mustangᶲ	85	101	103	107	651	1087	14.9	14.5	13.3	4.6	2.1	2.6
LPB Spitfireᶲ	92	103	n/a	766	2436	1777	15.4	15.3	14.3	1.3	0.9	1.8
Corackᶲ	99	103	103	271	884	814	14.4	14.4	13.8	1.6	1.0	1.4
Suntopᶲ	95	108	104	652	913	1468	14.0	13.3	12.9	3.2	1.7	3.4
Beckomᶲ	99	108	104	1051	1800	1338	14.3	13.9	13.4	3.2	0.9	2.0
Janz	97	108	107	597	1656	1930	14.7	14.6	14.1	4.0	0.7	1.1
Maceᶲ	102	108	104	1300	2075	2312	14.1	13.4	12.8	1.7	1.0	1.9
Scepterᶲ	103	108	107	1375	1740	2125	13.4	13.1	12.9	2.2	1.7	2.1
Mitchᶲ	104	112	109	754	1810	2032	14.1	13.7	13.1	3.1	1.3	3.2
LPB Trojanᶲ	109	112	108	1817	1562	1850	13.4	13.1	12.9	1.1	1.4	2.1
Sunvale	109	112	111	623	1146	1377	15.3	14.7	14.2	2.6	1.0	1.7
LongReach Reliantᶲ	112	112	109	522	1114	1662	14.1	13.6	12.9	2.0	1.2	1.8
DS Pascalᶲ	113	112	110	978	981	1460	14.4	14.2	13.9	1.5	1.8	4.4
Kioraᶲ	109	114	114	1636	2176	2185	14.8	14.0	14.5	1.9	1.9	2.0
Suntimeᶲ	113	112	114	2038	2387	2204	14.3	13.4	12.8	1.7	1.5	3.8
LPB Lancerᶲ	112	117	114	417	1183	1685	15.4	14.0	14.2	1.9	1.0	1.9
EGA Gregoryᶲ	114	117	112	763	1540	1545	14.3	13.7	13.6	1.2	0.9	2.2
Cutlassᶲ	113	117	114	1368	1585	1545	14.4	13.6	13.5	1.0	1.1	2.7
Coolahᶲ	118	116	114	1197	1735	2016	13.9	13.4	12.9	1.0	0.9	1.6
Sunmaxᶲ	134	129	121	1720	2242	2163	14.0	14.2	14.4	1.4	3.3	6.4
EGA Eaglehawkᶲ	137	136	124	1567	2705	2280	14.0	13.5	13.9	2.0	7.4	11.8
Sunlambᶲ	144	138	126	1840	2557	2126	15.0	14.8	14.4	1.3	2.0	3.7
LPB Kittyhawkᶲ	145	138	128	944	1495	1641	15.6	15.9	14.6	0.9	1.0	2.3
Longswordᶲ	151	140	125	1026	1772	1737	16.4	15.7	14.6	0.8	1.0	2.2
EGA Wedgetailᶲ	151	138	130	1056	1389	1499	16.4	16.2	15.6	0.8	1.4	1.7
RGT Accrocᶲ	188	173	165	*	*	*	*	*	*	*	*	*
Manningᶲ	196	181	173	*	*	*	*	*	*	*	*	*
TOS average	**116**	**119**	**115**	**967**	**1601**	**1739**	**14.6**	**14.2**	**13.7**	**2.0**	**1.6**	**2.9**
lsd per TOS	**1.49**	**1.51**	**1.49**	**381**	**381**	**384**	**0.70**	**0.70**	**0.70**	**0.31**	**0.31**	**0.31**
lsd between TOS		**1.48**			**421**			**0.748**			**0.33**	

*** Did not reach growth stage**
Least Significant Difference (lsd) indicated within TOS and between TOS; P(0.05)

At Emerald, Mitchᶲ was the stand out variety again in TOS1 for yield, LongReach Mustangᶲ topped TOS2 and Corackᶲ an APW classification wheat topped TOS3, with Sceptorᶲ (AH) and Suntopᶲ (APH) not far behind. Yields obtained at Wellcamp were much lower, with Suntimeᶲ yielding the highest in TOS1, EGA Eaglehawkᶲ for TOS2, and several varieties yielding over 2 t/ha in TOS3. It is interesting to compare grain protein across varieties as higher yields generally mean lower proteins through dilution of available nitrogen (N), however when two similar yielding varieties have significant differences in protein, it is safe to assume that genetic traits are also dictating grain protein levels. This was seen in varieties such as Tenfourᶲ and LongReach Lancerᶲ producing similar average yields, yet a 2% difference in grain protein.

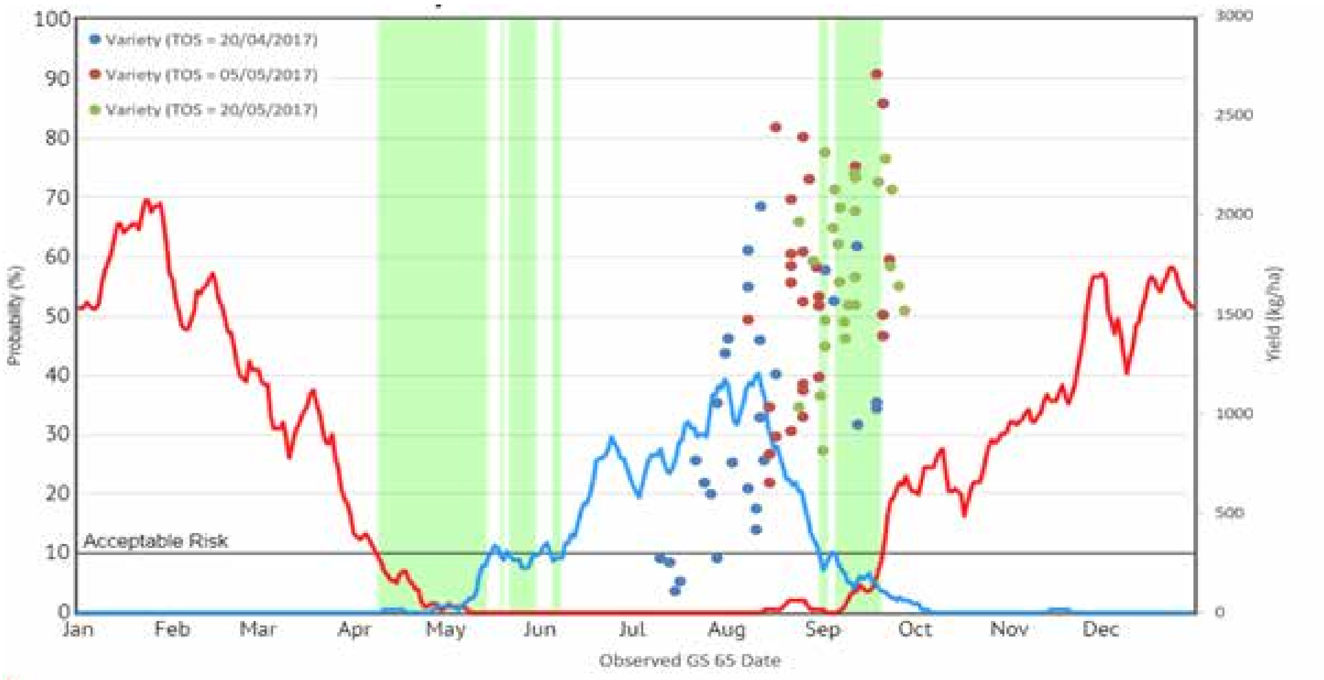


Figure 8. All three Wellcamp TOS flowering date results superimposed over a CliMate app risk model evaluating the likelihood of temperatures above 30°C or below 2°C for any given date using historical data since 1990; the green columns indicate times of year when the risk of the temperature either exceeding 30°C (red line) or dropping below 2°C (blue line) is less than a 1 in 10 year likelihood; P(0.05)

Implications for growers

The relationship between biomass accumulation and time to GS65 was evident for both sites, particularly for the mid and quick spring wheat type varieties. Interestingly, that correlation disappeared by GS90 for Emerald (possibly due to temperature stress), yet was maintained for the Wellcamp site for at least the quick varieties. Biomass accumulation was higher at the Wellcamp site, however considering the compromised yield data due to weather events, it is unknown if this would have been converted to extra yield or was just related to the difference in row spacing configuration.

2017 was an exceptional year for frost, particularly at the Wellcamp site. The aim of any wheat grower must be to get the crop flowering during a period where frost risk is minimised, yet not at the cost of heat stress. This can be seen when you look at historical data in the CliMate app for the site (Figure 8), and then superimpose the yield x flowering date data from 2017. Some general rules of thumb are to aim for a period when daily minimums don't drop below 2°C (blue line) and ideally don't exceed 30°C (red line).

For this example we have chosen an accepted risk of either of the thresholds being exceeded is a 1 in 10 year event (represented by the line across at 10% probability). If we were prepared to accept a 1 in 2 year's risk, it would 50%, and so on. Based on historical data, (in this case 1990-2017) the likelihood of daily temperatures NOT exceeding 30°C or dropping below 2°C is less than one in 10 anywhere you see the green columns on the graph. This lines up with where optimum yields were achieved, even for a disastrous year like last year. However, if we pushed planting dates back into mid or late June, the risk of a heat stress event during flowering would have spiked considerably.

Acknowledgements

This experiment was part of the project 'Optimising grain yield potential of winter cereals in the Northern Grains Region', Bilateral Agreement G104, 2017-2020, co-invested by the Grains Research and Development Corporation and New South Wales Department of Primary Industries under the Grains Agronomy and Pathology Partnership (GAPP) in collaboration with the Queensland Department of Agriculture and Fisheries.

Trial details

Location:	Emerald
Crop:	Wheat
Soil type:	Grey cracking Vertosol with PAW down to 150 cm in excess of 230 mm
In-crop rainfall:	61 mm from TOS1 to harvest in 9/10/2017, 25 mm of irrigation was also applied between TOS1 and 2, to assist with emergence, no additional water was applied
Nutrition:	Soil tests indicated sufficient N to ensure yield was not limited; 35 kg/ha of Granulock® Z was applied with the seed at planting

Location:	Wellcamp
Crop:	Wheat
Soil type:	Black Vertosol, strongly self-mulching down to 1.25 m, sitting on a more alkaline red to brown medium to heavy alkaline clay
In-crop rainfall:	251 mm (160 mm fell between 1 October and harvest in November). A number of sharp storms crossed or passed near the site during October: pea size hail on 24 October caused significant head shattering, and winds on 19 October also caused shattering
Nutrition:	Soil tests indicated sufficient N to ensure yield was not limited; 35 kg/ha of Granulock® Z was applied with the seed at planting

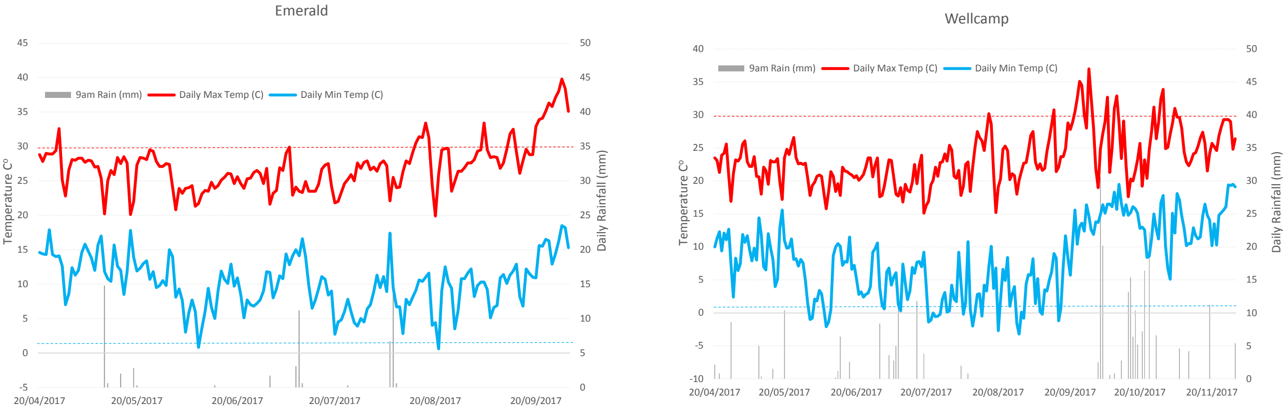


Figure 9. Daily rainfall, minimum and maximum weather observations for Emerald and Wellcamp
Note the blue and red dotted bars at 2°C and 30°C; these are the points where possible cold stress or heat stress could have occurred to the trial

The Wellcamp site received hail on 24 October 2017, causing significant head shattering and limiting the usefulness of the harvested yield data at this site

Wheat: impact of plant population, row spacing and time of sowing on yield—Emerald

Darren Aisthorpe
Department of Agriculture and Fisheries

RESEARCH QUESTION: *What is the yield impact of low establishment on early planted wheat crops in central Queensland?*

Key findings

1. Plant early and keep plant establishment as high as possible to maximise yield irrespective of variety or row spacing configurations.
2. Increase in yield as plant population increased was less in the April plant compared to the May planted treatments, however April planted treatments generally out-yielded May treatments.
3. If planting in less than ideal conditions (such as moisture seeking), plant as early as possible to maximise yields with varieties that compensate well at low populations when planted early, such as LongReach Gautlet$^{\phi}$ and LongReach Lancer$^{\phi}$.

Background

Building on the Variety Specific Agronomy Packages program work in 2015 and 2016 investigating the impact of row spacing (rs) x population (pop) x variety on yield, this trial looks to take the research further by adding the element of time of sowing (TOS) into the equation. Anecdotal evidence from the 2015 and 2016 TOS trials indicated that early planted wheat (but still planted within a reasonable planting window to avoid both frost and heat stress), with lower plant populations appeared to compensate well and yielded similarly to later planted treatments with significantly increased established plant populations. Further investigation of this observation was of particular interest given this type of scenario often occurs in Central Queensland (CQ) when wheat is deep planted early in the winter season and plant establishment can be lower as a result.

What was done

Five wheat varieties were tested for their response to a range of plant populations, row spacings and time of sowings.

The experiment was a split-plot design consisting of four replicate blocks, split for four main plots randomly allocated to row spacing by two time of sowings. Five varieties by four target plant populations were randomly allocated to 20 sub-plots within each main plot.

The treatments were:

1. Wheat varieties: EGA Gregory$^{\phi}$, LongReach Gauntlet$^{\phi}$, LongReach Lancer$^{\phi}$, LongReach Spitfire$^{\phi}$ and Suntop$^{\phi}$
2. Target populations: 30, 60, 90 and 150 plants/m^2
3. Row spacings: 25 and 50 cm
4. Time of sowings (TOS) : 21 April and 17 May 2017.

The trial was planted using a cone planter with Boss Ag TX45 parallelograms. Establishment, flowering and maturity date and head counts were recorded. The trial was harvested 27 September 2017 with post-harvest grain quality observations made on sub samples collected.

Results

When the data was analysed a four way interaction was observed between row spacing, density, TOS and variety (Figure 1). The statistical significance of row spacing was the weakest of the interactions and only occurred in very limited scenarios. Higher yields were observed for the first time of sowing compared to the second, in line with previous research, particularly at established populations lower than 50 plants/m^2. Varietal responses to TOS were different with the May sowing date being significantly more sensitive to established plant population than the April planting.

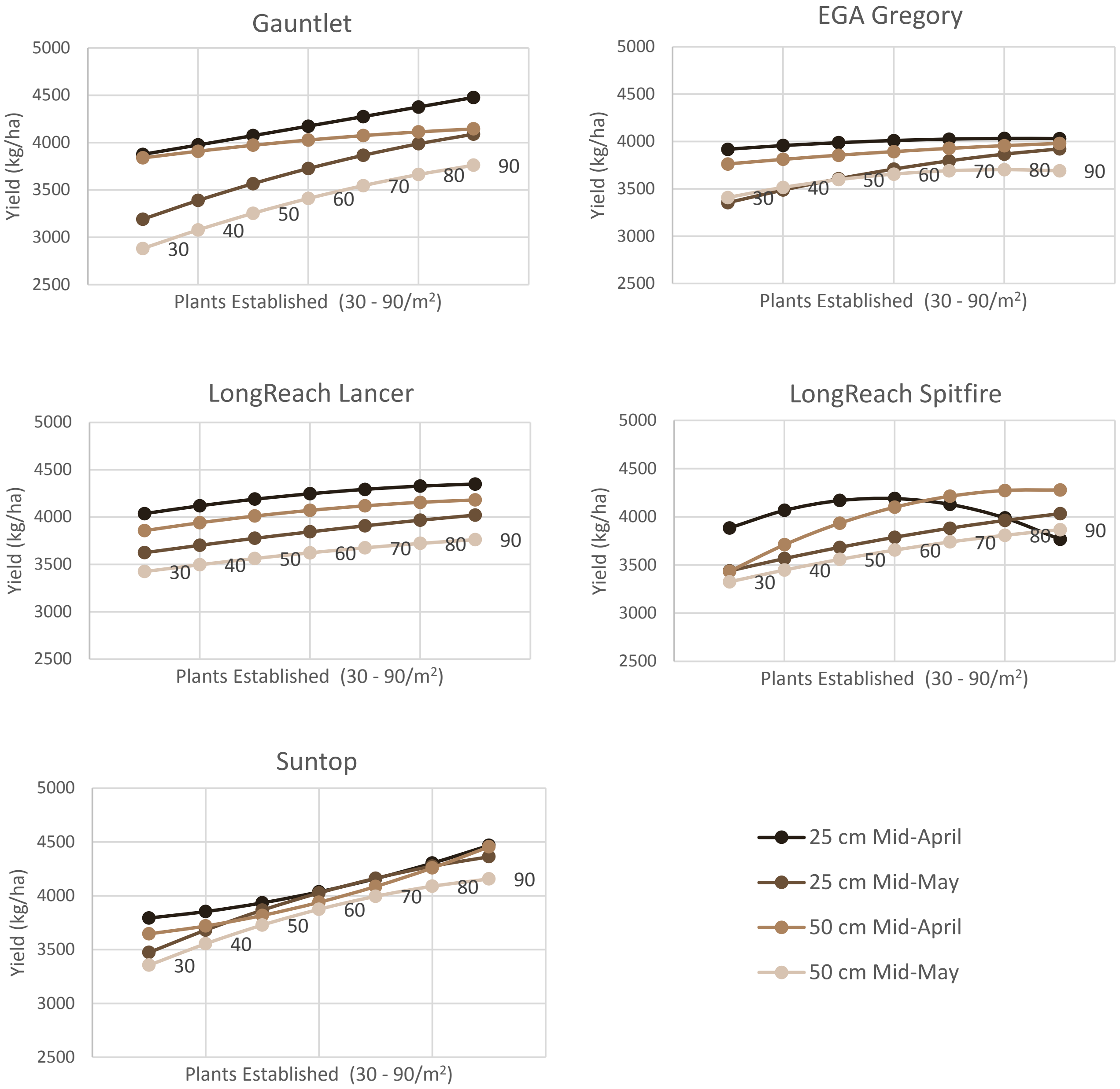


Figure 1. Varietal response to row spacing, establishment and TOS

185 kg/ha Standard Error of Difference (sed); P(0.05)

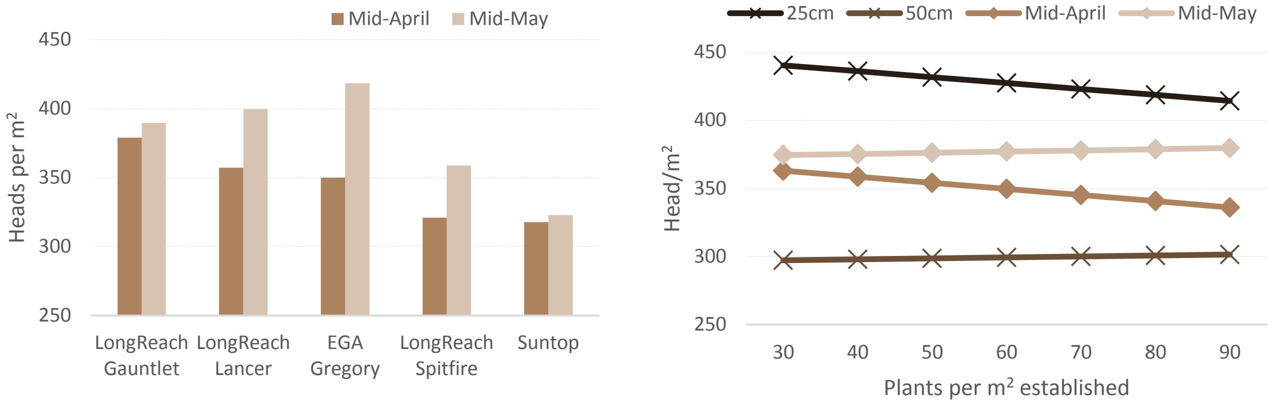


Figure 2. Average maturity headcounts for all treatments

lsd across varieties = 1.977; different letters indicate a significant difference; sed in line graph, across row spacing is 11 and across TOS is 12.1; P(0.05) for both graphs

EGA Gregoryᶲ's yield response was relatively flat (particularly for the April planted treatments) across population densities and TOS dates, conversely LongReach Gauntletᶲ showed a significant yield response to population, and TOS dates (yield increased as population increased), with the highest yield achieved in the April TOS. Also note the spread between the late planted wheat and the early planted wheat yields, particularly at lower populations (less than 50 plants/m^2) for LongReach Gauntletᶲ, LongReach Lancerᶲ and EGA Gregoryᶲ.

The effect of TOS on screenings was variable with LongReach Gauntletᶲ and LongReach Spitfireᶲ not increasing significantly from the April TOS date to the May TOS (Table 1). However, LongReach Spitfireᶲ was the only variety with screenings in excess of 5% for the first TOS date.

Table 1. Effect of TOS date on screenings (%)

	TOS			
Variety	mid-April		mid-May	
EGA Gregoryᶲ	4.6	c	7.5	g
LongReach Gauntletᶲ	4.0	b	3.9	ab
LongReach Lancerᶲ	3.5	a	4.9	cde
LongReach Spitfireᶲ	5.2	e	5.2	de
Suntopᶲ	4.8	cd	6.1	f
lsd	2.17			

Least Significant Difference (lsd) 2.17; P(0.05)

Headcounts were taken at GS90 (plant maturity) pre-harvest for all treatments. In the varietal comparison, only Suntopᶲ and LongReach Gauntletᶲ did not have significantly different headcounts between the two sowing dates. There was no significant difference in headcounts from the low to high established populations (Figure 2). The 25 cm row spacing wheat had significantly higher head numbers than the wider row spacing wheat, however the number of heads reduced as plant populations increased.

Similarly, the mid-May planted wheat showed no significant change in heads across the establishment range, however for the mid-April planting, head counts reduced significantly as establishment increased.

Implications for growers

Narrow row spacing configurations appear to have maximised yield in this trial from 2017, however, the difference between the two row spacing configurations was not statistically significant. From a trial as multi-faceted as this, it is always challenging to draw definitive conclusions, however there are some clear messages to emerge from the data.

- Plant early and keep plant establishment as high as possible to maximise yield no matter what variety or row spacing configurations.
- Increase in yield as plant population increased was less in the April plant compared to the May planted treatments, however April planted treatments generally out yielded May treatments.
- If planting in less than ideal conditions (such as moisture seeking), plant as early as possible to maximise yields with varieties that compensate well at low populations when planted early, such as LongReach Gautletᶲ and LongReach Lancerᶲ.
- Screenings increased significantly in three of the five varieties from the April to the May TOS dates.
- More heads on the plant does not equal more yield.

Acknowledgements

This trial was funded by the Department of Agriculture and Fisheries.

Trial details

Location:	Emerald
Crop:	Wheat
Soil type:	Soil type: Grey cracking Vertosol with PAW to 150 cm in excess of 230 mm
In-crop rainfall:	152 mm Emerald from TOS1 to harvest in 27 September; 25 mm of irrigation was applied between TOS1 and 2 to assist with emergence of TOS1; no additional water was applied
Nutrition:	Soil tests indicated sufficient N to ensure yield was not limited. 35 kg/ha of Granulock Z® was applied with the seed at planting

Sorghum: row configuration x plant population—Emerald

Darren Aisthorpe[1] **and Simon Clarke**[2]
[1]Department of Agriculture and Fisheries
[2]Queensland Alliance for Agriculture and Food Innovation

RESEARCH QUESTION: *Is there potential to increase yields and profits by matching sorghum hybrid selection and management to the available resources, e.g. initial soil water and expected seasonal conditions, in rainfed cropping systems?*

Key findings

1. The highest yields were obtained with a solid 1 m row spacing.
2. Screenings increased as population density increased.
3. Further work required in finding a balance between yield and grain quality.

Background

In rainfed cropping systems in Central Queensland (CQ), traditional sorghum agronomic practices are based on the industry standard hybrid, MR-Buster, planted with a traditional air seeder or cog type metering system. The cropping systems have been developed around this 20+ year old variety, and its propensity to compensate for sub-ideal establishments or above average rainfall years, yet still yield in poor seasons.

The ability of MR-Buster to compensate has allowed target populations to be reduced, and row spacing to be widened with lower yield loss in an above average year and some security of income in a below average season. However, for modern hybrids, it is possible that this agronomic management may not optimise yield. This research aims to investigate if there is potential to increase yields and profits by matching hybrid selection and management to the available resources, e.g. initial soil water, and expected seasonal conditions.

What was done

The trial was planted on the 14 February 2017 at the Emerald Research Facility using a Monosem double disc precision planter. Four varieties were planted: MR-Buster, MR-Apollo, MR-Bazley and MR-43. The trial was planted in solid and single skip row configurations based on a 1 m row spacing.

Flowering dates were recorded during the growing season with flowering occurring between 22 April and 28 April. Biomass cuts were taken prior to the mechanical harvest. The plant material was split into main stem and tillers to allow assessment of both where yield was being produced and relative grain quality.

Ex-cyclone Debbie passed over the Emerald region at the end of March (prior to flowering), bringing rain of up to 45 mm and wind gusts in excess of 50 km/h. Post-Debbie there was little to no rain received during the critical flowering and grain fill periods (see Trial details).

Results

Establishment was lower than the original target levels and while it did vary between varieties, on the whole, it was relatively consistent across treatments (Figure 1).

There was minimal, yet statistically significant variation in flowering dates between varieties and treatments. There was a six day difference between the earliest and latest treatment to achieve 50% flowering (Figure 2).

Machine harvested yields across the trial showed a significant difference in yield between hybrids and row spacing configurations (Table 1). There was not a significant difference for the plant population treatment. MR-Buster and MR-Bazley were the highest yielding hybrids, both producing around 6.8 t/ha. The solid row configuration produced 1 t/ha more than the skip row configuration. Overall, predicted yields were well above the industry average for the region (3.5 t/ha).

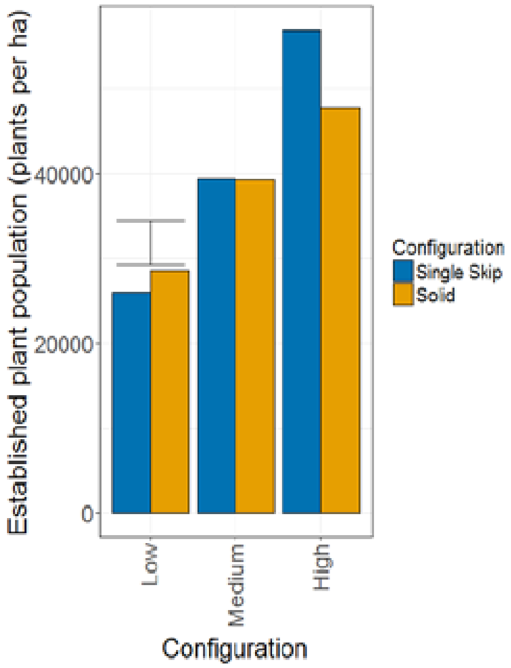


Figure 1. Establishment in plants/ha across treatments for the three population densities
lsd is 5150 plants/ha; P(0.05)

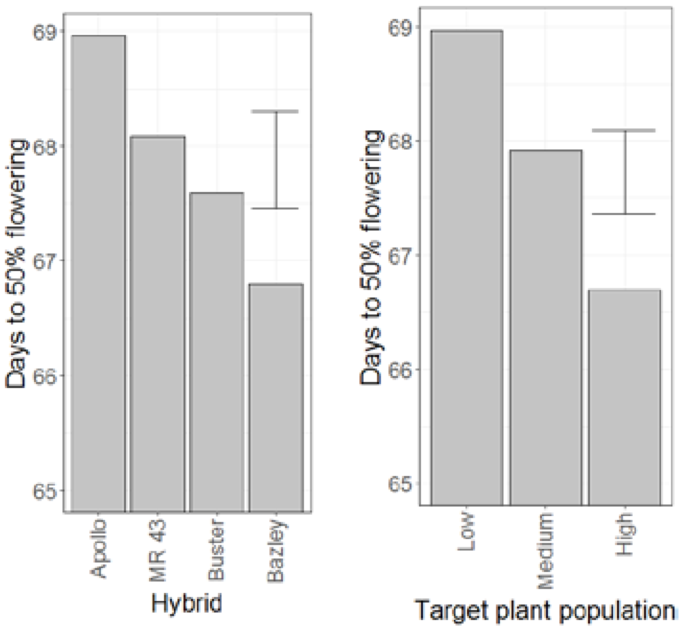


Figure 2. Average days to 50% flowering for all varieties and row spacing configurations.
Significant difference indicated on graph; P(0.05)

Table 1. Average yield results for variety comparison and row configuration comparison; P(0.05)

Hybrid	kg/ha	lsd
MR-Buster	6930	a
MR-Bazley	6805	ab
MR-43	6594	bc
MR-Apollo	6480	c
Average lsd	309 kg	

Configuration	kg/ha	lsd
Solid	7179	a
Single Skip	6226	b
Average lsd	298 kg	

At the low density, on average, MR-Buster and MR-Bazely produced more than 40% of the total yield on tillers (Figure 3). As population density increases, there was a consistent reduction in tiller count for all varieties. MR-Buster still had a higher yield contribution from tillers than the other varieties at the high density configuration. Both MR-Apollo and MR-Bazley had the lowest tiller contributions at the highest target density. While there was no statistical difference in yield between the three population densities, it is apparent that there was a trend of yield increase as population density increased.

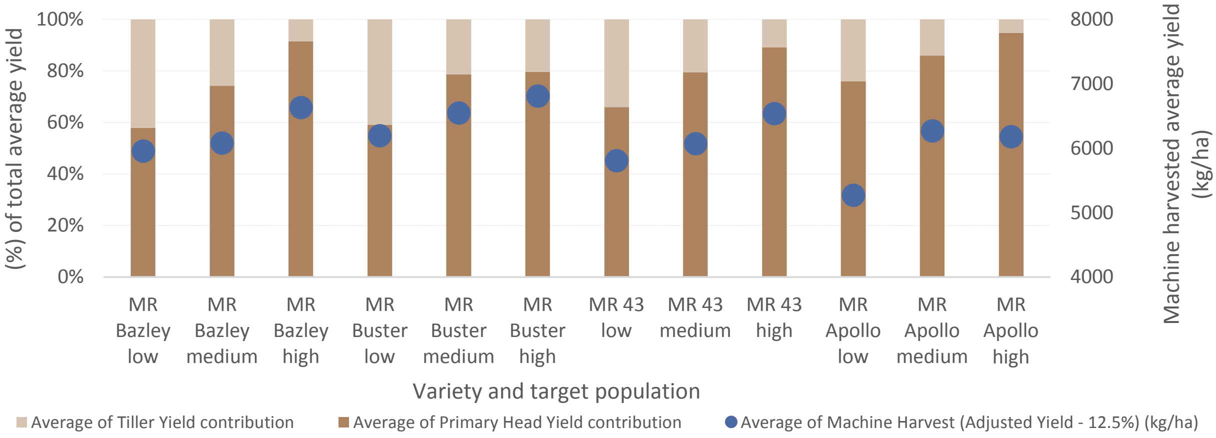


Figure 3. Average yield and yield contribution across population treatments. The graph also depicts main stems and tiller stems contribution to total yield. There was a statistical difference between varieties (Table 1), however there was no statistical difference between target density yields

Plant biomass production was reflective of final yield (Table 2), with respect to the difference between solid and skip row planting configurations. However there was no significant difference in biomass across the target population densities, and only a minimal difference between varieties across treatments. Only MR-43 produced sufficient additional biomass to be statistically different to the other three varieties.

Table 2. Difference in biomass production between the two row configurations; P(0.05)

Configuration	kg/ha	lsd
Solid	10852	a
Single Skip	8710	b
Average lsd	1520 kg	

While all commercial varieties on the market will produce tillers, there is some variation between hybrids as to how prolific the tillering will be for a given agronomic scenario. Tiller numbers on average decreased as population increased (Figure 4). There was insufficient data to conclusively show a significant difference between varieties, however there does appear to be a strong trend towards MR-Buster and MR-Bazley having higher tiller counts.

In Figure 5, population does show an increasing trend on the main shoot screenings, however that trend is stronger for tillers, despite not being considered statistically significant.

Hybrid also appears to be a significant driver as on average MR-Bazley had significantly lower screenings than MR-Apollo or MR-Buster.

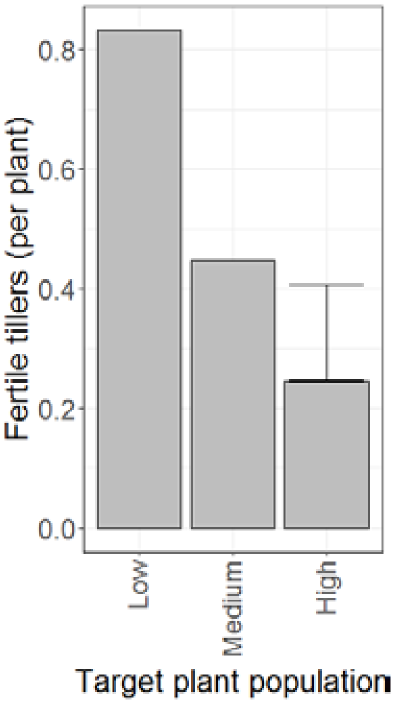


Figure 4. Population response to fertile tiller production; P(0.05)

Table 3. Average Screenings between varieties; P(0.05)

Hybrid	lsd	Back transformed predicted screenings (%)
MR-Apollo	a	4.11
MR-Buster	a	3.79
MR-43	ab	3.63
MR-Bazley	b	2.96
Average lsd		0.233

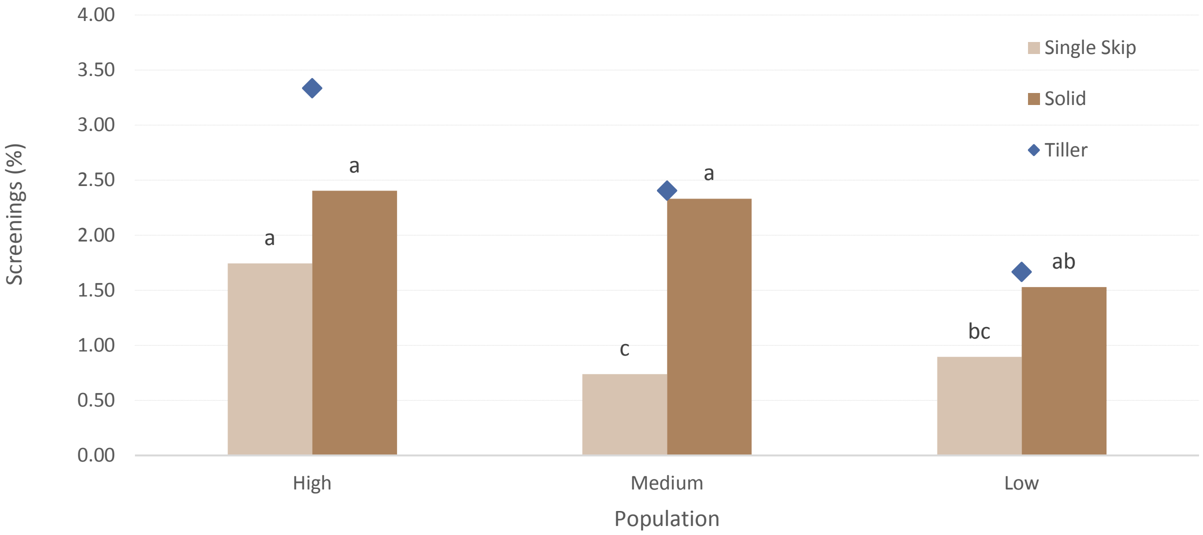


Figure 5. Screenings response to population
Different lower cap letters indicate a significant difference for main stem tiller response P(0.05); bot not for the average tiller response, P(0.055)

Implications for growers

Screenings are typically a symptom of moisture stress during the grain fill period, generally when the plant has set more seeds than it is capable of filling. Post ex-cyclone Debbie, there was little to no rain between the end of March and mid-June, the peak grain fill period for the crop, while daily average maximum temperatures remained above 28°C and minimum temperatures didn't drop below 15°C until mid-May (Figure 6). MR-Bazley in this trial produced high yields and the lowest screenings across the four varieties.

This research trial has shown that genetic and agronomic factors affected the grain yield, and the formation of yield derived from main shoots or tillers. The observation that MR-Bazley sown at low plant populations showed lower screenings than MR-Buster, despite both having a large proportion of the yield formed on tillers, questions the assumption that tiller yield increases screenings. Growers will need to balance the overall yield potential and risk of screenings in their management decisions.

Acknowledgements

Thanks to Queensland Alliance for Agriculture and Food Innovation (QAAFI) Toowoomba (James McLean, Joseph Eyre & Daniel Rodriguez), the Department of Agriculture and Fisheries and the Grains Research and Development Corporation for funding the project as part of UQ000075 'Tactical agronomy for sorghum and maize'.

Trial details

Location:	Emerald DAF Research Facility
Crop:	Sorghum
Soil type:	A cracking, self-mulching, Grey Vertosol in excess of 1.5 m deep. Estimated PAWC to 1.5 m of approximately 240 mm. Starting PAW at planting was 195 mm. Post-harvest PAW indicated average PAW was ~140 mm to 1.5 m, more than 70 mm of that was sitting below 1 m depth
In-crop rainfall:	222 mm of rain in-crop. The field was pre-irrigated before planting, then 25 mm of water was applied after a side dressing of N
Fertiliser:	Previous testing indicated that no starter fertiliser was required. 143 kg/ha of N was available at planting down to 150 cm. 138 kg/ha of N was applied 7 March 2017. Post-harvest, an average of 59 kg/ha of N was available

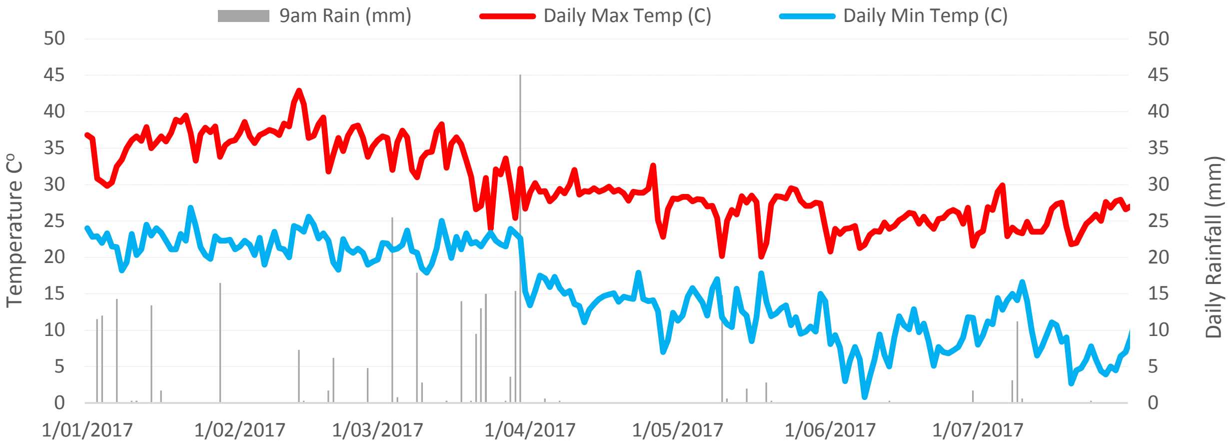


Figure 6. Daily minimum and maximum temperature ranges experienced during the duration of the trial

Maize: hybrid by population by row configuration—Emerald

Simon Clarke[1] and Darren Aisthorpe[2]
[1]Queensland Alliance for Agriculture and Food Innovation
[2]Department of Agriculture and Fisheries

RESEARCH QUESTION: *Can different maize hybrid and agronomy combinations optimise production to suit local and expected conditions by maximising yields and profits and minimising risks?*

Key findings

1. 1.5 m wide rows yielded about 0.5 t/ha more than 1 m rows.
2. Hybrid Pac 606IT was high yielding across all tested population and row configuration combinations.
3. Pac 606IT at 40,000 plants/ha yielded about 1 t/ha more (on average) than the other treatments.

Background

Currently sorghum is the dominant dryland cereal crop in Queensland due to lower production costs and greater yield reliability than other summer cereals. However, having well-adapted maize hybrids and agronomy packages for Central Queensland (CQ) will provide options for farmers to diversify cropping systems and profit from emerging market opportunities.

Understanding how different maize hybrids and agronomy combinations perform across sites and seasons will help farmers optimise their maize production to expected conditions, maximising yields and profits, and minimising risks.

What was done

The trial was planted 16 February 2017 at the Emerald Research Facility using a Monosem double disc precision planter. Four hybrids were planted: Pioneer P 1070, Pioneer P 1414, Pioneer P 1467 and Pacific Seeds Pac 606IT. The trial was planted on two row spacing configurations: 1 m solid and 1.5 m solid spacing. Target populations were 20,000, 40,000 and 60,000 plants/ha. Soil samples were taken prior to planting for analysis. Additional nitrogen was side dressed after emergence to ensure yield was maximised.

Emergence occurred within four days and was within 10% of the target population excluding a planting error in the high density (60,000 plants/ha) treatment for P 1467. Unfortunately both the 40,000 and 60,000 plants/ha treatments for this hybrid were planted at the same density of 40,000 plants/ha. Flowering and silking dates were recorded during the growing season, maturity dates were measured and biomass samples taken prior to mechanical harvest of all plots. During biomass collection, the plant material was partitioned to identify where yield was produced. Seed quality was also measured.

Prior to flowering, ex-tropical cyclone Debbie passed close to the Emerald region, bringing up to 45 mm of rain and wind gusts in excess of 50 km/h. A number of treatments were affected by this combination, resulting in lodging. There was little rain during the flowering and grain fill periods (see Trial details).

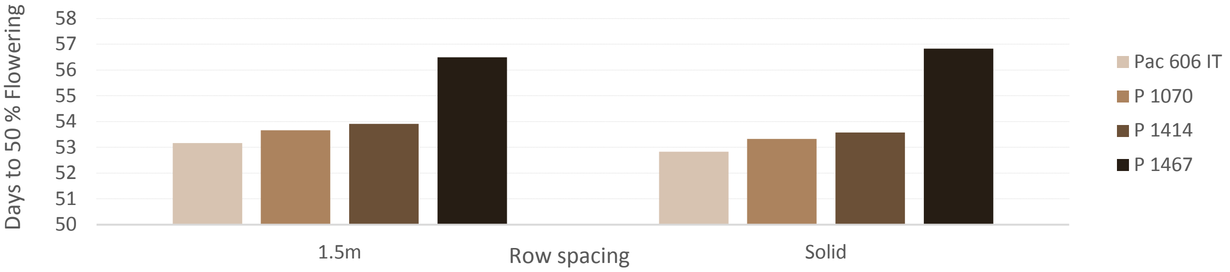


Figure 1. Average days to flowering for both row configurations

Results

Flowering and silking occurred between 8 April and 14 April. Difference between the four hybrids in days to flowering were observed, with P1467 being the longest (Figure 1). Across population densities, the range in time to flowering was less than three days.

Maturity biomass samples were collected 20 June, with the objective of not only assessing total biomass production, but also the contribution tillers and secondary cobs made to final yield. Differences were observed between hybrids with Pac 606IT and P 1414 producing significantly more biomass on average than P 1070 (Table 1). As was expected a plant density of 40,000 and 60,000 plants/ha produced significantly more biomass than the lower plant population of 20,000 plants/ha (Table 2). However there was no significant difference in biomass between plant density and hybrid, nor was there a statistically significant effect of row spacing on biomass.

Table 1. Average biomass production for all four hybrids across the treatments

Hybrid	Biomass (kg/ha)	lsd
Pac 606IT	10154	a
P 1414	10045	ab
P 1467	9030	bc
P 1070	8938	c
Average lsd:	1050 kg/ha	

Treatments denoted by contrasting letters are significantly different

Table 2. Average biomass production for all three target densities across all treatments

Density ('000/ha)	Biomass (kg/ha)	lsd
20	8553	a
40	10480	b
60	9593	b
Average lsd:	906 kg/ha	

Treatments denoted by contrasting letters are significantly different

Significant differences were observed across treatments in yield. However the lodging appeared to have an effect on final yields, particularly for the quick Pioneer varieties, P 1070 and P 1414 (Figure 2). The three quicker varieties were more significantly affected than the longer season and less advanced P 1467, suggesting growth stage was the more important determinant of susceptibility to lodging than hybrid.

Irrespective of the hybrid or plant population, 1.5 m wide rows yielded about 0.5 t/ha more than 1 m rows (Table 3). A population of 40,000 plants/ha provided higer yields than 20,000 or 80,000 (Figure 3). The highest yielding variety was Pac 606IT (Figure 4).

Table 3. Average yield x row spacing configuration

Configuration	Avg. yield (kg/ha)	lsd
1.5m	3885	a
Solid	3425	b
Average lsd:	386 kg/ha	

Difference in letter indicates statistically difference in result; P(0.05)

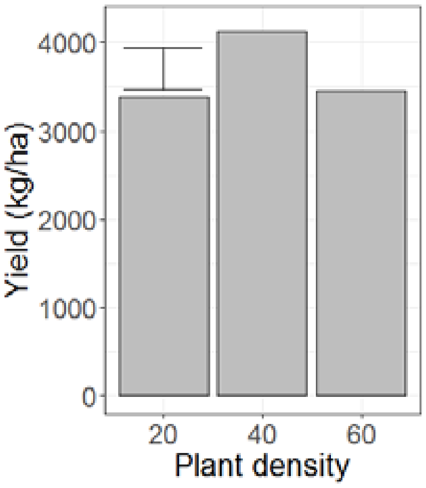


Figure 3. Average yields across varieties and row spacing configurations for target plant populations; lsd was 472 kg/ha; P(0.05)

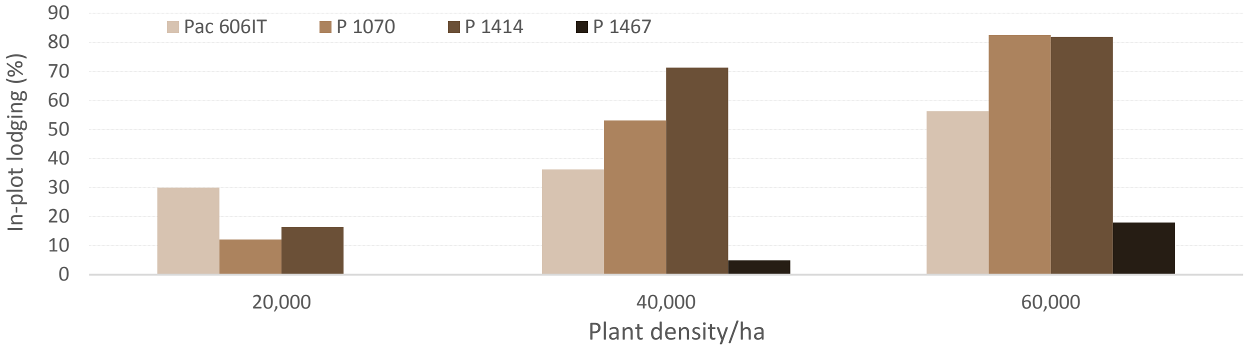


Figure 2. Effect of lodging between treatments as a result of cyclone Debbie

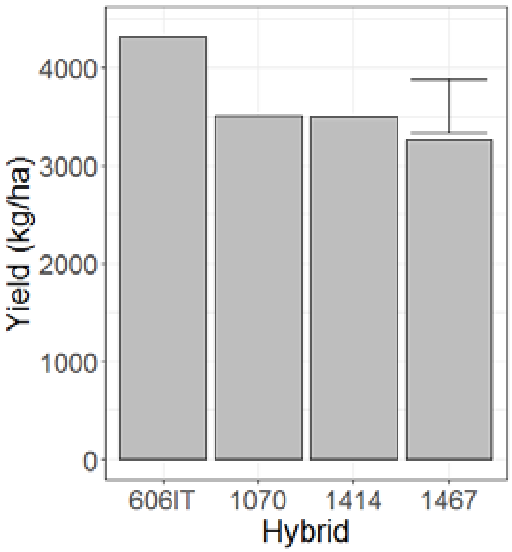


Figure 4. Average yield across row spacing and density treatments; lsd is 555 kg/ha; P(0.05)

Implications for growers

This trial provides an excellent example of how hybrid, population density and row configuration can influence yield and economic returns in a particular site and season. However, the optimum selection will change season-to-season depending on weather patterns.

An important observation was the lack of tillering across most of the hybrids. Even in low density treatments, tillers accounted for less than 10% of total biomass, which flowed through to yield. At the low density 1 m treatment, tillers accounted for less than 9% of total yield, and made negligible contributions to yield in the high density treatments.

Both yield and biomass, for this particular trial, point towards the wider row spacing configuration being the optimum configuration at a plant population of 40,000 plants/ha. Harvest index (total yield/biomass) also suggests the wider row spacing was more efficient than the narrow row configuration at converting biomass into yield. In terms of water use efficiency (WUE) (Figure 5), the 1.5 m row spacing made better use of the water available during the growing season, with the 40,000 plants/ha treatment having the highest WUE. In contrast, WUE of the 1 m configurations declines with increased population.

Acknowledgements

James McLean, Joseph Eyre and Daniel Rodriguez from Queensland Alliance for Agriculture and Food Innovation Toowoomba, the Grains Research and Development Corporation (as part of UQ000075 'Tactical agronomy for sorghum and maize') and the Department of Agriculture and Fisheries for funding the project.

Trial details

Location:	Emerald Research Facility
Crop:	Maize
Soil type:	Cracking, self-mulching, grey Vertosol in excess of 1.5 m deep PAWC to 1.5 m: ~240 mm (estimated) PAW at planting: 153 mm Harvest PAW: ~129 mm
In-crop rainfall:	222 mm of rain in-crop, 320 mm cumulative by trial's end. Pre-irrigated before planting; additional 25 mm water applied after N side dressing
Fertiliser:	78 kg/ha of N available at planting, 138 kg/ha of N applied as a side dressng after emergence, and 74 kg/ha of N present in the soil at harvest

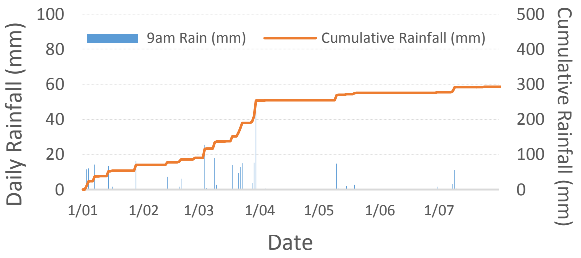


Figure 6. Rainfall during the trial

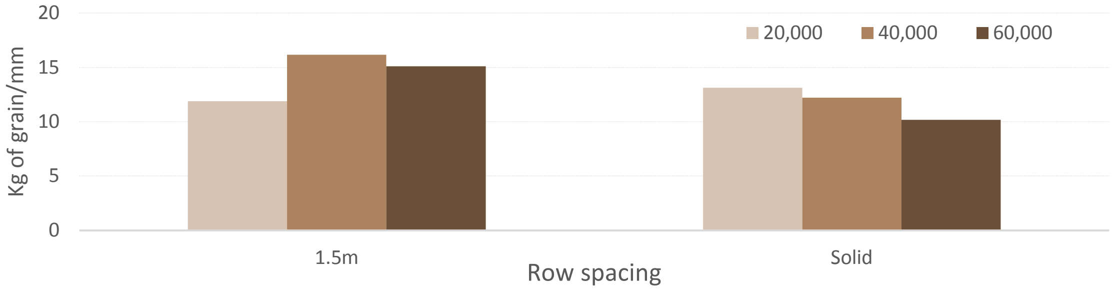


Figure 5. Average water use efficiency (kg of grain/mm water used) between row densities and row spacing configurations

Pulse research

Over the past four years there has been a series of trials in both southern Queensland (SQ) and Central Queensland (CQ) focused on the interaction between genetics, environment and management (GEM) for mungbeans, chickpeas, faba beans and soybeans. This approach has had a strong focus on plant physiology and hence a number of the outcomes were measured not only by grain yield but also by dry matter production, harvest index and water use efficiency.

Trials conducted so far have incorporated spatial variability (populations and row spacing), weather impacts (time of sowing), water use efficiency (irrigated and dryland) and biomass manipulation across a number of commercial varieties (genetics). These trials not only gave information that can be directly related to best practice agronomic recommendations but can also help define the plants' key physiological characteristics, which in turn can be used to inform future areas of productivity improvement.

The 2017 trials have basically confirmed and added to a number of key findings from previous trial data; for example, the 2017 mungbean trials showed a yield response to narrow rows (25 cm) that could increase profitability up to $530/ha. Time of sowing continues to play a major role in yield potential with March plantings in CQ almost doubling yield compared to planting in December. Mungbeans are particularly vulnerable to stress situations, being driven by plant-water relationships that are impacted by temperature, humidity and evaporative demand. Responses to irrigation events can be variable depending on weather and timing of application. Mechanisms for improving biomass accumulation generally improve grain yield unless conditions at flowering are extreme.

Chickpea experiments are showing the relationship between dry matter and grain yield is not consistent. May has long been regarded as the optimum planting window in CQ for chickpeas and in this 2017 experiment that was confirmed, and coincidently harvest index was also maximised. The 2017 trials provided the first opportunity to manipulate biomass, particularly in early sowing windows, and provided interesting responses but no yield improvements. Time of sowing was also seen to be the main driver of yield in the SQ faba bean trial.

The future of mungbean research is bright with new mungbean projects commencing in 2018 that will continue to provide further understanding into mungbean agronomy and physiology.

Interactions of mungbean physiology in relation to time of sowing, row spacing, variety and foliar nitrogen application—Emerald

Doug Sands
Department of Agriculture and Fisheries

RESEARCH QUESTION: *Is grain production and vegetative yield in mungbeans significantly influenced by time of sowing, soil water conditions, variety, row spacing and foliar nitrogen application?*

Key findings

1. Planting in early March almost doubled yields compared with planting in early December.
2. Additional irrigation had the biggest impact in the December sowing (47%).
3. Foliar nitrogen had a small impact on yield in the March sowing but only under dryland conditions on narrow rows (12%).
4. Jade-AU⦻ was slightly more productive than Satin II⦻ in a January sowing.

Background

Over the past three years the Queensland Pulse Agronomy Initiative project (UQ00067) has conducted several trials across Central Queensland (CQ) investigating the impact of row spacing, population, variety, time of sowing (TOS) and soil water conditions on mungbean production. This work has highlighted the mungbean plant's compensatory physiology and its ability to change its structure, particularly in relation to row spacing and population. Productive differences in genetics are generally small but responses to weather conditions can be large. There have also been large differences in production when the plant has had access to only stored soil moisture versus in-crop rainfall.

Consistency in harvest index figures (0.3–0.35) across a number of these trials suggests that dry matter production will determine grain yield when there are no other restrictions evident (big plant = big yield). Factors that determine dry matter production in the first 40 days of the crop's lifecycle will ultimately determine grain yield. It is important therefore to understand what conditions have the most influence on dry matter production and how much we can influence these conditions in order to maximise grain yields.

This experiment has attempted to quantify the level of mungbean production across a range of summer weather conditions (TOS) in relation to four specific variables; soil water, variety, row spacing and foliar nitrogen application.

What was done?

The trial was conducted at the research facility based at the Emerald Agricultural College. Mungbeans were planted at three sowing dates; (TOS) 8 December, 18 January and 2 March, with each TOS block planted twice in each replicate so that one block could be supplemented with sprinkler irrigation (changing soil water conditions) with the other left as dryland. Each of these blocks were then split into two row spacing (25 cm and 100 cm) and each row spacing block was further split into eight treatments consistng of two varieties (Jade-AU⦻, Satin II⦻) by four foliar nitrogen (N) treatments (0, 10, 20 and 30 kg/ha).

The foliar N treatments were applied at a rate of 10 kg/ha with 200 L/ha of water. Each treatment got either one, two or three applications approximately two weeks apart with the first application applied 14 days after sowing (DAS). Each of the three TOS blocks were replicated three times.

Each plot was 2 m wide by 16 m long and Granulock® SuPreme Z™ fertiliser was applied with the seed at 30 kg/ha at planting.

Due to ongoing dry conditions and a short turnaround from a wheat cover crop, the trial block was pre-irrigated twice before the first planting, ensuring there were consistent soil moisture conditions. The December and March TOSs were planted with irrigation while the January TOS was planted on rainfall.

Table 1. Summary of key physiological development periods for all three sowing times

Time of Sowing	Physiological stage	Date	Calendar days	Growing day degrees (°Cd)	Rainfall (mm)	Irrigation (mm)	Starting PAWC (mm)
TOS1 (December)	Planting	8/12/2016					124
	First Flower	13/1/2017	36	628	72	50	
	Desiccation#	10/2/2017	64	1159	33	50	
TOS2 (January)	Planting	18/1/17					147
	First Flower	21/2/17	34	671	33	50	
	Desiccation#	27/3/17	68	1254	118	40	
TOS3 (March)	Planting	2/3/17					166
	First Flower	11/4/17	40	629	157		
	Desiccation#	31/5/17	90	1114	19	50	

#Desiccation decisions were made based on the maturity of pods in the dryland treatments

Neutron probe tubes were placed in the January TOS with readings taken at 10 cm intervals from a starting depth of 15 cm, down to a depth of 105 cm and data recorded twice weekly. Only select plots were monitored by neutron probe, based on row spacing and soil water treatments; variables such as variety and foliar N treatment were kept consistent. Two tubes were used in each plot so readings could be taken between the rows (inter-row) as well as within the rows (on-row).

A number of measurements were recorded throughout the life of the crop. These included starting Plant Available Water (PAW) and a full soil analysis at planting, plant counts, light interception, dry matter cuts, hand harvest, and machine harvest. Weather data was logged every 15 minutes.

Results

The complexity of this trial has meant a large amount of data has been collected and analysed. This report summarises the data and highlights the most significant findings. The results section is divided into four sub-sections; grain yield, yield components, weather and soil water.

The key agronomic development data (Table 1) shows that December (TOS1) and January (TOS2) had very similar growth patterns with both crops reaching maturity in less than 70 days. Rainfall distribution was also different; with the December (TOS) receiving good rainfall prior to flowering and the January TOS receiving good rainfall after flowering. The March TOS had a much slower growth pattern, which is more typical of southern growing areas. The March TOS also had the benefit of more rainfall in its vegetative phase leading up to flowering.

Drone image of trial site with December and January TOS in place

Grain yield

Five variables were assessed (time of sowing, soil water conditions, row spacing, variety and foliar nitrogen). A five-way analysis of the yield data has provided at least one significant interaction involving four variables; variety by foliar nitrogen by row spacing by time of sowing (TOS). This interaction (Figure 1) highlights the complexity of interpreting this information.

There was a significant relative difference between the three TOS, with yield steadily increasing in the later TOS. In addition, the yield difference between row spacing got larger as the TOS got later and the yield increased. The 25 cm rows consistently out-yielded the 100 cm rows. There are some small interactions between variety and foliar N that will be discussed later in the results section.

Further analysis was done on a four-way interaction where one variable is set as a constant. Two analyses were done:

1. TOS as a constant; interactions were sought from data plots contained within one individual time of sowing
2. Foliar N (N 0 plots only) as a constant; interactions were sought from data plots that had no foliar N applied.

1. Analysis: soil water conditions, row spacing, variety and foliar nitrogen against time of sowing

TOS1

The only significant interaction came from the difference between the soil water conditions (rainfed and irrigated) that were created by adding extra water via selective overhead irrigation applications. TOS1 was planted in December (Table 1) and had good growing conditions leading up to flowering, however at the start of flowering heat wave conditions were present and seemed to limit the flowering period for this crop in both the irrigated and rainfed treatments. Visually, the flowering period seemed similar between treatments, however yield results suggest that significantly more flowers were successful in setting grain in the irrigated treatments (Table 2).

Table 2. Means yields for main interaction in TOS 1

TOS1	Yield mean	lsd 5% (231.5)	Pods/m^2 mean	lsd 5% (38.6)
Irrigated	901.4	a	205	a
Rainfed	610.6	b	159	b

lsd = least significant difference i.e. different letters indicate significant difference

Generally yields were low so differences between treatments tended to be small. Harvest index was also low (0.12-0.19) indicating that although the plants set up for a promising yield with good height and dry matter production, conditions around flowering and pod set limited the conversion into grain yield.

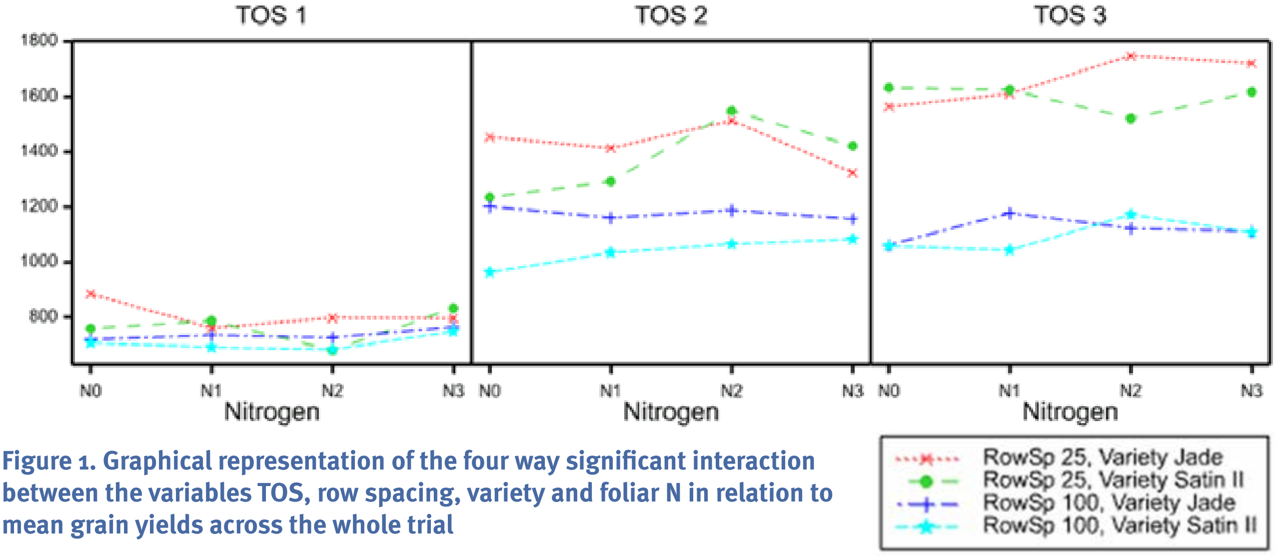


Figure 1. Graphical representation of the four way significant interaction between the variables TOS, row spacing, variety and foliar N in relation to mean grain yields across the whole trial

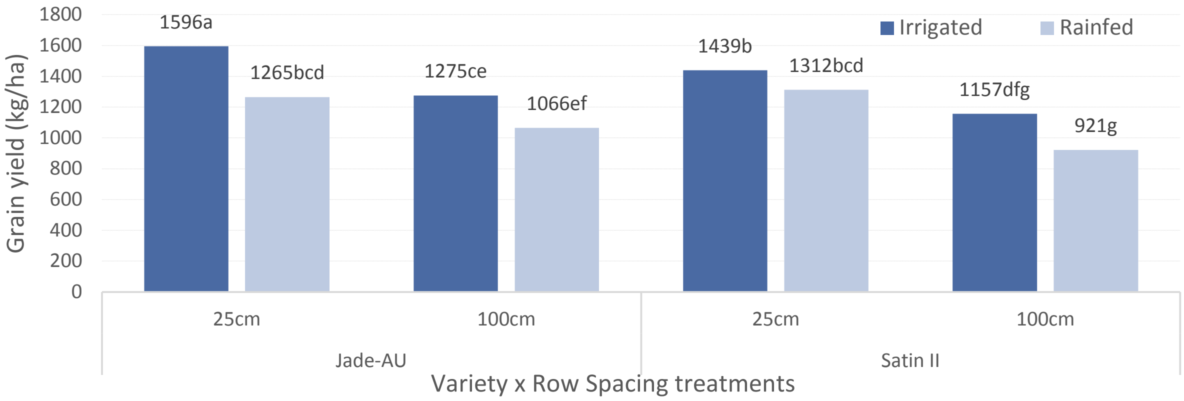


Figure 2. Mean grain yield interaction between row spacing, variety and soil moisture conditions in TOS2
Means with the same letters are not significantly different at P(0.05) level

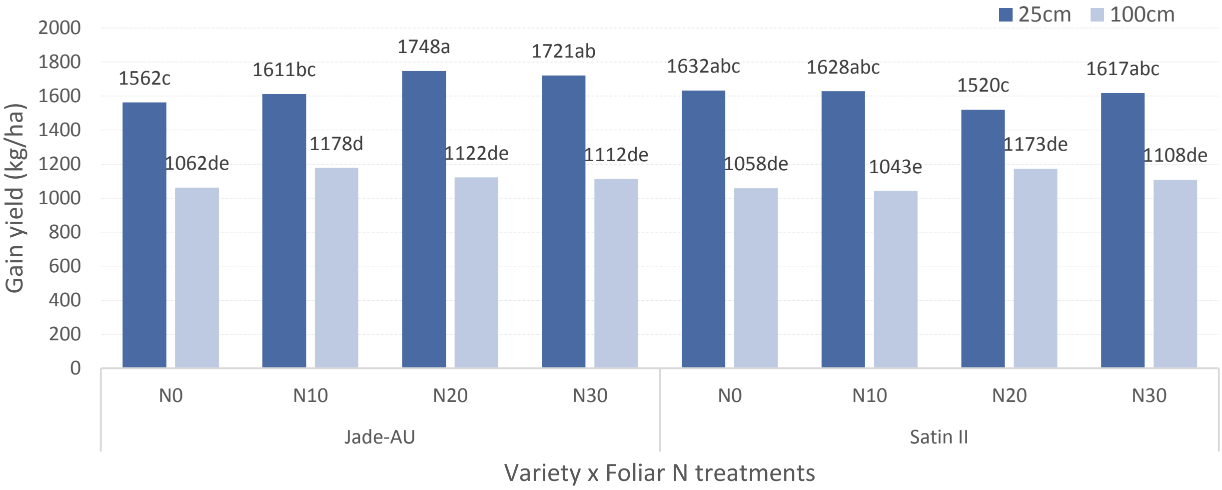


Figure 3. Mean grain yield interaction between variety, row spacing and foliar N in TOS3
Means with the same letter are not significantly different at P(0.05) level

TOS2

The interaction between row spacing, variety and soil moisture conditions was most significant in TOS2 (Figure 2). The irrigation applications only made a significant contribution to yield in the 25 cm plots planted with Jade-AU$^{\phi}$, which produced an extra 331 kg/ha (26.2%) over the rainfed plots. Irrigation made no other significant contributions in any of the other treatments.

Jade-AU$^{\phi}$ was significantly better than Satin II$^{\phi}$ when compared in 100 cm rows across both irrigated and rainfed plots. Jade-AU$^{\phi}$ also performed better in irrigated (but not rainfed) 25 cm rows than Satin II$^{\phi}$.

Within each variety, and consistent with soil water conditions, 25 cm rows performed better than 100 cm rows by at least 24% (irrigated) and 19% (rainfed).

Another significant interaction in TOS2 was variety by foliar N, however this was a more subtle interaction which could be summarised by Satin II$^{\phi}$ being more responsive to Foliar N than Jade-AU$^{\phi}$ with yield improving by a range of 12-17%.

TOS3

The major significant interaction in TOS3 was between row spacing, variety and foliar N applications (Figure 3). Within this interaction there is a clear and consistent difference in row spacing with the 25 cm rows delivering an increase in yield of 47-55.8% in Jade-AU$^{\phi}$ and 29.6–54.3% in Satin II$^{\phi}$. This is the strongest response to row spacing out of the three TOS tested in this trial.

Less obvious but still significant is the interaction between variety and foliar N. Jade-AU$^{\phi}$ responded to foliar N application by 9-10% (from Nil), whereas Satin II$^{\phi}$ had no response. This was the exact opposite of what occurred in TOS2 and it is not clear why the varieties reacted this way.

2. Analysis: time of sowing, soil water conditions, row spacing, variety against foliar nitrogen

Within the second four-way analysis the variable of foliar N is ignored to more easily examine interactions across TOS and define broader trends that are occurring across the trial. The results of this analysis suggest there are three significant components;

- Soil water conditions
- Row spacing and TOS
- Variety and TOS.

The difference between irrigated and rainfed plots amounts to just over 27% increase in yield on average across the whole trial (Table 3). Most of these differences were seen in TOS1 and TOS2 with the differences in TOS3 almost negligible (Figure 4). Late seasonal rainfall may have had an impact on the effectiveness of the irrigation treatment in the last two TOS. Additionally, the lower evaporative demand and slower growth rates may have also contributed to the similarity between rainfed and irrigated yields.

Table 3. Mean yield comparison for soil moisture conditions averaged across all treatments

Treatment	Yield mean	lsd 5% (139)
Irrigated	1238	a
Rainfed	973	b

lsd = least significant difference i.e. different letters indicate significant difference

The interaction between variety and TOS (Figure 5) demonstrates that Jade-AU$^{\phi}$ produced nearly 20% more yield than Satin II$^{\phi}$ for the January TOS, however this was not seen in either the December or March TOS. Conditions around the December TOS had a large negative impact on yield regardless of variety (50-60%) while the Jade-AU$^{\phi}$ yield was similar in the January and March TOSs.

The other main interaction in this four way analysis is between TOS and row spacing (Figure 6). This interaction shows significant differences in yield between 25 cm and 100 cm rows as the yield bracket increases across TOS. The December TOS shows no difference in row spacing when yields are low (<1 t/ha) however in subsequent plantings, significant differences emerge with the biggest yield gain being in the 25 cm rows on the March TOS (50% improvement over 100 cm rows). This yield advantage of narrow rows in situations when conditions are suitable for higher yielding crops (>1 t/ha) is consistent with previous row spacing trials. The 100 cm rows could not improve their

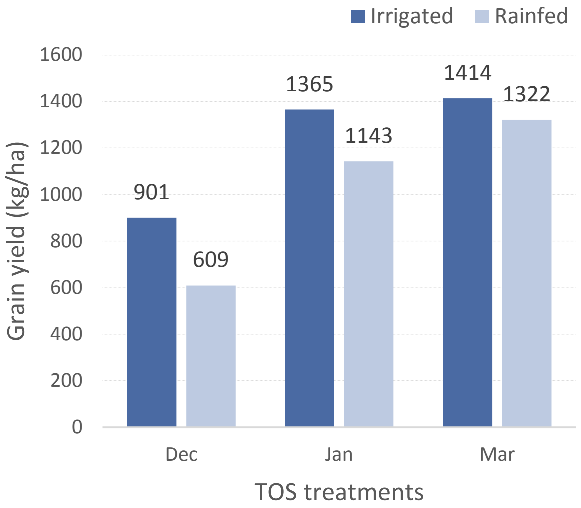


Figure 4. Mean grain yields for irrigated and rain grown treatments across the three TOS

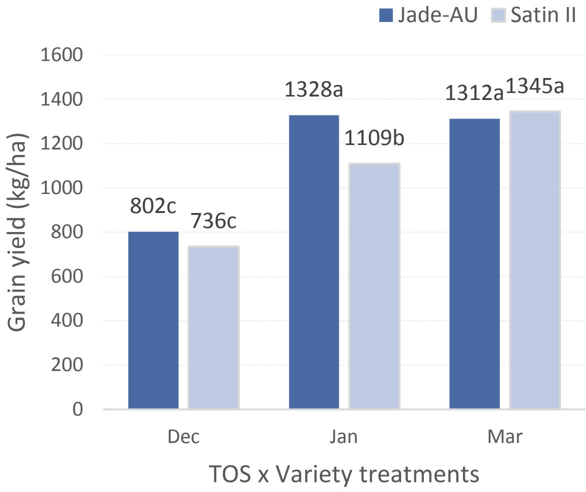


Figure 5. Mean grain yields for varieties compared across all TOS

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

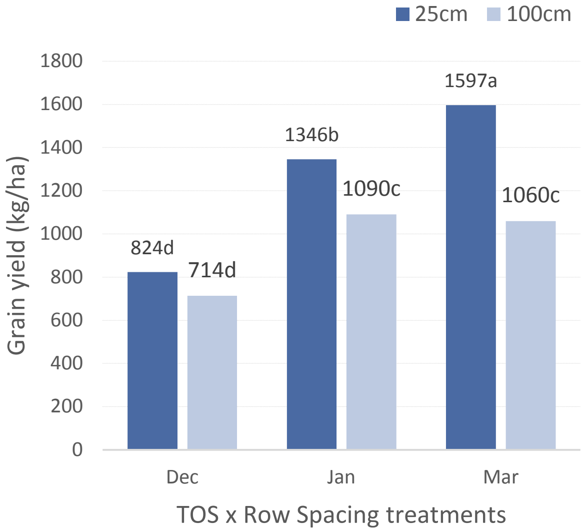


Figure 6. Mean grain yields for row spacing across all three TOS

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

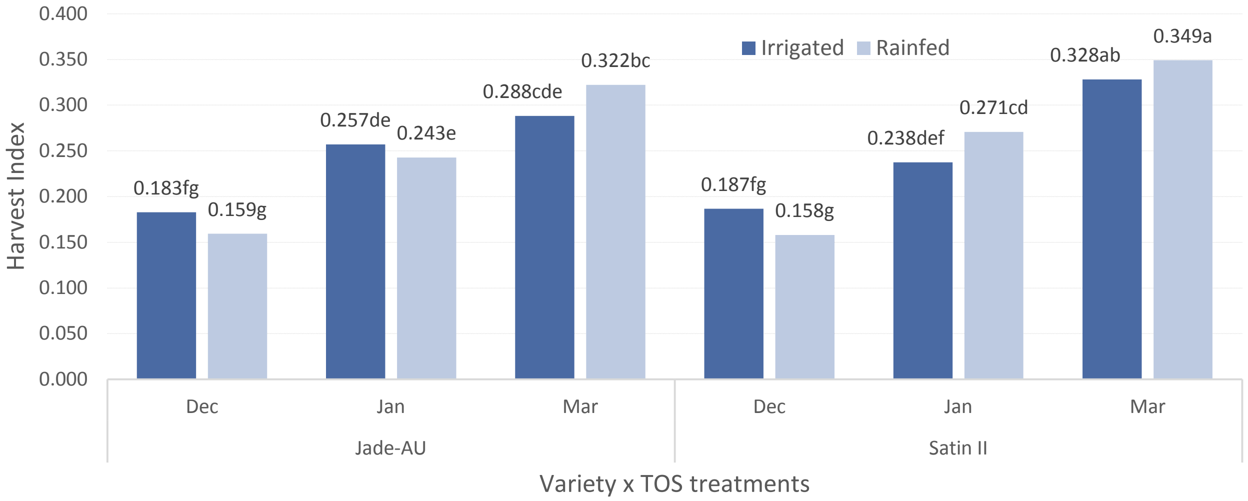


Figure 7. Mean harvest index comparison across variety, soil water conditions and TOS
Means with the same letter are not significantly different at P(0.05) level

yield when conditions changed under the later planting scenario.

Aside from the yield data collected in this trial, some key physiological data represents further insights into the growth patterns of mungbeans.

Comparison between 1 m rows (middle) and 25 cm rows (either side) in TOS3

Components of yield

a) Harvest index

The harvest index data from across the trial indicates a strong interaction with TOS (Figure 7). In both varieties there is a significant difference between the December and January TOS. In Satin II$^{\phi}$ there is also a significant difference between January and March planting dates. In the Jade-AU$^{\phi}$ treatments there is a signicant difference between the rainfed treatments in March and both the irrigated and rainfed treatments in January.

There are no significant differences between soil water conditions in each TOS in relation to harvest index nor much difference between varieties. Rainfed Satin II$^{\phi}$ had a small advantage over Jade-AU$^{\phi}$ in the March TOS.

Data from a number of trials in the last three years indicate that mungbean grain yields have a strong correlation to dry matter production.

Left to right (TOS1, TOS2, TOS3); comparison of dry matter production between TOS at the same physiological stage

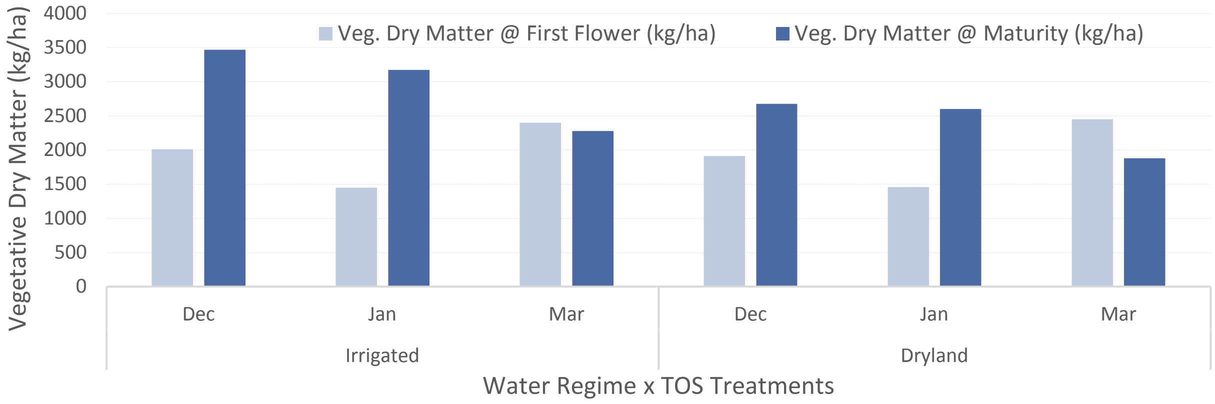


Figure 8. Mean vegetative dry matter yields collected at first flower and maturity for each row spacing and TOS treatment

A consistent harvest index across a range of conditions means high grain yields are achieved by high vegetative production.

This harvest index ranges from 0.3–0.35 and is a useful tool for checking whether a crop has achieved its potential. Figure 7 shows that the March TOS was the only crop that achieved its potential. Theoretically, the December TOS should have produced an extra 500 kg/ha and the January TOS should have produced an extra 300 kg/ha to achieve the same harvest index as the March TOS. The reasons for the two earlier planting dates not achieving their potential yields are not yet clear, however there is further data from this trial that may lead to some insights into this performance.

b) Dry matter production

The vegetative dry matter data collected (Figure 8) at both flowering (light blue bars) and maturity (dark blue bars) shows some dramatic differences in the physiological development of the three TOSs. This data is based on the vegetative yield (leaves and stems), as the pod yield has been separated out of the maturity dry matter cuts. The December TOS shows a 57% (1000–1200 kg) increase in vegetative biomass after flowering has begun. The January TOS shows an even larger increase with vegetative yields almost doubling (1200–1500 kg/ha) after flowering has begun. The March TOS shows a completely opposite growth pattern with vegetative yields slightly decreasing (12–15%) after flowering has begun.

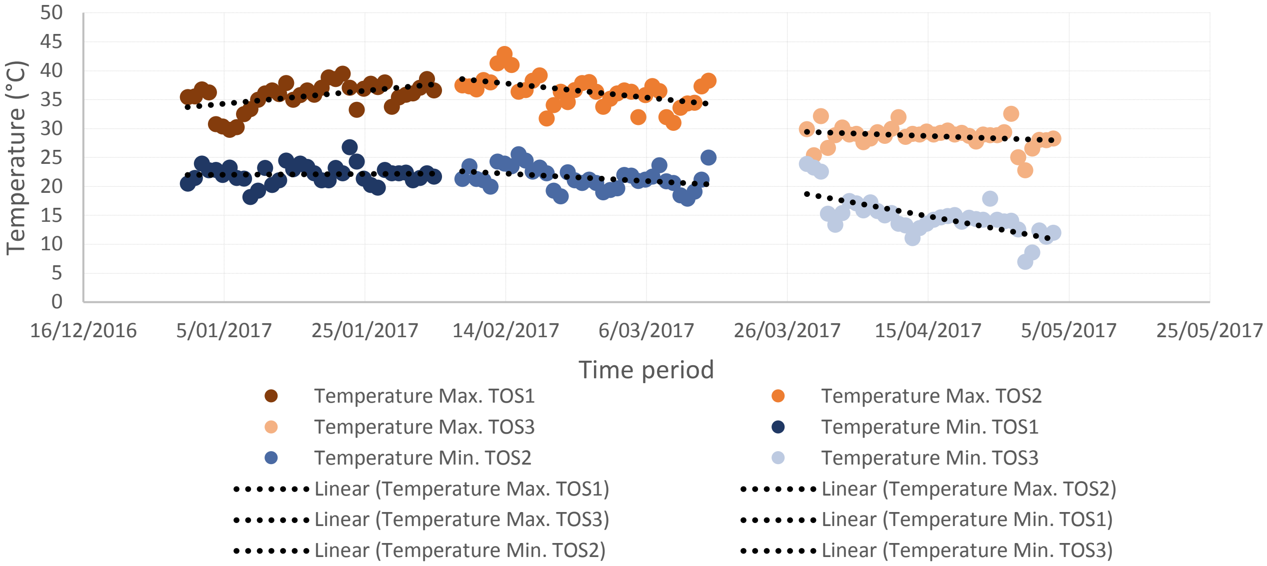


Figure 9. Comparison of daily maximum and minimum temperatures for a five week period (two weeks prior to first flower, three weeks after first flower) across all three TOS

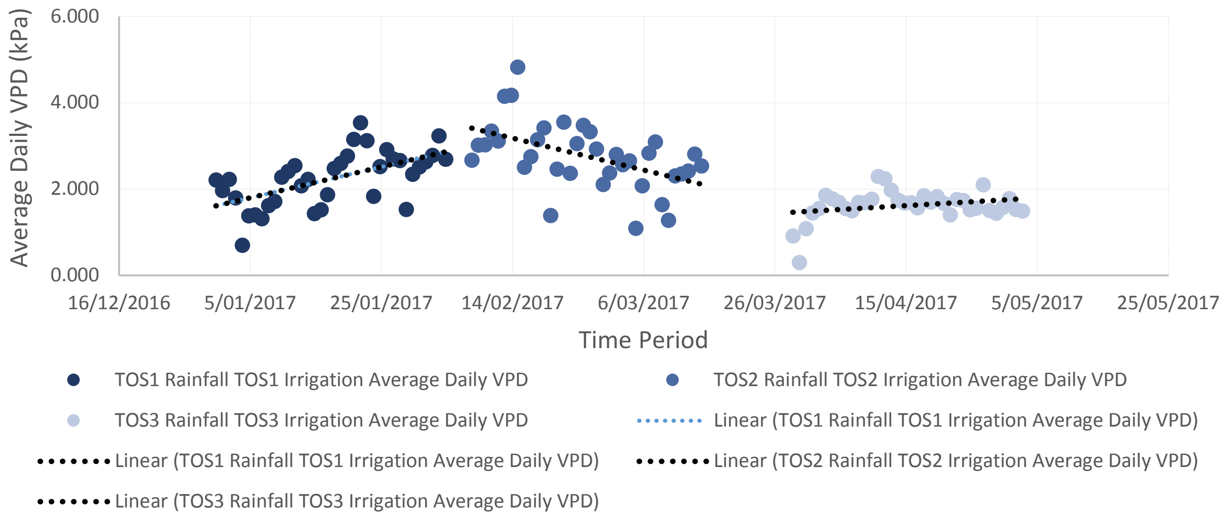


Figure 10. Comparison of average daily vapour pressure deficit (VPD) for a five week period (two weeks prior to first flower, three weeks after first flower) across all three TOS

These results are surprising since the mungbean species is classed as a vegetatively determinant crop, therefore the accumulation of vegetative biomass should be completed before it switches into reproductive mode. While the March TOS has followed this pattern, the other two TOSs have done the opposite. This divergence in growth pattern between TOSs offers some insight into how the plant reacts to the environment.

It is also important to understand the mechanism by which the plant accumulates dry matter as there is a consistent relationship between dry matter and grain yield. The main differences between TOSs are mostly weather conditions (rainfall, temperature, humidity, radiation). An examination of weather components is essential in trying to find the reason for these changes in the plants' physiology.

Weather conditions

Weather data is inherently variable and makes it difficult to ascertain clear patterns across specific periods. It is also difficult to know the required scale of difference to make a direct impact on plant development and where the critical thresholds are. Temperature data (Figure 9) does show a reasonable difference in maximum and minimum temperatures between the March TOS and the two earlier TOSs. Trends indicate that December has a slightly increasing set of temperatures across flowering while January has a slightly decreasing trend.

At the time of flowering for the December TOS, temperatures were close to 40°C and the flowering period was very short with no secondary flush of flowers occurring.

Average daily vapour pressure deficit (VPD) data is calculated from the simultaneous temperature and humidity readings. The data for this experiment (Figure 10) was calculated from weather data recorded on-site at 15 minute intervals. The daily average was derived from all readings taken during daylight hours.

VPD data is useful because it takes into account how dry the air is at each temperature increment. The hotter and drier the air is the bigger the difference between moisture conditions inside the leaf of the plant and the outside environmental conditions. This influences how fast water needs to move through the plant's system, which will be mitigated by how fast the plant can take up that water from the soil profile.

The VPD data for TOS1 and TOS2 (Figure 10) shows a similar pattern to the temperature data (Figure 9) although the trend lines have a steeper gradient. Once again there is a clear difference between the March TOS and the earlier TOS. There is a trend for increasing vapour pressure in the December planting leading into flowering, whereas the January plant has a decreasing trend.

The evapotranspiration (ET_0) data (Figure 11) also shows a similar pattern across the TOSs as the temperature and VPD data (Figures 9 and 10). There are stronger trends for increasing evaporation leading into flowering for the December TOS and the opposite trend for the January TOS. There is again a big difference in the evaporation rate for the March planting compared to the earlier TOSs.

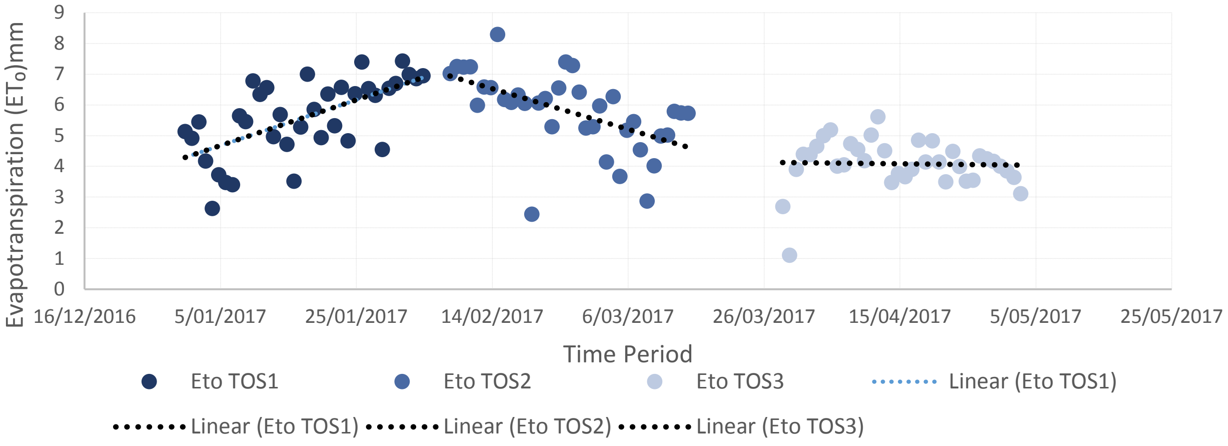


Figure 11. Comparison of daily evapotranspiration (ET_0) for a five week period (two weeks prior to first flower, three weeks after first flower) across all three TOS

This weather data (Figures 9-11) shows each TOS was experiencing a different set of climatic conditions as they approached flowering and moved into setting pods. The December TOS had increasing maximum temperatures, increasing VPD and increasing evaporation as it tried to set seed. This puts the plant under increasing pressure by having to pump more water through its system to maintain normal metabolism during its early reproductive phase, consequently putting pressure on the plant's root system to access the water in the soil profile.

The January TOS experienced similar circumstances as the December TOS except that as the plant moved into flowering and pod set, the weather conditions started easing. The March TOS experienced a very different set of conditions around flowering and pod set with temperatures, VPD and evaporation much lower and far more consistent. This weather data may explain part of the relative difference in yields between the three TOSs. The other major factor that needs to be considered in relation to this weather data is the relationship with soil water.

Soil water

a) Rainfall and irrigation

Rainfall and irrigation distribution (Figure 12) around the critical flowering period shows a different situation for each TOS. The December TOS only had small rainfall events that may not have had much impact in the crop given the evaporative demand at the time. The irrigation events in this TOS would have had the largest influence on soil moisture conditions which may explain why the biggest significant yield difference (47%) between rainfed and irrigation treatments occurred in TOS1 (Table 2).

The January TOS had little rainfall early in the period when the first irrigation treatment was applied, however later in the flowering period significant rainfall events occurred directly after

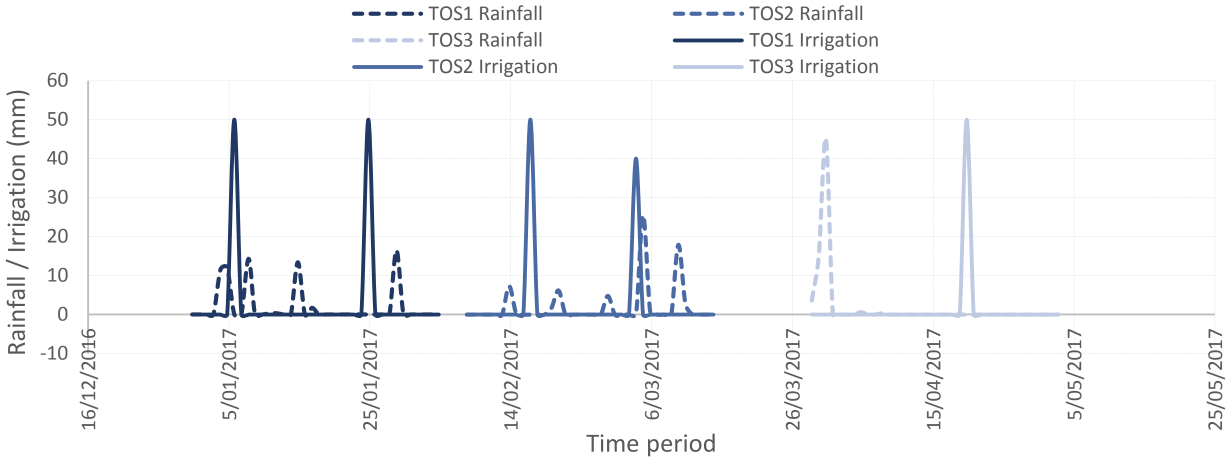


Figure 12. Rainfall and irrigation distribution for a five week period (two weeks before first flower, three weeks after first flower) across all three TOS

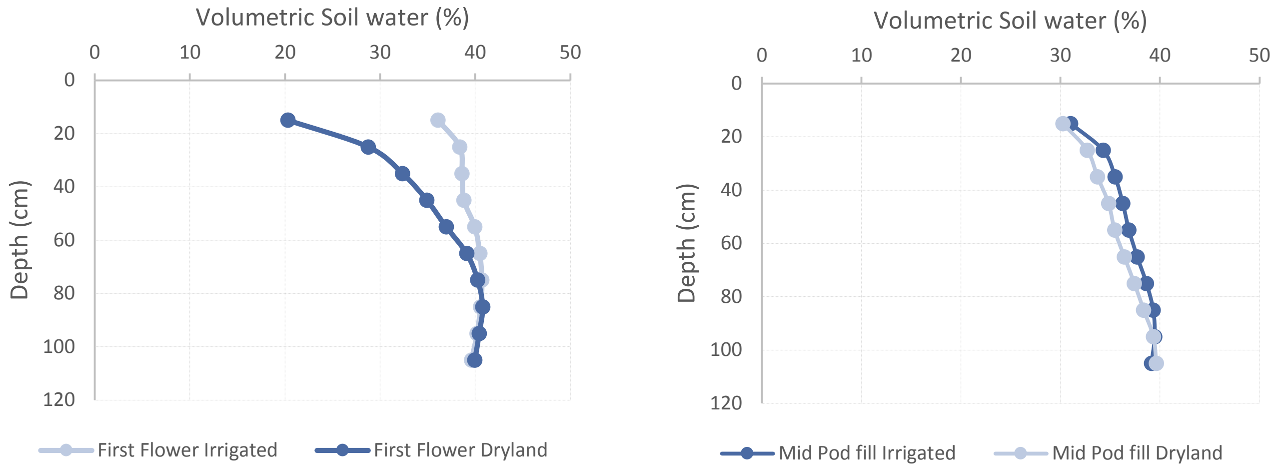


Figure 13. Volumetric soil water comparisons between irrigated and rainfed treatments measured at first flower (left) and mid pod fill (right) in the January TOS

the second irrigation treatment which would have largely negated the impact of the second irrigation treatment.

Grain yield differences between the rainfed and irrigation treatments in the January TOS were small and generally not significant except in the 25 cm row plots planted with Jade-AUⓅ (Figure 2). This is surprising given that it was expected that irrigation in the vegetative stage just prior to flowering would have had a bigger impact on yield than rainfall later in the flowering period.

The March TOS had plenty of rainfall (157 mm) leading up to flowering and a slighlty higher level of stored moisture at planting (Table 1). Irrigation did not occur during this period as it may have induced waterlogging effects. There was no rainfall after the start of flowering for this TOS, meaning the irrigation treatment that occurred in the pod filling stage was not compromised by any other rainfall events.

The grain yields from the March TOS showed no significant difference between rainfed and irrigated treatments. This result is more in line with expectations that the plant sets up its yield prior to flowering or at flowering rather than in early pod fill. Additionally, the March TOS had slower growing conditons that improved the plants' ability to perform off stored moisture hence a much lower dependence on irrigation or rainfall to achieve their potential. The early irrigation in the January TOS did not promote a bigger yield gain over the rainfed treatments and it is not easily understood why this has occurred.

b) Soil water measurements

The January TOS had neutron meter access tubes placed in a number of plots which were monitored twice weekly. The data collected gives a more in depth insight into the changing soil moisture conditions in relation to particular growth stages of the crop.

The volumetric water comparison between the irrigated and rainfed treatments at first flower (Figure 13), show an expected divergence between the two soil water conditions leading into flowering. Depth of draw down does not seem to go past 60 cm at this growth stage (first flower). By mid pod fill the divergence has disappeared (Figure 13) because rainfall has refilled the profile to the same level as the irrigation treatments hence negating the impact of irrigation in this stage of plant growth.

The neutron data comparison between 25 cm rows and 100 cm rows (Figure 14) shows the 25 cm row consistently drawing the soil water down faster than the 100 cm rows. This may explain part of the yield advantage that 25 cm rows seem to have over 100 cm rows (Figure 2). Another difference in the soil water use is that the 25 cm rows seem to draw down deeper in the profile than the 100 cm rows (90 cm versus 60 cm depth), which is consistent across both rainfed and irrigated treatments although the difference is less pronounced in the irrigated treatments.

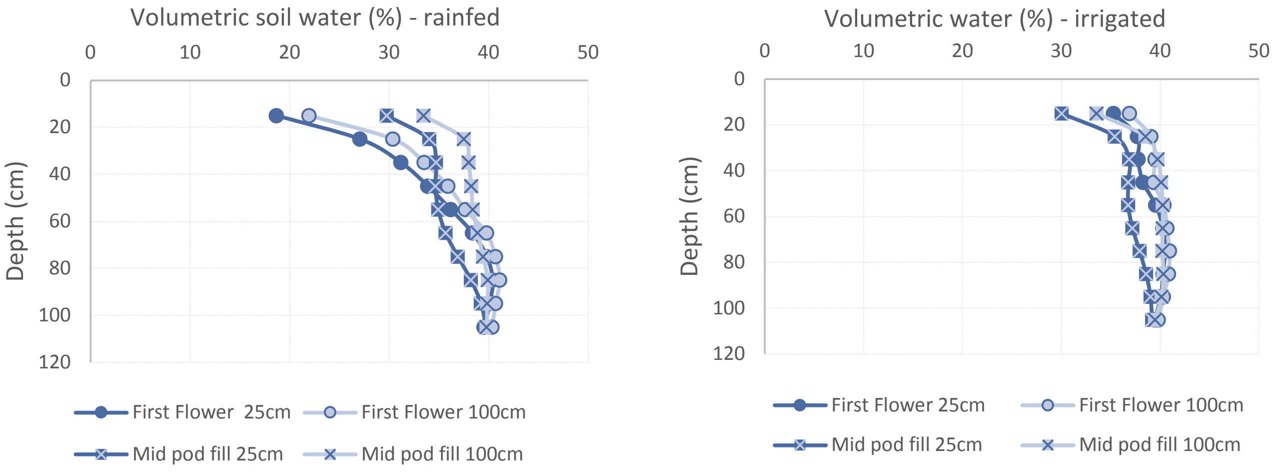


Figure 14. Volumetric soil water draw down comparison between 100 cm and 25 cm rows at first flower and mid podfill in the January TOS: rainfed treatments (left) and irrigated treatments (right)

The 100 cm row treatments appear to draw water out of the inter-row space at the same rate as from under the row (Figure 15). The row spacing data (Figure 14) would suggest that the 100 cm rows do not draw down the plant available water as hard as the 25 cm rows. This characteristic of the 100 cm rows may be because root mass is diluted over a bigger soil volume and therefore there is less root surface area to absorb water within a given cubic volume of soil.

Implications for growers

Changes to management systems for mungbean production such as moving to narrow rows can increase mungbean profitability; at a price of $1000/t the yield benefits of 25 cm versus 100 cm rows observed in this trial ranged from $110 to $530/ha. Trial results also showed significant differences between the three TOSs, 824 kg/ha (December TOS) to 1597 kg/ha (March TOS) driven by the different weather conditions across the growing season.

Most of this variability seems to be linked to plant-water relationships that are impacted by temperature, humidity and evaporative demand. In terms of weather patterns, later plantings (February and March) will allow the plant to grow dry matter and set flowers in conditions that put the plant under less pressure in relation to maintaining water balance. Consequently irrigation and in-crop rainfall have less impact on production.

Alternatively, later planting windows can be impacted by declining radiation levels that in turn limits biomass production, which is

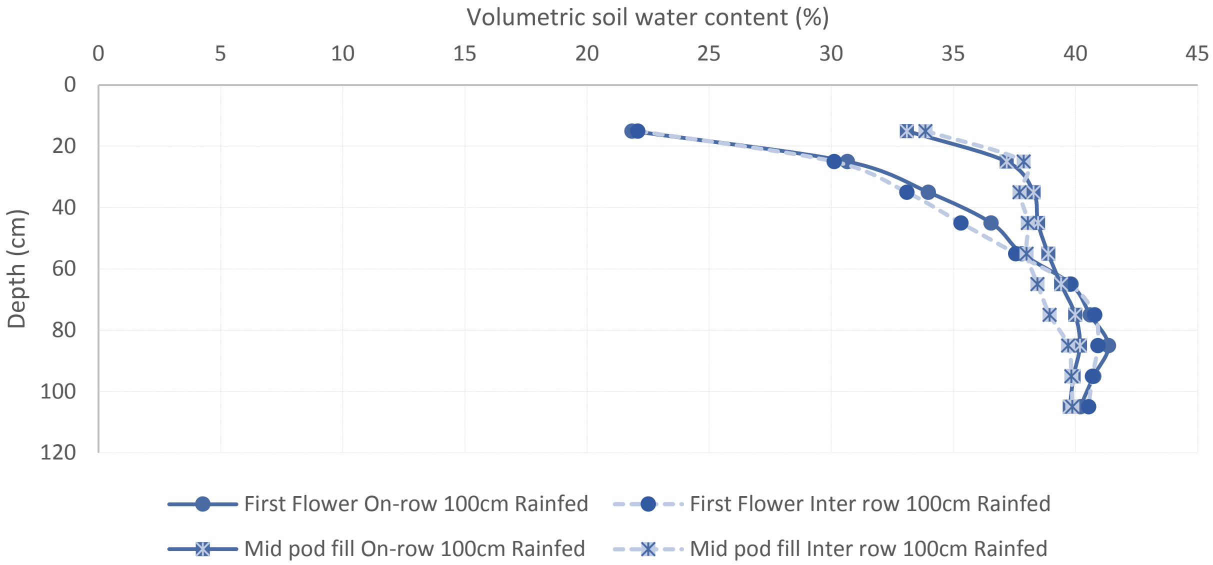


Figure 15. Volumetric soil water differences between measurements taken on the plant row (on-row) and measurements taken between the plant rows (inter-row). These measurements were taken from the 100 cm rows in the rainfed treatments

then linked to yield potential. Earlier planting windows can set higher biomass production but only if the water balance of the plant can be maintained. Once the plant goes into a stress condition all growth stops and this will impact on eventual yield.

There are factors that can mitigate some of these environmental effects such as irrigation (or a well timed rainfall event), good nutrition and variety selection; however the right planting window will still make the biggest impact on yield. Later planting may not generate the highest yield potential but it may be the most reliable yield potential.

Understanding the stress mechanism in the plant and where its thresholds are, is important work that still needs to be undertaken. Being able to predict the weather conditions that are best suited to optimal growth characteristics will go a long way towards making mungbean yields more reliable.

Acknowledgements

The Queensland Pulse Agronomy Initiative (UQ00067) is funded by the Grains Research and Development Corporation, the Queensland Alliance for Agricultural and Food Innovation, and the Department of Agriculture and Fisheries.

Trial details

Location:	Emerald Agricultural College
Crop:	Mungbeans
Soil type:	Black/Grey cracking Vertosol
In-crop rainfall:	105 to 176 mm
Fertiliser:	SuPreme Z™ at planting (30 kg/ha)

Selected soil fertility characteristics of the trial site:

Depth (cm)	Nitrates	Colwell P	Sulfur (KCl-40)	Exc. K	BSES P	ECEC
0-10	20	30	6	0.95	71	35
10-30	8	6	4	0.49	46	37
30-60	5	2	6	0.42	37	38

First flower dry matter cuts in TOS1

Neutron probe data collected twice weekly

Mungbean: Understanding impact of row spacing, population and time of sowing on crop water-use patterns—Warwick

Kerry McKenzie and Grant Cutler
Department of Agriculture and Fisheries

RESEARCH QUESTION: *How are crop water-use patterns affected by changes in agronomic practices?*

Key findings

1. Irrigation improved mungbean biomass accumulation.
2. Narrow rows led to better crop development and yield.
3. Narrow rows converted moisture to grain more efficiently.

Background

Mungbeans play a significant role in cropping systems in Queensland and northern New South Wales with increasing areas planted under favourable seasonal conditions. Whilst previous research has focused on developing a better understanding of agronomics, this trial work was conducted to gain a better understanding of how changes in agronomic practices affect the water-use patterns of mungbeans.

Treatments

The trial was run at the Hermitage Research Station (HRS) situated near Warwick in southern Queensland with the following treatments:

- plus and minus irrigation
- two time of sowing (TOS) dates (TOS1: 6/1/2017 and TOS2: 13/02/2017)
- two row spacings (25 and 100 cm)
- three plant populations (20, 30 and 40 plants/m^2).

The variety Jade-AU$^{\Phi}$ was planted to all treatments. Irrigation was applied using trickle tape. A total of 63 mm was applied as irrigation in addition to in-crop rain for TOS 1.

Neutron moisture meter (NMM) access tubes were installed in TOS1, 30 plants/m^2 plots at both 25 and 100 cm row spacings. Two access tubes were installed in each plot, the first within the planted row and the second midway between two rows for each row spacing. Access tubes were installed in all three replicates. Soil cores removed when installing the access tubes were sectioned at 20 cm depths, weighed and dried at 105°C, and gravimetric water volume calculated. The NMM probe was calibrated using these samples. Soil moisture was measured at 20 cm increments starting at 25 cm to a depth of 125 cm throughout the season.

Results

The TOS2 block established satisfactorily, however it suffered nutritional deficiencies due to a contour bank having been removed in the year prior and further impacted with untreated disease during the season. This resulted in very uneven growth that has confounded the results. As such any further results and discussion will only relate to the TOS1 trial block.

Established plant populations were low in all the 100 cm row spacing plots, with only 10-21 plants/m^2, which did not meet the targeted populations of 20, 30 and 40 plants/m^2. The 25 cm row spacing established populations were in line with the targets.

This has confounded the results for this trial, making interpretation difficult i.e. were differences due to row spacing or population. Previous mungbean population trials from the Queensland Pulse Agronomy project have shown that population does not have a significant impact on grain yield whether in a low or high yielding environment. Therefore any significant differences in dry matter and grain yield were assumed to be driven by row spacing treatments.

Dry matter production

Significant differences were observed in the TOS1 trial, with higher dry matter production in the 25 cm row spacing. The difference between dryland and irrigated treatments were not significant, most likely due to 75 mm of rain immediately prior to the scheduled irrigation (as the crop started to flower). The additional water did not lead to an increase in dry matter.

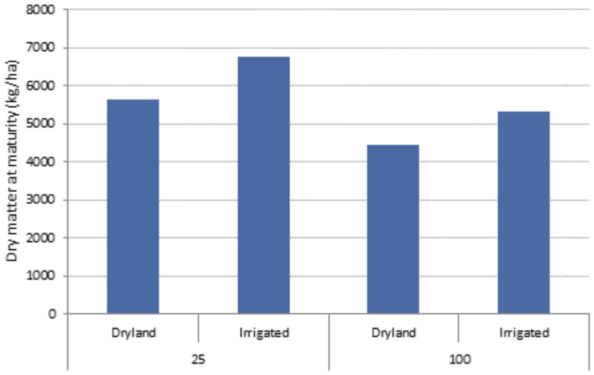


Figure 1. Dry matter at maturity for TOS1
(lsd at 5% is 490.1 kg)

Grain yield

Grain yield was unexpectedly high in this trial with a site average of over 2600 kg/ha. Significant differences were measured due to row spacing and an interaction between row spacing and irrigation.

In line with dry matter production, grain was maximised at the narrower row spacing, the 25 cm treatment averaging 3000 kg/ha and 100 cm 2337 kg/ha when dryland and irrigated yields were combined.

There was an interaction effect of irrigation and row spacing; an increase in grain yield was observed from the 25 cm row spacing when irrigated. However, there was no statistical difference between the dryland treatments and the 100 cm irrigated treatment (Figure 2: dark blue columns). More significant yield differences for irrigation were not realised and this is suspected to be due to no additional water in the irrigation treatment during the vegetative phase given the 75 mm of rain falling and the subjective nature of the irrigation scheduling i.e. the crop didn't look like it needed water.

Hand harvested results (Figure 2: light blue columns) were generally higher than the machine harvested yields, suggesting some losses due to machine harvest, but confirming the higher than expected yields given the season and the dry matter produced.

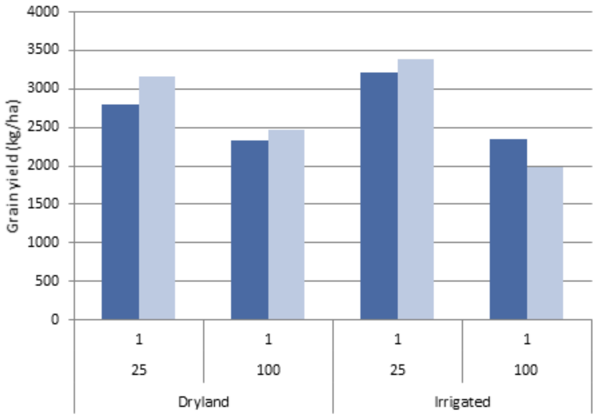


Figure 2. Grain yields from machine plot harvester (dark blue) and and-harvested (light blue) for TOS1

Dryland mungbeans on 100 cm rows generated an impressive income of between $2797 and $2956/ha depending on yield measurement (handcut versus plot harvester) (Table 1), however reducing row spacing to 25 cm generated an increase in income of between ~$560 and ~$830/ha. Irrigation in addition to reduced row spacing, gave an additional benefit of between ~$270 and ~$490/ha.

Table 1. Mungbean income ($/ha) for rowspacing * irrigation

	100 cm dryland	25 cm dryland	25 cm irrigated
Plot harvested	$2797	$3356	$3845
Hand cut	$2956	$3785	$4056

Installing neutron moisture metre tubes

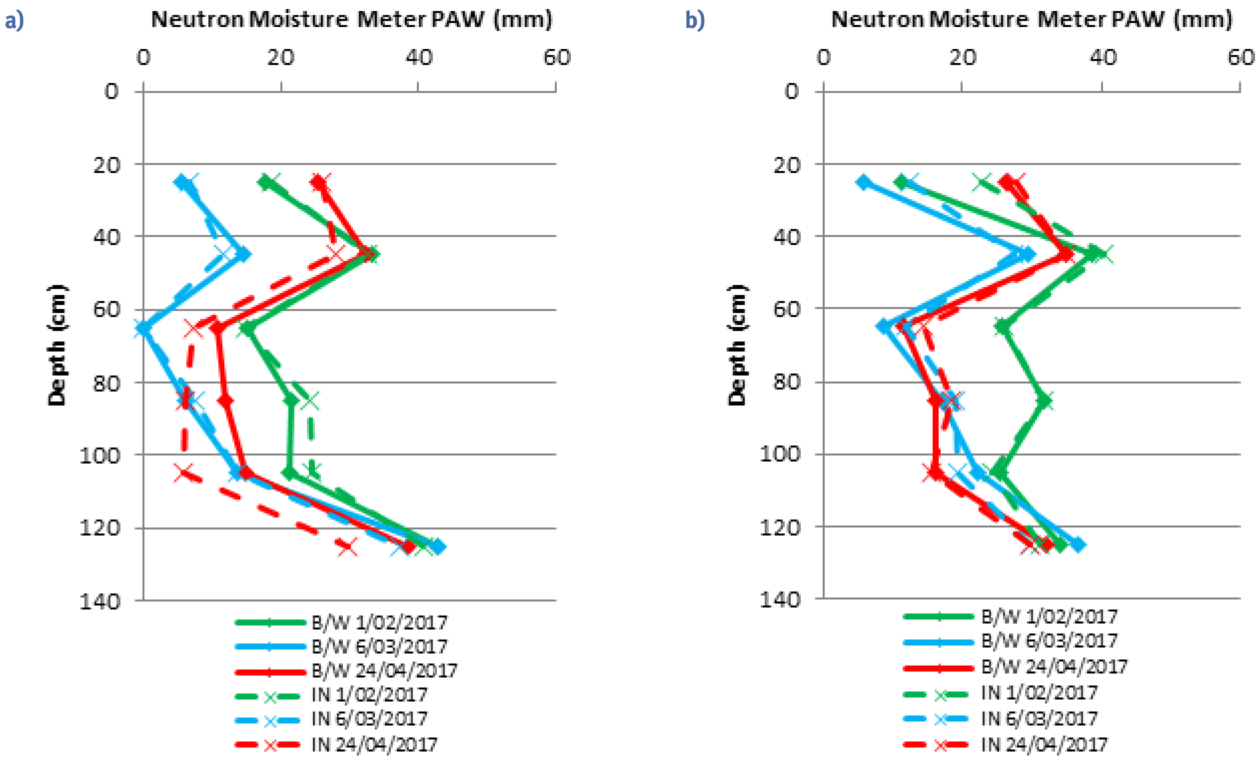


Figure 3. Soil water for (a) dryland and (b) irrigated mungbeans at 25 cm row spacing at three dates during the growing season (solid lines are between the rows and dashed line in the row)

Water extraction

Water extraction patterns were measured with neutron moisture probes throughout TOS1 (major findings between row spacings and water regimes reported, not full data set).

Three dates are displayed;

- 1/2/17 – approximately one month after planting
- 6/3/17 – mid pod fill (after irrigation)
- 24/4/17 – crop desiccation (after 100 mm rainfall at the end of March).

In the dryland 25 cm row spacing treatment (Figure 3a), the in-row and between-row soil moisture readings were essentially the same at the first three readings. By 6 March (mid pod fill) the soil water had been removed down to 105 cm of the profile, the majority of the soil water extraction was to a depth of 85 cm. By maturity, some moisture had been removed from in the row at 125 cm depth. However, the final reading showed that the in-row profile has not refilled at depth (105 cm +) with the cyclone Debbie rainfall to the same extent as on the row.

The 25 cm irrigation treatment (Figure 3b) did not remove water to a similar depth as the dryland, however water was still removed down to 105 cm. As with the dryland treatment there was little difference in extracted soil moisture measured in the row and between the rows.

At 100 cm row spacing, it was noticeable that there was little to no water movement below 105 cm for the dryland treatment (Figure 4a) whereas there was in the 25 cm row spacing. With both the irrigated and the dryland, by the start of March (mid pod fill) more soil water had been removed from the between row position than in the row to a depth of 65 cm. This difference was also evident by the third reading, but only down to a depth of 45 cm. Anecdotally, when the irrigation was being applied it took longer to refill the profile of the 100 cm row spacing plots as compared to the 25 cm.

When comparing the water use between row spacings, the overall pattern of removal is similar with the greatest removal to a depth of 65 cm, but with continuing removal to 105 cm and beyond in some cases. This data indicates that mungbeans have a much larger rooting depth than the traditionally accepted 60 cm where there are no subsoil constraints as in this site. Water removal appeared to be greater between the row in the 100 cm spacing to a depth of 65 cm.

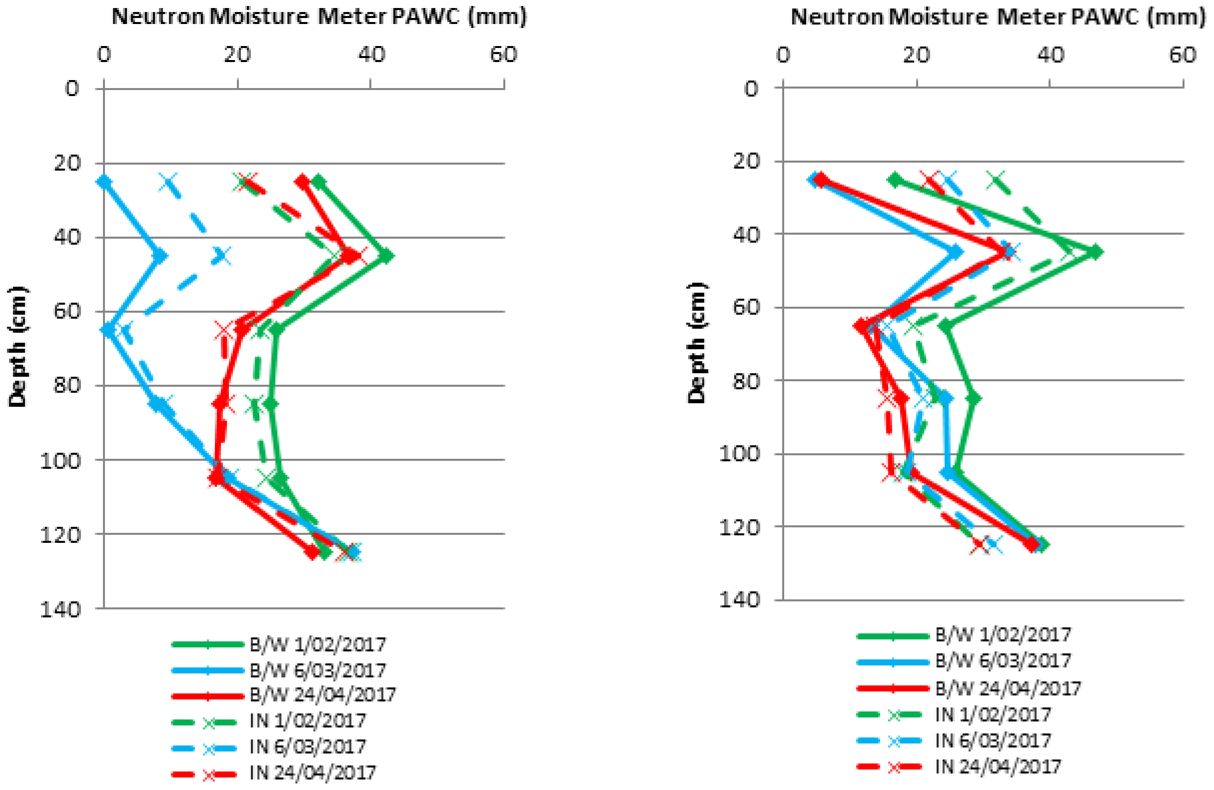


Figure 4. Soil water for dryland (a) and irrigated (b) mungbeans at 100 cm row spacing at three dates during the growing season (solid lines are between the rows and dashed line in the row)

Implications for growers

Mungbeans planted on the narrower row spacing of 25 cm produced greater yield across all treatments compared to the wider 100 cm spacing. This is consistent with previous trials conducted as part of the Pulse Agronomy project. The additional yield is in response to increase in the amount of light intercepted as measured in this and previous trials and therefore the crop has more energy for photosynthesis, resulting in more dry matter production. This trial again supports that the 25 cm not only extracts more water from the profile but also converts this water more efficiently to grain.

Due to the consistent rain throughout the season and the late rainfall from cyclone Debbie, there was no significant difference between the dryland and irrigated treatments however the trend for more yield with irrigation was evident with higher yields achieved at the 25 cm row spacing. In this trial with its environmental conditions there was no benefit over the dryland treatments by irrigating the 1 m row spacing.

Total soil moisture removal is increased from the inter row space with 100 cm row spacing, however it is suggested that this is driven by evaporation and not transpiration and it was interesting to see similar water use between all treatments with the greatest removal to a depth of 65 cm, but with continuing removal to 105 cm and beyond in some cases, indicated that mungbeans have a much larger rooting depth than the traditionally believed 60 cm.

Acknowledgements

The team would like to thank Hermitage Research Farm for hosting this trial as well as the Grains Research and Development Corporation (UQ00067), Queensland Alliance for Agriculture and Food Innovation and the Department of Agriculture and Fisheries for the funding support of the project.

Trial details

Location:	Hermitage (Warwick)
Crop:	Mungbean (var. Jade-AU⁽ᴰ⁾)
Soil type:	Black Vertosol

Interactions of chickpea physiology in relation to time of sowing, row spacing, biomass reduction and soil water conditions—Emerald

Doug Sands
Department of Agriculture and Fisheries

RESEARCH QUESTION: *Is the production of grain in chickpeas significantly influenced by manipulating biomass production across different times of sowing, soil water conditions and row spacing?*

Key findings

1. The use of Broadstrike™ as a plant retardant was generally effective in limiting biomass at flowering.
2. Limiting biomass at flowering did not produce any yield improvement.
3. May sowing produced the best yields and the best harvest index.
4. 75 cm rows had a yield advantage over 50 cm rows.
5. Soil water savings made by biomass reduction did not promote extra yield.

Background

Over the past four years the Queensland Pulse Agronomy Initiative project (UQ00067) has conducted several trials across Central Queensland (CQ) investigating the impact of row spacing, population, variety, time of sowing (TOS) and soil water conditions on chickpea production. This work has highlighted the plant's compensatory physiology and its ability to change structure, particularly in relation to row spacing and population. It has also shown that productive differences in genetics are generally small but responses to changing seasonal parameters can be large.

Chickpeas are remarkably resilient to seasonal changes by changing the speed of reproductive development. Crops planted later in the season (June and July) have yielded surprisingly well under warm spring temperatures when adequate soil moisture is available.

Harvest index figures can change across TOS with late sowings nearly always having a significantly higher harvest index. This means that the relationship between dry matter accumulation and grain yield is not consistent in this crop species. In some circumstances (early planting) the plant is growing more dry matter than it requires to maximise grain yield and this would seem to be a waste of resources (soil water and nutrition).

In a CQ environment, the early planting window will always be used when autumn rainfall is non-existent and deep-planting techniques need to be used to access stored soil moisture from summer rainfall events. It would be of great benefit to the industry if the early planting window could be utilised to achieve the same harvest index as the later planting windows.

This experiment is designed to see if a crop growth retardant could be used to minimise early dry matter accumulation in order to conserve soil moisture for flower and pod set.

What was done?

A trial was conducted at the research facility based at the Emerald Agricultural College (Table 1). Chickpeas (PBA Seamer⁽ᴰ⁾) were planted at three sowing dates; 12 April, 16 May and 19 June 2017. Each TOS block was split into two water treatments; one block had an irrigation application at flowering and the other block was left as rainfed. These split blocks were further broken up into two row spacings (50 cm and 75 cm) and four biomass reduction treatments. These biomass reduction treatments included a control, slashing, spraying Broadstrike™ at full rate (25 g/ha) and spraying Broadstrike™ at a half rate (12.5 g/ha). The biomass treatments were applied at two different timings; 28 days after sowing (28DAS) and 42 days after sowing (42DAS), thus giving eight biomass reduction treatments across the two row spacings. Each time of sowing (TOS) main plot was replicated three times across the trial site.

Table 1. Summary of trial design

Trial design	Treatments
Main plot	Time of sowing (3)
Split plot	Irrigated or rainfed (2)
Sub split plot	75 cm or 50 cm row spacing (2)
Sub sub split plot	28DAS – control (C), slashed (S), ½ Broadstrike™ (1/2BS), Full Broadstrike™ (BS) 42DAS – control (C), slashed (S), ½ Broadstrike™ (1/2BS), Full Broadstrike™ (BS) (8)
Replicates	3
Site total	288 plots

Example of treatments in April TOS; foreground plot was slashed 42DAS, middle plot sprayed full rate of Broadstrike™ 28DAS, background plot was slashed 28DAS

The slashed treatments were implemented with a hedge trimmer and cut the plants about 5 cm above the ground. Broadstrike™ treatments were applied with a shrouded boom with a minimum of 90 L/ha of water.

Each plot was 4 m wide by 12 m long and SuPreme Z™ fertiliser was applied with the seed at 30 kg/ha at planting. The first two TOSs were planted on rainfall events but the June TOS required irrigation to create a planting opportunity. This irrigation was applied across the whole site uniformly.

Detailed soil water monitoring was carried out with neutron probe tubes placed in the April TOS only. The monitoring included readings taken at 20 cm intervals from a starting depth of 15 cm, down to a depth of 115 cm, and data was recorded twice weekly. Each monitored plot contained two tubes; one in the plant row (on-row) and another placed between the plant rows (inter-row). The slashed treatments (42DAS) and the related control plot was monitored across both row configurations; in the irrigated and rainfed treatment blocks.

A number of other measurements were recorded throughout the life of the crop. These included plant counts, light interception (before, during and after flowering), dry matter cuts at first flower and maturity, plant mapping at maturity, machine harvest and weather data recorded every 15 minutes. Also measured was the planting and harvest plant available water (PAW) and a full soil analysis.

Drone image: Comparison of 3 TOSs on the 28 August 2017 in second replicate. April TOS drying down prior to harvest, May TOS in peak grain fill, June TOS in early flower; rainfed strips in May TOS are starting to drop leaf

Results

The complexity of this trial has resulted in a large amount of data collected and analysed. This report will summarise and highlight the most significant findings. This experiment was focused on biomass manipulation of chickpeas to improve harvest index and thereby also improving yield through more efficient use of soil resources. This report will focus on whether this biomass manipulation achieved significant improvements and what influence row spacing and irrigation had on the biomass treatments. Soil water and weather data for the experiment will also be presented. The key physiological data (Table 2) outlines the basic seasonal parameters that the crops experienced. As expected, days to flower and days to maturity both decreased as the TOS got later in the season.

Table 2. Summary of key physiological development periods for all three sowing times

Time of Sowing	Physiological stage	Date	Calendar days	Growing day degrees (°Cd)	Rainfall (mm)	Irrigation (mm)	Starting PAW (mm)
April	Planting	12/4/2017	0	0	0	0	94
	First Flower	17/6/2017	66	1253	21	50	
	#Maturity	15/8/2017	125	2273	61	50	
May	Planting	16/5/2017	0	0	0	0	84
	First Flower	19/7/2017	64	1122	20	50	
	#Maturity	8/9/2017	115	2015	43	50	
June	Planting	19/6/2017	0	0	0	0	83
	First Flower	20/8/2017	62	1075	40	0	
	#Maturity	6/10/2017	109	2069	131	50	

#Note: Maturity dates were based on the control plots for the purpose of this table (some treatments had a delayed maturity date)

The days to maturity decreased by a larger margin than days to flowering, indicating that a general characteristic of chickpeas is that its flowering period is more flexible than its vegetative period, which can be a reflection of the warmer temperatures encountered by the later TOS. An example of this is between May and June where there is a reduction in days to maturity but almost no change in the growing day degrees.

The June planting date had the most water available, mainly due to in-crop rainfall in the post-flowering period. Unfortunately this is not a positive impact on the production of this TOS as 91 mm of this rainfall fell just before harvest when the plant had nearly reached maturity.

Harvest losses were greater in the June TOS given the amount of weather damage that was sustained. Plant mapping data indicates the difference in harvest values between the June TOS and the earlier TOS.

Summarised plant mapping data (Table 3) suggests the June TOS was disadvantaged by the rainfall prior to harvest with machine harvest losses higher than the May TOS. This does not change the overall analysis too much as the April and May TOS still created more yield, however it does show that the relative differences (~500 kg/ha) between the three TOSs are more evenly distributed.

Table 3. Comparison of plant mapping data (hand harvest) with machine harvest grain yields

TOS	Machine harvested yields (kg/ha)	Est. hand harvested yields (kg/ha)#	Yield difference (kg/ha)	Harvest losses (%)
April	2392	3070	678	22.1
May	2814	3683	869	23.6
June	1433	2373	940	39.6

 # Note: Individual plants assessed for total grain weight and then multiplied by average plant counts across selected plots. Plant mapping was carried out before major rainfall occurred

Comparison of June TOS before (left) and after (right) 91 mm of rain

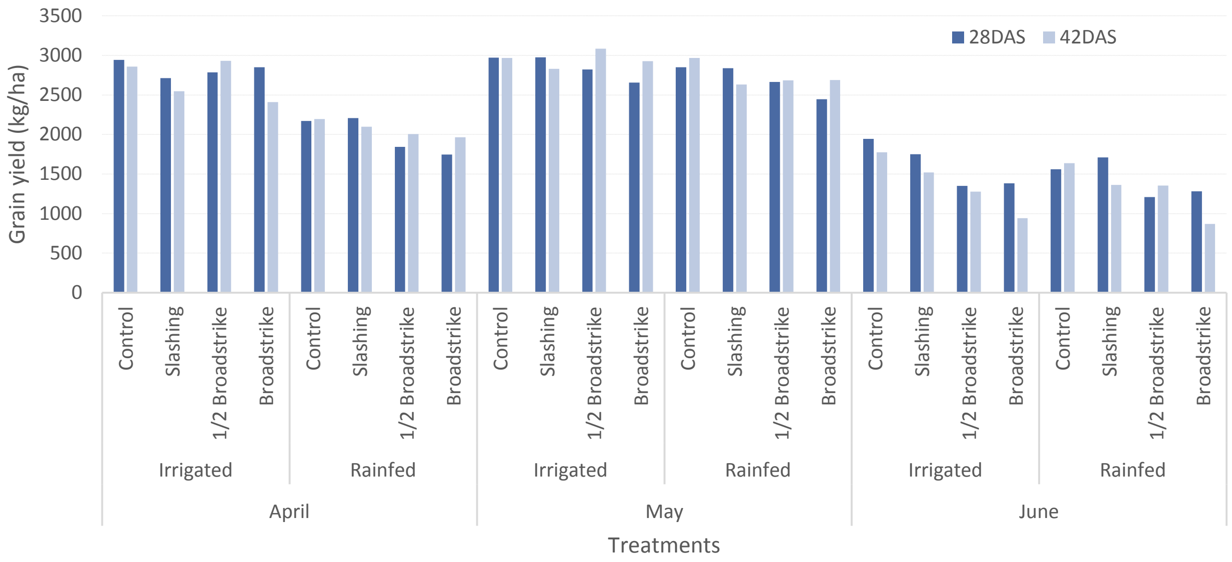


Figure 1. Summarised grain yield data across all treatments

The summarised yield data (Figure 1) gives a broad picture of how the treatments sit in relation to each other. As there are a number of interactions within this data set it is useful to understand some of the main differences. When comparing average yields; May TOS had the highest yields (2828 kg/ha), followed by April (2429 kg/ha) and June had the lowest (1474 kg/ha). Irrigated differences were variable within TOSs but overall the irrigated blocks had 357 kg/ha advantage (2422 to 2065 kg/ha). Surprisingly, the wider row spacing of 75 cm had the advantage over 50 cm by 229 kg/ha (2358 to 2129 kg/ha) although this also varied within each TOS.

Overall the biomass reduction treatments did not have any advantage over the controls (C: 2430 kg/ha, S: 2276 kg/ha, ½ BS: 2193 kg/ha, BS: 2076 kg/ha), however there were a number of interactions within each TOS so these averages are not a true reflection of the performance of these treatments. There was almost no difference between the time of application of these treatments (28DAS 2266 kg/ha, 42DAS 2221 kg/ha), although this also is not a true reflection of the number of interactions that were identified that involved the timing of application.

Dry matter production

Examination of the dry matter production data across all three TOSs (Figures 2, 3, 4) would suggest that in general the biomass reduction treatments did reduce dry matter (DM) production at flowering but by maturity many of those differences were gone.

For the April TOS (Figure 2 (a) and (b)), the slashing treatment at 42DAS was the most significant reduction compared to the controls and this was consistent at flowering and at maturity in both row spacings. The full BS application had the biggest effect on DM at flowering in the 75 cm rows.

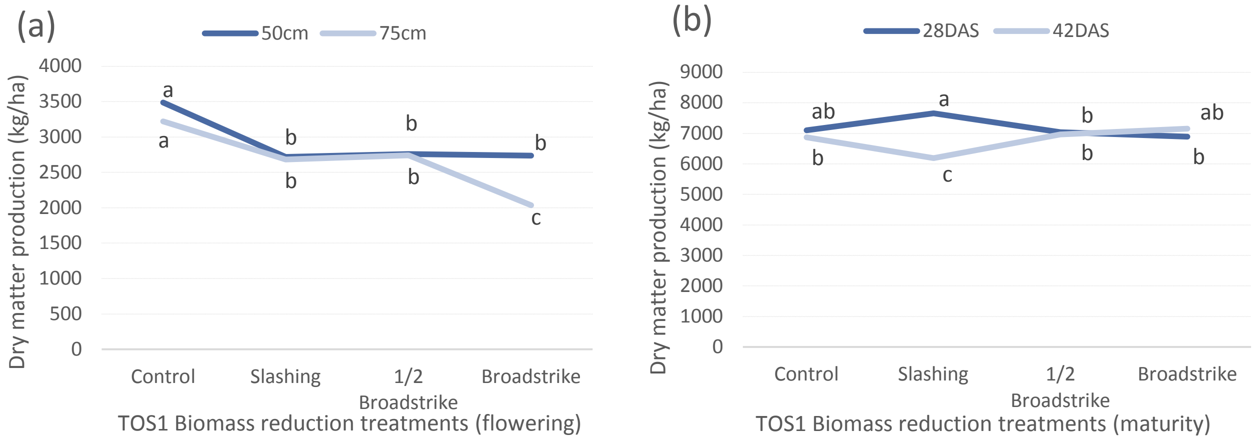


Figure 2. April TOS biomass reduction interaction at flowering (a) and maturity (b)
Values with common letters are not significantly different; P(0.05)

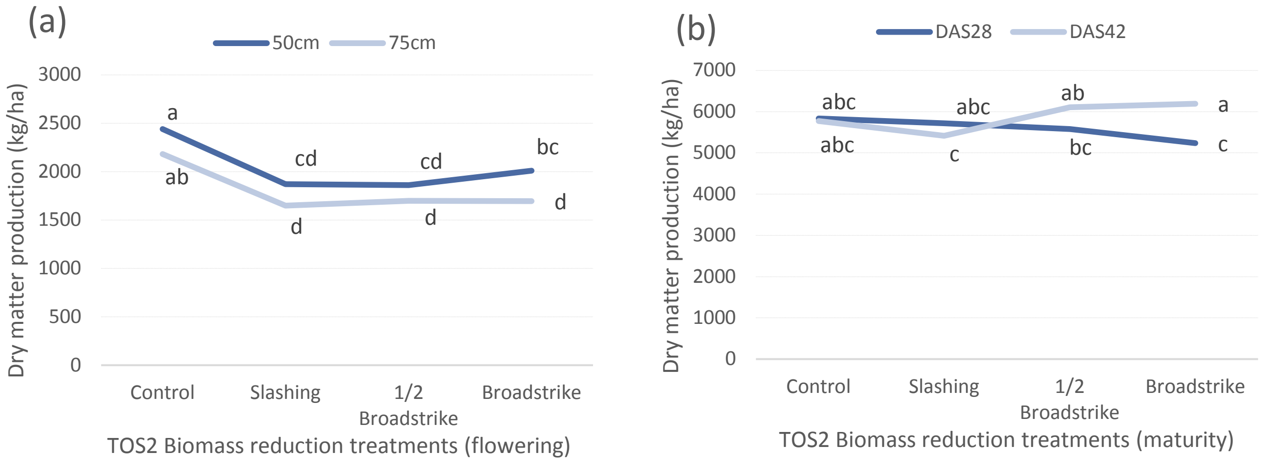


Figure 3. May TOS biomass reduction interactions at flowering (a) and maturity (b)
Values with common letters are not significantly different; P(0.05)

In the May TOS (Figure 3 (a) and (b)), the most significant interaction was with the full rate BS application sprayed at 28DAS and 42DAS. Surprisingly the 28DAS application reduced DM the most but it still was not significantly different to the controls. At flowering, all treatments reduced dry matter production compared to their respective controls, with the largest reduction in the 75 cm rows. By maturity, these reductions had been negated and the only significant interaction was the timing of the treatments; with the 28DAS at full BS still reducing total DM production.

In the June TOS (Figure 4) there was a general interaction between the timing of applications (DAS) rather than any specific difference between treatments. In this case the 42DAS had the biggest reduction in DM even though there was no significant differences between treatments.

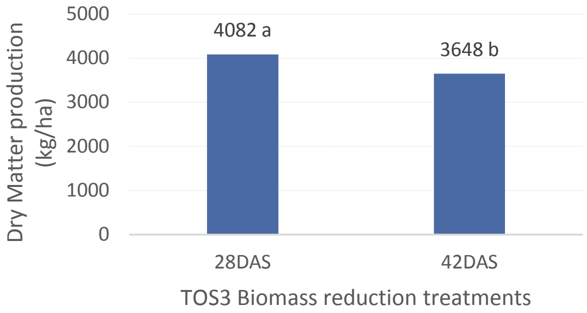


Figure 4. June TOS biomass reduction response
Values with common letters are not significantly different; P(0.05)

It should be noted that between TOSs there were distinct differences in DM production (April 6982 kg/ha, May 5731 kg/ha, June 3865 kg/ha). It is clear that the chickpea plant can recover and flex its DM production in relation to setbacks that occur during the vegetative phase.

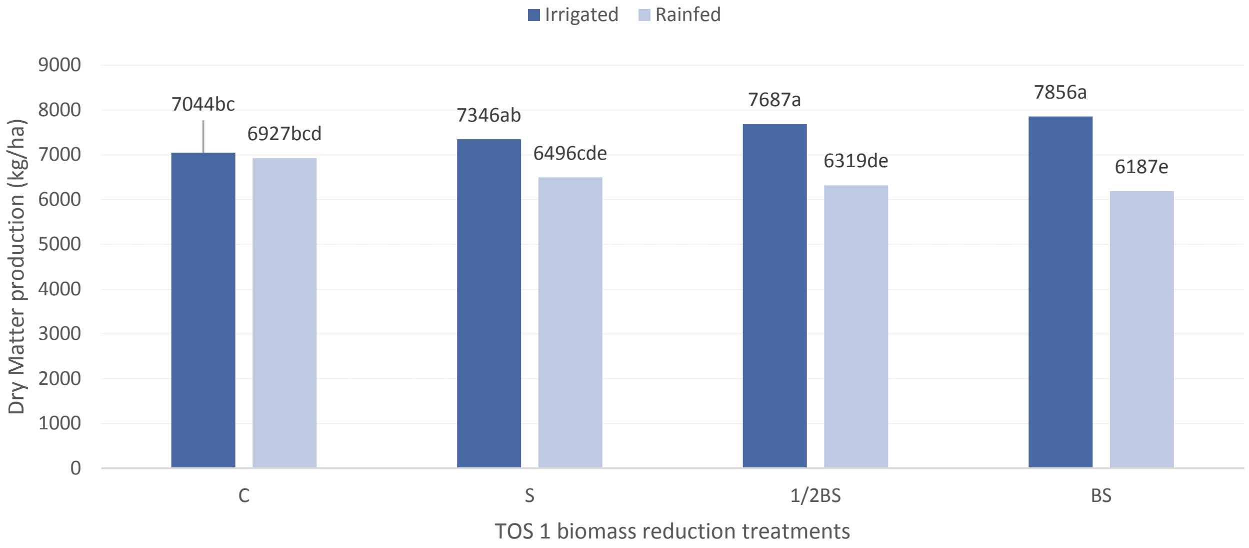


Figure 5. TOS1 DM interaction with irrigation and biomass reduction treatments

Total DM comparisons at maturity in the April TOS show an interaction between the biomass reduction treatments and irrigation application (Figure 5). The irrigation has significantly assisted the biomass reduction treatments to recover the equivalent DM as the control plots by the time the plant reached full maturity. Interestingly the full BS treatment produced more DM than the control after irrigation but significantly less DM than the controls in the rainfed treatment. The BS treatments may have affected root development as well as vegetative growth.

Similarly in the May TOS (Figure 6) there was a consistent difference between the irrigated and rainfed plots of nearly 1000 kg/ha. There was no significant differences between the biomass reduction treatments.

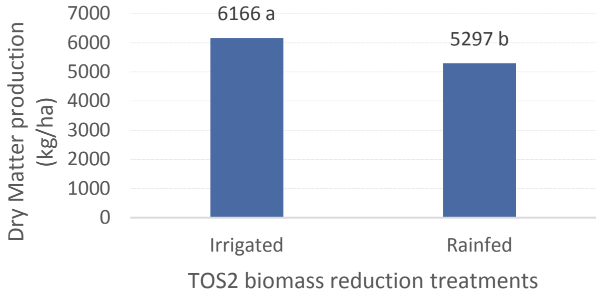


Figure 6. TOS2 DM interaction with irrigation and biomass reduction treatments

There was no response to irrigation in the June TOS which means there was a greater restriction to DM yield than soil water availability, which possibly could be attributed to seasonal influences as the plant matured in only 109 days (Table 1).

Harvest index

Similar to previous years the harvest index (HI) does not match the same trend as DM production (April 0.347, May 0.498, June 0.375), with May TOS having the highest HI and consequently the highest yield.

The main change in DM production was between TOSs therefore it was no surprise that the main differences in HI were also across TOSs. The May TOS produced the best HI (Figure 7 (a)), which was significantly higher than either the April and June TOSs. There was also an interaction with the irrigation treatments. The April TOS produced a higher HI under irrigation whereas this response was reversed in the May TOS with the rainfed treatments producing the best HI. The DM production in May increased with irrigation but decreased harvest index; indicating grain production may have been similar across those treatments with only DM changed; pointing towards DM not necessarily contributing to grain yield.

Another notable interaction was a significant reduction in HI from the application of BS in the 50 cm rows (Figure 7 (b)) as opposed to the control and the 75 cm treatments. In general there were no significant interactions with row spacing in the DM data at full maturity, therefore it could be surmised that changes in the HI response across row spacings had come mainly from grain yield improvement.

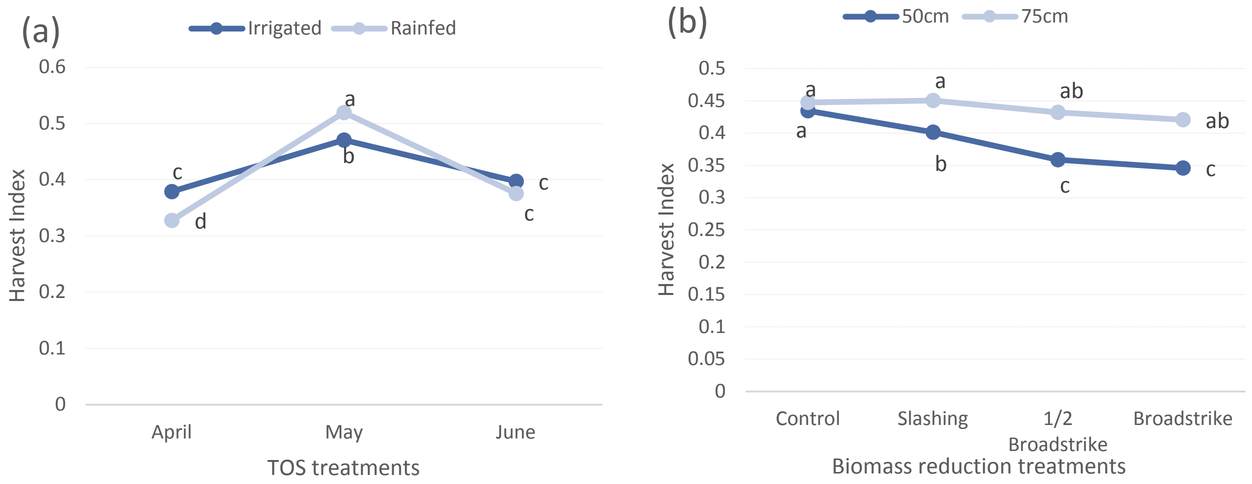


Figure 7. Significant interactions in relation to harvest index across whole experiment: (a) TOS and (b) biomass reduction

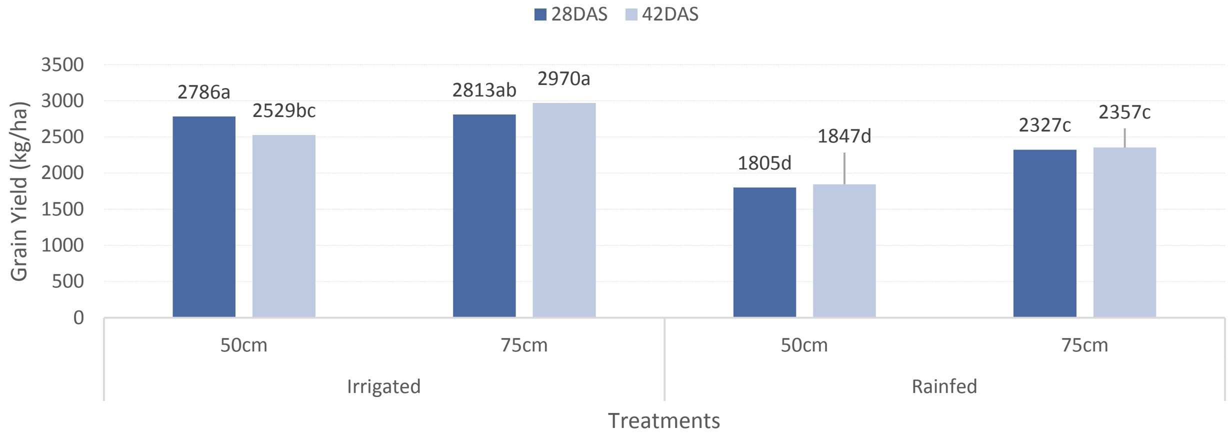


Figure 8. Significant interaction between irrigation, row spacing and application timing in April TOS

Grain yield

The April TOS had a number of interactions in grain yield. Firstly, row spacing and irrigation treatments have made a significant difference (Figure 8) with the 75 cm rows under irrigation producing a 500–600 kg/ha difference over their rainfed counterpart. The 50 cm rows made an even bigger difference with irrigation (600–900 kg/ha) compared to the rainfed treatments. Row spacing was significant in the rainfed treatments but less so in the irrigation comparison and the timing of application of biomass reduction treatments was only significant in the 50 cm with irrigation.

Secondly, the April TOS grain yield was largely unresponsive to any biomass reduction treatment that occurred at the 28DAS (Figure 9 (a)). There was a clear significant difference between the row spacing controls but this was not maintained across the other treatments. There was no significant response within the 50 cm row treatments against the control.

Late maturing plot in April TOS, BS applied 42DAS

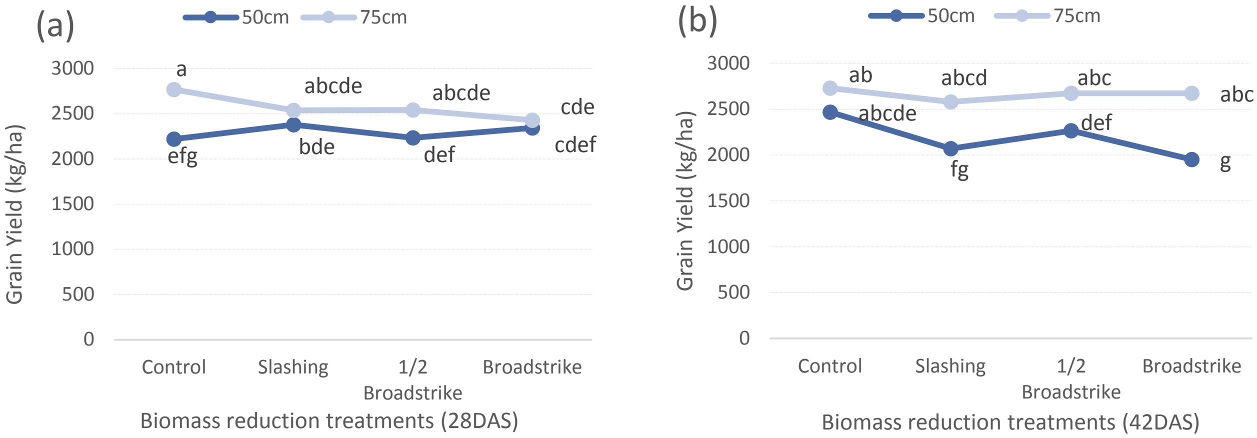


Figure 9. April TOS significant grain yield interactions across biomass reduction treatments: (a) 28DAS and (b) 42DAS

April TOS after slashing at 42DAS

There were changes when treatments were applied 42DAS (Figure 9 (b)). Both the slashing and full BS treatments yielded significantly less than the control in the 50 cm rows. All the 50 cm row treatments yielded significantly less than their 75 cm counterparts except the control plots and there was no significant differences in the 75 cm row treatments compared to their own control plots.

It would seem that the 50 cm rows responded negatively to the later application of BS at the full rate and slashing in the April TOS; whereas the 75 cm rows were quite resilient to the biomass reduction treatments.

In the May TOS (Figure 10 (a)) the 28DAS applications had a more significant interaction than the April TOS. Both BS treatments in the 28DAS application produced a significant reduction in grain yield compared to the control. In the 42DAS applications, only the slashing caused a significant yield deduction.

The June TOS (Figure 10 (b)) pattern was similar, with both BS treatments applied 28DAS having significantly lower yields than both the slashing and the control treatments. The main difference between the May TOS and the June TOS was in the 42DAS applications, with all three biomass reduction treatments causing a significant decline in grain yield against the controls.

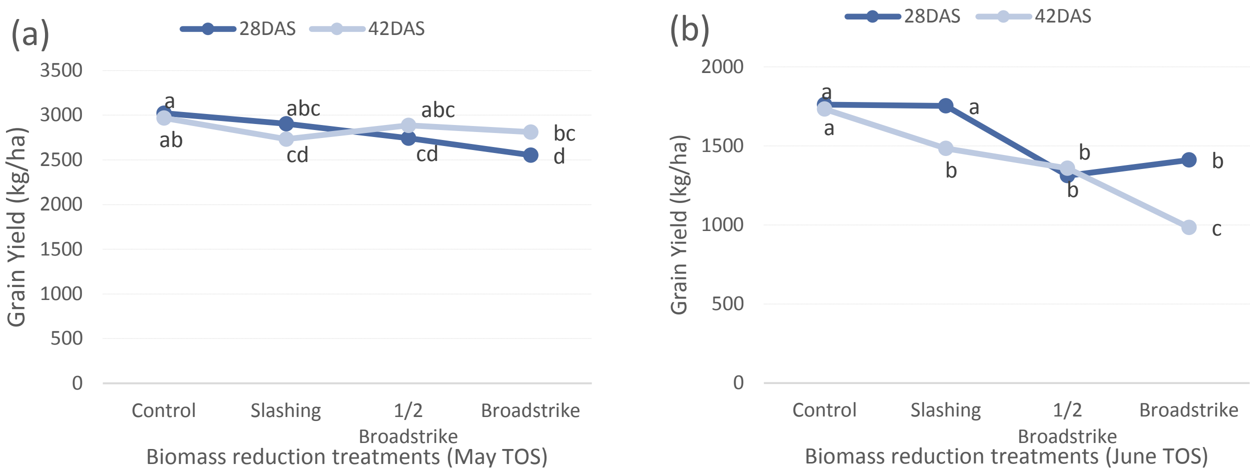


Figure 10. Significant grain yield interactions with biomass reduction treatments across (a) May TOS and (b) June TOS

The timing of applications for biomass reduction had an impact on grain yields but it was not consistent across TOSs. The April TOS was more affected by the treatments in the 42DAS window, although most of this was in the 50 cm row spacing. The May TOS was more affected by treatments in the 28DAS window, but in general the differences were small. The June TOS was affected by both application windows; the 42DAS application produced the biggest differences.

Generally slashing had the biggest impact in the later application window but again this was not consistent. There was very little difference in yields between the two BS applications except in the June TOS where the later application window with the full strength BS application created the biggest yield decline.

The original aim of this experiment was to improve the efficiency of the early planting window for chickpeas through manipulating biomass. This experiment has shown that the biomass reduction treatments did have an effect on DM production at flowering but by full maturity that effect had disappeared. This manipulation in biomass has led to no improvement in grain yield over the untreated controls. HI data would suggest that the efficiency of grain yield production was still largely affected by TOS rather than biomass manipulation.

This indicates either the biomass reduction treatments were not the most effective treatments for this experiment or that the concept of manipulating early biomass production is a difficult pathway for making early planted chickpea crops more efficient.

Soil water

Soil water measurements were obtained by taking neutron probe measurements twice a week across a number of selected plots in the April TOS only. These plots included:

- Biomass reduction treatments: slashing and controls (42DAS only)
- Row spacing: both 50 cm and 75 cm rows (both inter-row and on-row)
- Soil water conditions: irrigated and rainfed
- Replicates: three

From this data, plant available water (PAW) curves can be built against the crop progression (days after sowing) and overall soil water usage can be tracked over time. Treatments to supress dry matter production prior to first flower were thought to save on resources such as water and nutrition during the vegetative phase of the crop.

The yield data for the April TOS (Figure 9 (a) and (b)) suggested that slashing impacted on the 50 cm row spacings, but not 75 cm. The soil water usage data (Figure 11) indicates that there was a reduction in water uptake by the plants in 75 cm rows but not in the 50 cm rows compared to their respective controls. The light blue lines (Figure 11) shows a distinctive difference in the draw down between the two treatments in the 75 cm rows. The dark blue lines, which represent the 50 cm row treatments show no difference through the entire crop cycle.

The PAW values in the 75 cm rows come back together at about the 110 (DAS) mark which would suggest that by the time the crop reached maturity the savings in soil water had been utilised. Despite the soil water difference there were no yield differences between the control

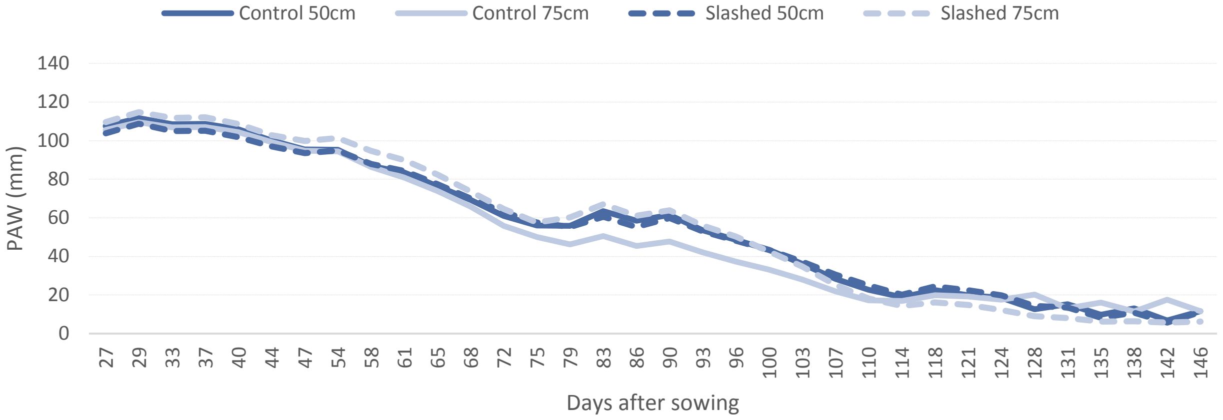


Figure 11. Soil water monitoring by neutron probe in April TOS, comparing slashed plots to control plots

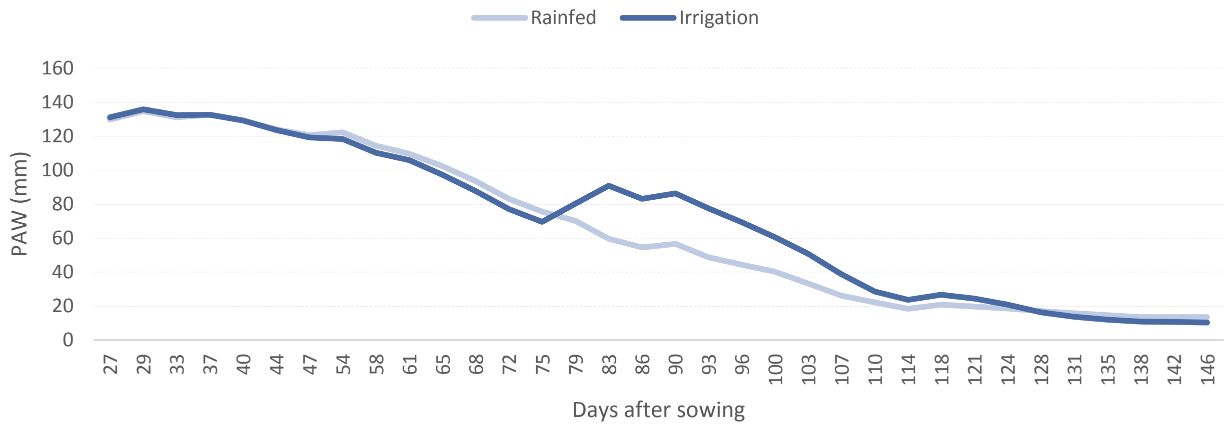


Figure 12. Soil water monitoring by neutron probe in April TOS, comparing irrigated plots to control plots

and slashed plots in the 75 cm rows but there was a significant yield differences in the 50 cm rows.

Slashing at 42DAS reduced DM at flowering for both the 50 cm and 75 cm row spacings. This should have achieved some soil water savings for use in grain production. However, the HI in the 50 cm rows was reduced (Figure 7(b)) indicating that they did not fulfil their grain potential. Similarly, the reduced DM in the 75 cm rows failed to increase HI and yield, meaning any water savings were not put into grain.

Slashing may have impeded root development in the vegetative phase, and so the rate of water uptake per day may have also been reduced during flowering and pod set. An impeded root system would have a greater effect on water use in wide rows, which was what was seen in the neutron readings (Figure 11). Therefore, it is unclear why the biomass and yield impacts of slashing were not larger in the 75 cm rows than the 50 cm rows.

There was a significant grain yield response in the April TOS (Figure 8) between the rainfed plots and plots that got one irrigation after first flower. The neutron data (Figure 12) shows the impact of the irrigation in relation to the rainfed plots. The most distinctive feature of this data is the extra water provided by the irrigation was totally utilised by the crop so that by the time full maturity was reached (125DAS), the level of PAW was almost exactly the same for both treatments. This could indicate that grain yield may still have been water-limited in both dryland and irrigated crops.

The irrigation has added between 500–900 kg/ha extra yield (20–54%) depending on row spacing and the timing of biomass reduction treatments (Figure 8). It is worth mentioning that the April TOS had the longest amount of time in the reproductive phase (59 days) so it had the best opportunity to make full use of the added water. It also had the lowest evaporative demand of the three TOS (Figure 15) which meant slower uptake of water and generally the ability to extract more water over a longer period. In

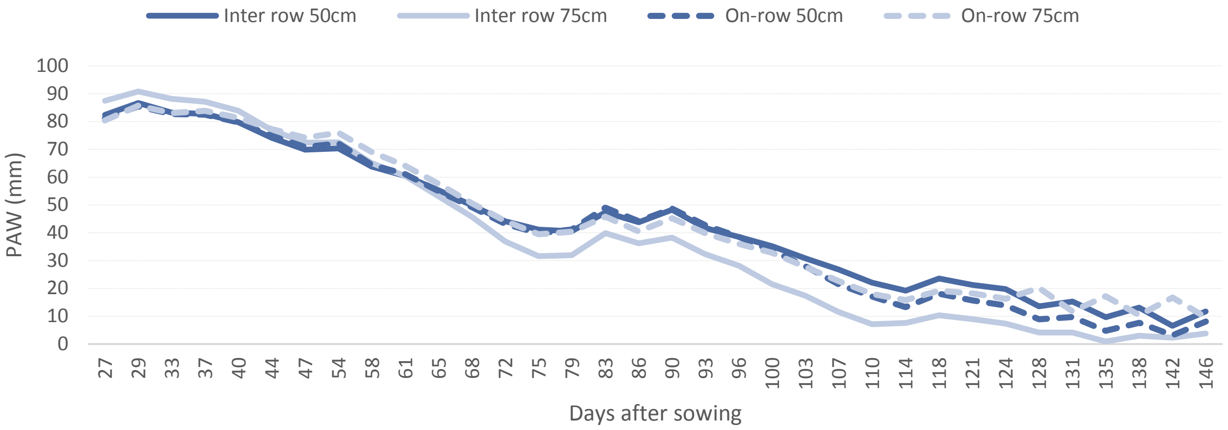


Figure 13. Soil water monitoring by neutron probe in April TOS, comparing inter-row and on-row measurements across 50 cm and 75 cm rows

the June TOS, the difference between irrigated and rainfed plots was not significant but its reproductive phase was only 47 days.

This experiment has shown a yield advantage to the 75 cm rows, which is unusual given that previous trials have shown that the wider rows, particularly 100 cm rows, have usually yielded significantly less than the narrower rows (25 cm and 50 cm). The difference between 50 cm and 75 cm rows is not enough to draw clear conclusions, however there is a distinctly different pattern of water uptake between the two row spacings.

Neutron tubes were placed both in the rows (on-row) and between the rows (inter-row), and data linked to water uptake patterns was collected (Figure 13). Leading up to flowering, the soil water was being drawn equally from both the inter-row space as well as on-row space. This was not unexpected in the 50 cm rows as the distance between rows is small enough for the water uptake pattern to be a lot more uniform.

After flowering (66DAS) the differences in water uptake changed within the 75 cm rows, as the inter-row space had a significantly bigger deficit than the on-row space. The 50 cm rows drew down more uniformly up until 100DAS and even after this time, the gap between the inter-row and on-row was too small to draw any major conclusions. This is the first year that neutron data has been recorded in chickpeas for CQ, so there is no historical data to compare to, however gravimetric data taken at harvest time in previous years has shown the inter-row space in 100 cm rows was drier in the top 50 cm compared to on-row data but below this soil depth the opposite occurs.

The larger deficit between the 75 cm rows was unexpected given that chickpeas are a tap rooted plant and logic would suggest that directly under the row would be more accessible for the plant. The wider row spacing could be changing the root structure as more plants are positioned closer together on a wider row forcing the plant to use more of its secondary roots for water uptake than its main tap root.

Weather

Previous trial data suggests that late planting tends to have shorter crop duration, lower yields but generally a higher harvest index. The early planting date tends to have the longest crop duration but not necessarily the highest yield or the best harvest index. A lot of this can be related to the weather that is experience by each TOS.

One of the key criteria for flowering is the mean daily temperature with the critical level of 14°C. Mean daily temperatures below this level will cause flower abortion and thus limit pod set. The plant compensates by extending the branch length and creating another node for a new flowering position. This in turn creates more vegetative mass and lowers harvest index. This compensation strategy works well while there is plenty of moisture available and growth rates are slow.

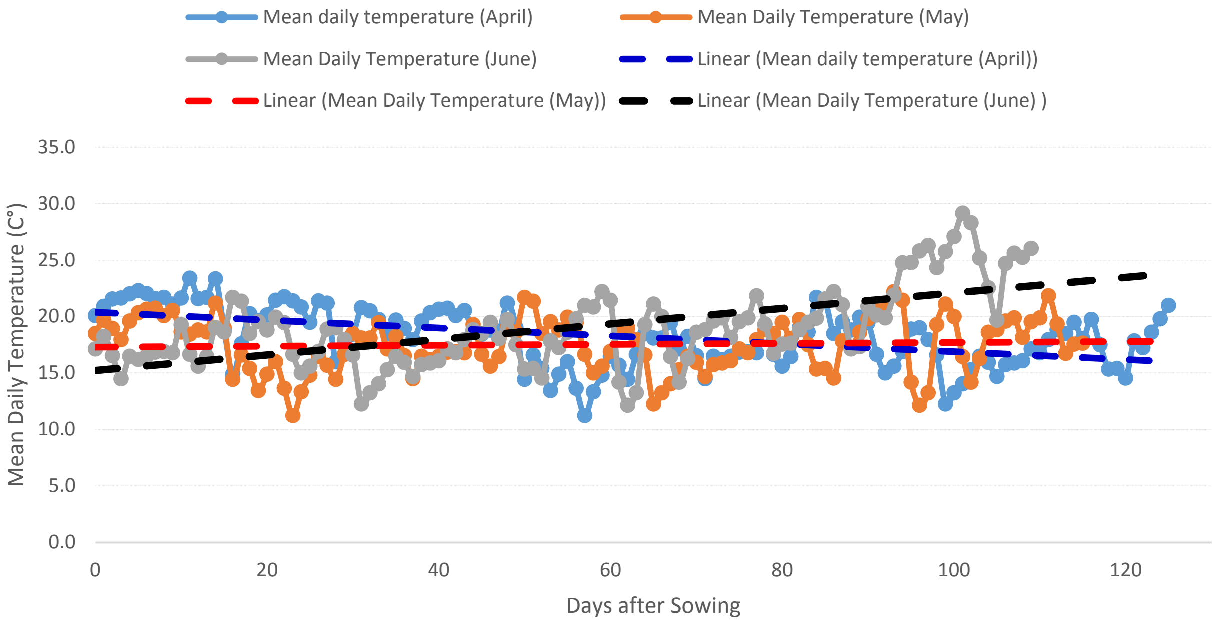


Figure 14. Comparison of mean daily temperature trends for each TOS

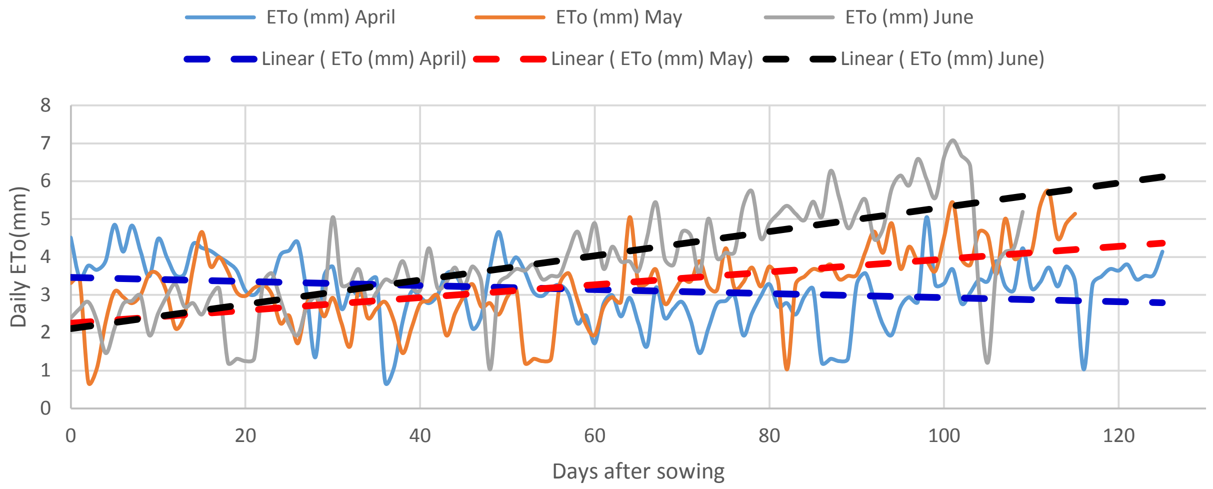


Figure 15. Comparison of evapotranspiration trends for each TOS

Mean daily temperature data from 2017 (Figure 14) shows both April and May TOSs had reasonably flat trends above the critical level of 14°C, although there were a number of individual days that fall below this critical level after flowering started (64-66DAS). The June TOS had a clear upward trend in mean daily temperature hence there were no days after flowering had started below the critical level. Generally the flowering period was largely uninterrupted for all three TOSs, which does not explain the eventual yield differences (Table 3) and changes in harvest index (Figure 7a)

The plant's ability to make the most of stored moisture will depend on the rate that it has to extract that moisture from the soil which will be governed to some extent by the environment or more specifically by the evapotranspiration rate.

Evapotranspiration (ETo) data (Figure 15) shows a distinctive change in the linear trends for each TOS. The April TOS had a flat rate across most of the growing season which ensured it could extract water at the slowest rate and consequently the slowest development (125 days to maturity). The June TOS had the steepest linear change in ETo; meaning that after flowering had started it had to maintain the fastest soil water extraction. The increasing ETo and increasing mean daily temperatures (Figure 14); meant that the June TOS had the fastest development to maturity (109 days) and this may have impacted on its ability to set yield. The May TOS (115 days) had a moderate increase in ETo and consequently its rate of development was also quicker than the April TOS (125 days) but less than the June TOS.

Yield data would suggest (Table 3) that the average yield increase between April and May TOS was 422 kg/ha (17%), largely attributable to the difference in rainfed yields. Comparing the two irrigated yields across April and May TOS, the difference is only 150 kg/ha (5.4%). Within each TOS the irrigation treatment made a statistically significant difference, however the April TOS had differences that were nearly three times those differences in the later TOS. The slower growth rate and lower evaporative pressure meant the April TOS could make the most of additional water in the irrigated treatments.

Another way of looking at this effect is that the April TOS had the largest dry matter accumulation and therefore needed the most amount of water to maintain its growth, hence the rainfed treatments ran out of water a lot sooner and the added irrigation had the greatest effect.

The yield advantage maintained by the May TOS over both the earlier and later TOSs may primarily be due to the best balance between minimum dry matter and maximum grain yield. The May TOS clearly had a significant advantage in harvest index (Figure 7a) over both of the other TOSs and this meant that it grew the smallest amount of dry matter for the highest grain yield. By optimising its dry matter production, it was not using water to maintain excessive plant material and also it managed to complete its maturity before the evaporative demand of spring temperatures started to put pressure on its water supply.

Implications for growers

The importance of TOS with chickpeas has been reinforced once again by this experiment. Previous trials have suggested that planting early chickpeas may improve dry matter accumulation (bigger plant) but it does not always guarantee the highest yields. Early planting dates often run into trouble in the early part of flowering with cooler temperatures aborting flowers and interfering with fruit set. The plant has the ability to compensate for this by extending its branches and setting up more fruiting nodes, however this is only possible if there is plenty of moisture to spare (as in 2016). In a drier year (like 2018) where stored moisture is more limited, the plants' ability to compensate is reduced.

The May TOS has long been regarded as the optimum planting window in CQ for chickpeas and in this experiment that was confirmed. What is less certain is why it performs so well. This experiment has given some data that suggests the reasoning might be tied to smaller biomass at the start of flowering and having no interruptions to early flower set.

The May TOS started flowering with nearly 1000 kg/ha lower vegetative mass than the April TOS but set an extra 500 kg/ha of seed. At maturity the May TOS still had just over 1000 kg/ha less dry matter but a harvest index that was nearly 0.5. The natural conclusion is that the extra dry matter in the April TOS cost a lot more stored moisture to maintain instead of saving that moisture for flower and seed production.

The main treatments in this experiment focused on reducing vegetative growth prior to flowering in order to save on stored soil moisture. The treatments did reduce vegetative mass at flowering but in the most part did not reduce the final dry matter weight at maturity for either the April or May TOS. In general, the use of Broadstrike™ at the full rate had a bigger impact than slashing as a plant retardant. Applying Broadstrike™ at 28DAS had a bigger impact in the early TOS but much less impact in the later TOS. This inconsistency in performance means it may not be the most reliable product to use in this situation. Soil water measurements would suggest that slashing did reduce the amount of water used prior to flowering (mainly in the 75 cm rows), however this water saving was not converted into more yield.

This experiment has shown that the chickpea plant can optimise dry matter production to produce an excellent HI from stored moisture in an ideal planting window. What remains is how we can manage the plant in an early TOS scenario to replicate what the plant naturally does in an ideal planting window.

Acknowledgements

The Queensland Pulse Agronomy Initiative (UQ00063) is funded by the Grains Research and Development Corporation, the Queensland Alliance for Agricultural and Food Innovation and the Department of Agriculture and Fisheries.

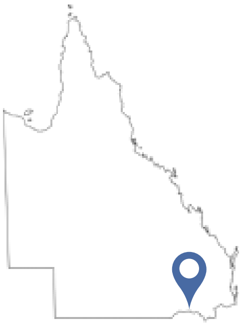
Trial details

Location:	Emerald Agricultural College farm, Field Research facility
Crop:	Chickpeas (PBA Seamer$^{\phi}$)
Soil type:	Black /Grey cracking Vertosol
In-crop rainfall:	43 to 131 mm, depending on TOS
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	21	51	8	0.81	91	33
10-30	17	14	9	0.40	33	33
30-60	11	4	11	0.32	17	34

Faba bean: Agronomic impact of row spacing, variety and time of sowing on crop development—Goondiwindi



Grant Cutler
Department of Agriculture and Fisheries

RESEARCH QUESTION: *How do changes in agronomic practices affect crop development and yield in faba bean?*

Key findings

1. The wider the row the lower the biomass accumulation.
2. Time of sowing has the largest effect upon crop development and yield.
3. Low in-crop rainfall limited the conversion of biomass into yield.

Background

Faba bean has been gaining popularity in the northern grains region in recent years (attributed to higher prices and improved varieties). Whilst southern Australia dominates the market, growers in the northern region are looking more favourably upon faba beans as an important crop to include in their cropping rotations; as an excellent break crop and for its high nitrogen-fixing abilities. An improved understanding of faba bean agronomy in southern Queensland will help growers better utilise them within their cropping systems.

Treatments

A trial was established 60 km west of Goondiwindi in 2017 with the following treatments:

- Two times of sowing (TOS): April (TOS1) and May (TOS2)
- Four row spacings: 25 cm, 50 cm, 75 cm and 100 cm
- Two varieties: PBA Nasma$^{\phi}$ and PBA Warda$^{\phi}$

The trial was planted using a 2 m, 7-row disc seeder. Row configurations were:

- 7 rows (25 cm spacing)
- 4 rows (50 cm spacing)
- 3 rows (75 cm spacing)
- 2 rows (100 cm spacing).

Soil Plant Available Water (PAW) was approximately 125 mm at the time of planting. Total dry matter (TDM) cuts were taken at flowering and just prior to maturity. Grain was harvested using a plot header.

Results

The season saw differences between the two TOSs. Early on, both treatments had accumulated similar dry matter at 50% flowering, however as the season progressed TOS1 produced significantly higher biomass (Figure 1) and a slightly higher grain yield (TOS1 0.9 t/ha; TOS2 0.6 t/ha). This data reflects that TOS2 struggled to accumulate biomass due to poor in-season rainfall, highlighting the importance of early sowing in faba beans.

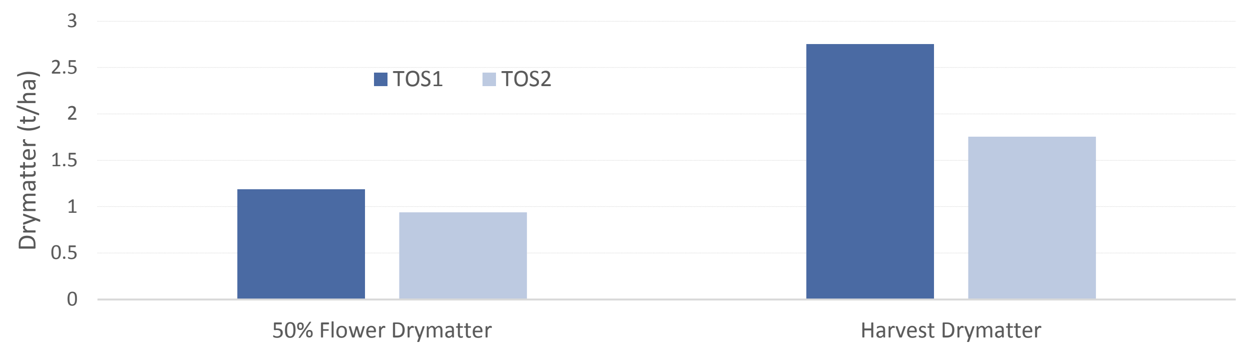


Figure 1. The effect of TOS on drymatter accumulation at 50% flower and harvest maturity

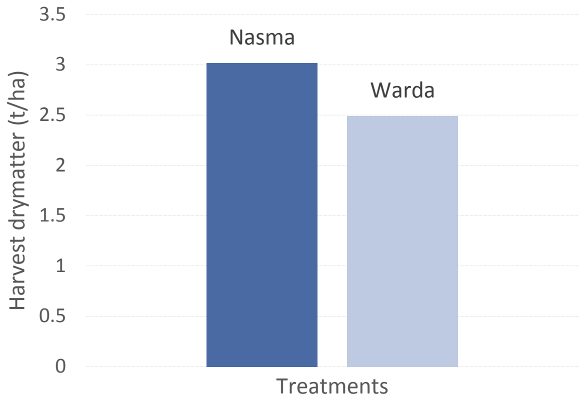


Figure 2. The effect of time of sowing on dry matter accumulation at 50% flowering and harvest maturity

Overall, average yields were obtained at the site, however slight varietal differences were observed (PBA Nasma$^{\phi}$ 1 t/ha, PBA Warda$^{\phi}$ 0.8 t/ha). There were large differences in dry matter accumulation between varieties (Figure 2) with PBA Nasma$^{\phi}$ producing 500 kg/ha more dry matter compared to PBA Warda$^{\phi}$. PBA Nasma$^{\phi}$ was also found to be higher yielding than PBA Warda$^{\phi}$ (1.04 t/ha compared to 0.77 t/ha). Also as expected, PBA Nasma$^{\phi}$ achieved a higher 100 seed weight than that of PBA Warda$^{\phi}$ (57.1 g versus 46.4 g).

Row spacing also affected dry matter. As expected, narrow rows accumulated more dry matter by the end of the season (Figure 3), however there was no obvious difference in yield. This can be attributed to the unusually dry season, which caused the crop to run out of moisture before crop yield potentials could be reached. These results are in line with previous trials highlighting the benefit of narrow row spacing on dry matter accumulation, however these past trials also indicated increased yields under these narrow row spacings.

Implications for growers

Narrow row spacings of 25 and 50 cm consistently produced higher dry matter yield than wider row spacings (75 and 100 cm). This effect has been seen across multiple trial sites and is usually accompanied by a yield benefit however, due to the lack of in-crop rain this trial was unable to convert the increased biomass into a yield response. While there was only a small varietal and row spacing effect on yield due to the dry season, there was a substantial reduction in yield in the later time of sowing. This can be attributed to poor rainfall during the season leading to lower yield potentials, however an April planting time is recommended for this region.

Acknowledgements

The team would like to thank the co-operators for hosting this trial as well as the Grains Research and Development Corporation, Queensland Alliance for Agriculture and Food Innovation and the Department of Agriculture and Fisheries for the funding support of the project (UQ00067).

Trial details

Location:	Goondiwindi, Queensland
Crop:	Faba bean (PBA Warda$^{\phi}$ and PBA Nasma$^{\phi}$)
Soil type:	Brown Vertosol
Rainfall:	210 mm
Fertiliser:	50 kg/ha Greenfield X ZN 2% at planting

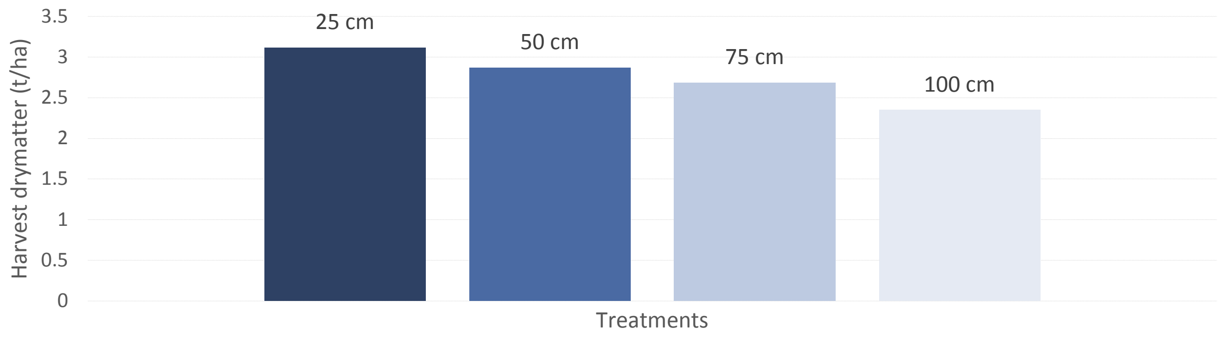


Figure 3. The effect of row spacing on dry matter accumulation at harvest maturity

Nutrition research

The nutrition research portfolio is continuing to explore crop responses aligned with deep placement of phosphorus (P) and potassium (K) across central and southern Queensland cropping soils. The 2017 results report on cumulative grain yield responses with economic implications. Nine sites had winter crops sown in 2017. This extended the experiments into their fourth, third and second crop. Many of these trials are demonstrating very positive economic returns from deep application of P and K, which should encourage growers to assess the need for deep placement of nutrients on their own farms.

In addition to researching residual response to an application, new research is exploring how more P can be put into crops to increase yield further. Questions explored cover choice of product, form of delivery (granular vs liquid), number of bands the fertiliser needs to be placed in, and the application rate of the nutrient.

Yield increases with grass crops (wheat, barley, sorghum) are becoming more consistent providing sufficient nitrogen and water is available to not supress yield gain. Even under tough seasonal conditions in winter 2017, positive yield increases with deep-P were measured across several sites.

Research is continuing with pulse crops, where yield effects have been less consistent. There were mixed yield outcomes with deep-P sites in 2017 with chickpea. Some sites had no effect while others delivered a 25% increase.

Continuing to monitor crops over the longer term is hopefully providing opportunity to further refine the response relationships across different seasonal conditions and this is an area for exploration in the future.

Residual value of deep placed phosphorus, potassium and sulfur in scrub soils—Dysart

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RESEARCH QUESTION: *Does the deep placement of phosphorus, potassium and sulfur have an impact on chickpea yields four years after the original application?*

Key findings

1. Chickpea yields doubled in response to deep-banded phosphorus treatments.
2. Chickpea yields increased up to 28% from deep-banded potassium treatments.
3. Chickpea yields did not respond to deep-banded sulfur treatments.

Background

Over the last four 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 is particularly evident in the non-mobile nutrients of phosphorus (P) and potassium (K). In some established zero tillage production systems there is a marked difference between the nutrient concentration in the top 10 cm of the soil profile and the deeper layers (10-30 cm and 30–60 cm), that cannot be explained by natural stratification. It would seem that this pattern of soil analysis 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 the one-off application of either P, K or sulfur (S) that is placed in these deeper more depleted layers can provide a grain yield benefit and whether that benefit can be maintained over several years. 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 at this site were established in August 2013. Since then, there have been three successive sorghum crops harvested from the site in 2014, 2015 and 2016. In 2017, a chickpea crop was planted on the site and harvested on 13 October 2017. Each crop has been monitored for response to the original deep-placed fertiliser treatments, both in grain yield and dry matter production. Additionally, both the dry matter samples and grain samples have had tissue analysis to quantify the nutrient uptake by the crop.

Table 1. Summary of application rates for all trials

Trial	Treatment label	Nutrient application rates (kg/ha)				
		N	P	K	S	Zn
Phosphorus	0P	80	0	50	20	0.5
	0P	80	0	50	20	0.5
	10P	80	10	50	20	0.5
	20P	80	20	50	20	0.5
	40P	80	40	50	20	0.5
	0P-KS	80	0	0	0	0.5
	40P-KS	80	40	0	0	0.5
	FR	0	0	0	0	0
Potassium	0K	80	20	0	20	0.5
	0K	80	20	0	20	0.5
	25K	80	20	25	20	0.5
	50K	80	20	50	20	0.5
	100K	80	20	100	20	0.5
	0K-PS	80	0	0	0	0.5
	100K-PS	80	0	100	0	0.5
	FR	0	0	0	0	0
Sulfur	0S	80	20	50	0	0.5
	0S	80	20	50	0	0.5
	10S	80	20	50	10	0.5
	20S	80	20	50	20	0.5
	30S	80	20	50	30	0.5
	0S-PK	80	0	0	0	0.5
	30S-PK	80	0	0	30	0.5
	FR	0	0	0	0	0

Phosphorous (P) trial

There were eight treatments in total (Table 1), which included four P rates; 0, 10, 20, and 40 kg of P/ha. All of these treatments had background fertiliser applied at the same time to negate any other potentially limiting nutrients. This background fertiliser included: 80 kg of nitrogen (N), 50 kg of K, 20 kg of sulfur (S) and 0.5 kg of zinc (Zn) per hectare. The next two treatments included 0P and 40P with background N and Zn, but without K and S (0P-KS, 40P-KS). The last two treatments were a farmer reference (FR), and an extra 0P plot to give two controls for each replicate. The FR treatment had nothing additional applied to normal commercial practice.

Treatments were applied using a fixed tine implement which delivered the P and K at 20 cm and the N and S, 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.

The 2017 chickpea crop had no fertiliser applied pre-plant. There was no starter fertiliser applied at planting but a biocatalyst product (Foundation™LM) was added with the inoculant as a liquid injection at a rate of 2.5 L/ha. The chickpea variety, Kyabra⦷, was planted at 40 kg/ha on 15 May 2017. The crop received 94 mm of in-crop rainfall of which 60 mm was received three days after planting and 18 mm was received a week before harvest.

Comparison of chickpea plants taken from treated (left) and untreated (right) deep P plots

Potassium (K) trial

There were eight treatments in total (Table 1), which included four K rates; 0, 25, 50, 100 kg K/ha. All of these treatments had background fertiliser applied at the same time to negate any other potentially limiting nutrients. This background fertiliser included: 80 kg of N, 20 kg of P, 20 kg of S and 0.5 kg of Zn per hectare. The next two treatments included 0K and 100K with background N and Zn, but without P and S (0K-PS, 100K-PS). The last two treatments were a farmer reference (FR) and an extra 0K to give two controls in each replicate. The FR treatment had nothing additional applied to normal commercial practice.

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

Sulfur (S) trial

There were eight treatments in total (Table 1), which included four S rates; 0, 10, 20, 30 kg S/ha. All of these treatments had background fertiliser applied at the same time to negate any other potentially limiting nutrients. This background fertiliser included: 80 kg of N, 20 kg of P, 50 kg of K and next two treatments included 0S and 30S with background N and Zn, but without P and K (0S-PK, 30S-PK). The last two treatments were similar to the other trials with an extra 0S treatment being included as another control and a farmer reference (FR) treatment.

Comparison of 40P plot on left and 0P plot on the right

Table 2. Mean grain yield comparison across treatments in P trial for chickpeas 2017

Treatments	Mean grain yields (kg/ha)#	Least significant difference P(0.05)	Relative difference to '0P' plots	
			(kg/ha)	(%)
FR	538	ab	-171	-24.1
0P-KS	463	a	-246	-34.8
0P	709	b	0	0.0
10P	959	c	250	35.3
20P	1172	cd	463	65.3
40P	1415	d	706	99.6
40P-KS	1099	c	390	55.0

Means with a common letter are not significantly different (lsd=231)
 # Note: Significant issues with the set-up of the plot harvester means these yields are undervaluing the true plot yields. Hand harvest data shown in Table 3 gives an indication of the scale of the harvest losses and what the potential plot yields might have been

Table 3. Mean hand harvest yield comparison across selected treatments in P and K trial for chickpeas 2017

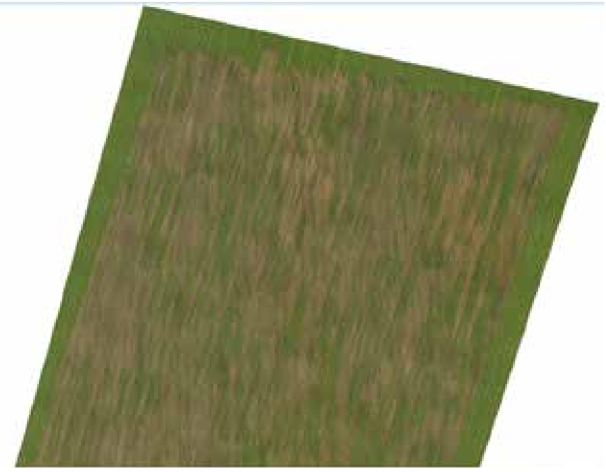
Selected Treatments	0P	40P	40P-KS	0K	100K	100K-PS
Mean grain yield (kg/ha)	413	2060	2250	1331	1880	681
Least significant difference P(0.05)	a	c	c	b	bc	a

Results

The results are presented on each trial separately. The 2017 chickpea crop represents the fourth crop harvested off this site since the initial treatments were applied. This report also includes the cumulative mean yield data from all four crops grown to date.

Phosphorus trial

There were visual differences in the paddock of the plots with deep P and this transferred through to the grain yield data (Table 2) which shows a clear significant difference between the 0P treatments and all four P treatments (10P, 20P, 40P and 40P-KS). The differences in yield results between the treatments is less clear and this may have been a symptom of the natural variability across the site from old gilgai depressions running diagonally across the site (see drone image).



Drone image capture: Diagonal striations across the site are consistent with the pattern of old lines of gilgais that previously existed before development. These narrow bands may have marginally higher nutrition levels than the surrounding soil profile

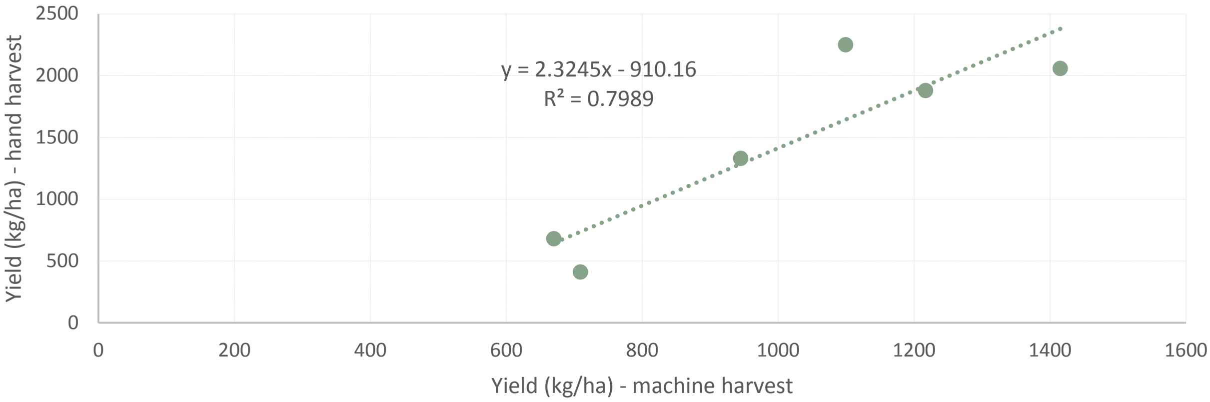


Figure 1. Linear relationship between hand harvested yields and machine harvested yields across selected treatments in 2017 chickpeas

Table 4. Cumulative additional profit ($/ha) compared to 0P

P Rate (kg/ha)	2014 Sorghum	2015 Sorghum	2016 Sorghum	2017 Chickpea	ROI
10	$36	$99	$137	$337	5.1
20	$16	$120	$201	$572	5.6
40	-$16	$53	$124	$689	3.9

Assuming P applied as MAP (22P, 11N) at $800/t and $30/ha in application costs, sorghum at $250/t, and chickpea at $800/t

What was significant was a doubling in the yield from the 0P plots compared to the top rate of 40P. There were also significant decreases in yield when KS fertiliser was removed (0P-KS and 40P-KS), which would indicate that the background fertiliser (KS) was also playing a role in this crop.

Crop yields were relatively low, as a result of a tough season but also a failure of the plot harvester to capture a percentage of the grain yield. Additional data taken prior to harvest included collecting individual plants from the high and low P plots and the high and low K plots. All the pods were hand harvested, thrashed and weighed. This effectively gives a theoretical yield level before mechanical harvesting (Table 3).

The hand harvest data (Table 3) can be plotted against the machine harvest data for the same plots (Figure 1). There was a consistent relationship for the harvest losses indicating that the top end yield for the high P plots was more likely to be 2000–2100 kg/ha. This represents about 85-90% of the yield obtained from the commercial harvest of the newly treated field surrounding the trial site, suggesting that the residual effect of deep P may be starting to drop off a little, but this will be confirmed in subsequent seasons.

The difference between 40P and 40P-KS plots was not observed in the hand harvested data (Table 3). This may reflect the uneven nature of the site where the gilgai influence across the site was impacting on parts of plots where small plot samples may have been collected. The machine harvest yields have the advantage of being able to average the whole length of the plot (24 m) and the gilgai effect can be minimised. The gilgai line may have marginally higher K levels which could be why the 40P-KS plots in the hand harvest yields were not significantly different to the 40P plots.

A comparison of yield results across the last four years (Figure 2) shows a consistent response to P at this site. Over the past four years the 40P treatment has returned an additional $689/ha in additional profit compared to 0P. Whilst the 40P rate had an upfront cost of $175/ha, this was almost wholly recovered in the first crop, with each following crop contributing directly to profit.

Currently the 20P rate has provided the highest Return on Investment (ROI), generating $5.60 in profit for every dollar spent, however it is expected that the 40P treatment will continue for longer, increasing its ROI in upcoming years (Table 4).

This demonstrates that one deep-banded application can maintain improved P uptake in-crop for at least four years in a P-limited soil.

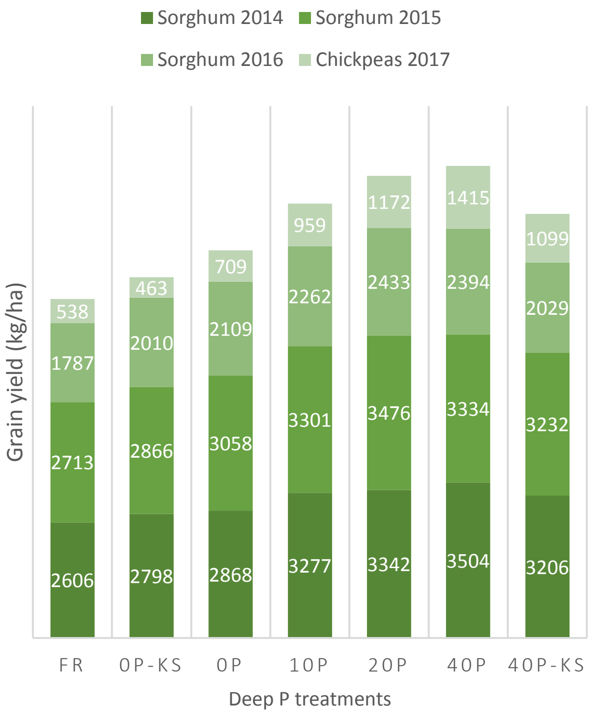


Figure 2. Accumulated yield response to P treatments for four successive crops grown on the trial site

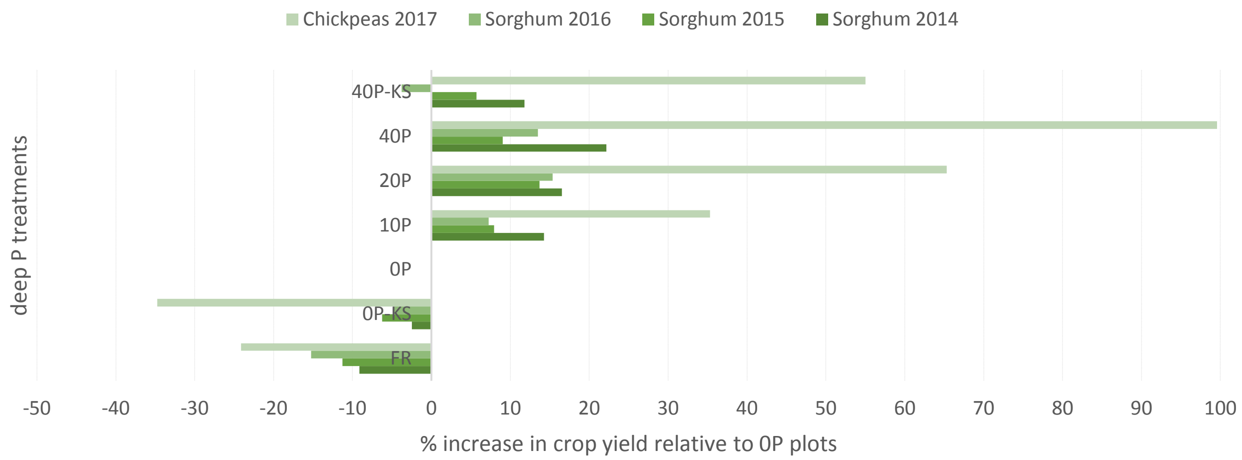


Figure 3. Relative response of grain yield to the deep-banded P treatments as a percentage of the 0P plots

The relative improvement (%) in chickpea yields across the P trial (Figure 3) dramatically exceed those in sorghum; with chickpea at least doubling its yield between the 0P and 40P plots while the best response in sorghum was 21%. This suggests that N may be playing a role in the limitation of yield in the sorghum, especially in the second and third crops after establishment when the additional N applied had been largely exhausted. It is also possible that chickpeas have a far higher requirement for P then the cereal species and will have a naturally larger relative response to additional P fertiliser.

Potassium trial

The K trial data (Table 5) shows a clear significant difference between the plots that had P applied as background fertiliser (0K, 25K, 50K, 100K) and those plots without background P (FR, 0K-PS, 100K-PS) which reinforces the fact that P is the most limiting element on this site. However, while the relative responses to differing rates of K are less clear-cut, it should be noted that this trial also experienced the same harvesting losses as the P trial, and so maximum yields are likely underestimated.

Table 5. Comparison of mean grain yields across treatments in the K trial for chickpeas 2017

Treatments	Mean grain yields (kg/ha)	Least significant difference P(0.05)	Relative difference to '0K' plots (kg/ha)	(%)
FR	664	a	-282	-29.8
0K-PS	685	a	-261	-27.6
0K	945	b	0	0.0
25K	1157	bc	211	22.4
50K	1125	bc	180	19.1
100K	1217	c	272	28.8
100K-PS	670	a	-275	-29.1

Means with the a common letter are not significantly different (lsd=241)

When the relationship derived from Figure 1 was applied to the machine harvested data in this trial, the yield of plots without background P remained relatively unchanged; but the response to background P and S increased (yields of 1160 kg/ha for the 0K treatment), and the response to applied K suggested maximum yield at 1600-1700 kg/ha.

There was a significant difference between 0K and 100K plots (272 kg, 29%) on the harvested yields (Table 5), but this could have been as much as 500 kg/ha (43%) based on the hand harvest estimates. Both hand harvested and machine harvested yield data suggested there is little difference between K rates (25-100 kg K/ha) in terms of grain yields. Interestingly, the yields with 100K in either Table 4 (1217 kg/ha) or estimated from hand-harvested yields (1727 kg/ha) were less than yields obtained by either measure in the 40P treatment in the P trial, but very similar to the P trial yields with 20P. The K trial only had a basal P application of 20P, so while this had produced a significant yield response consistent with this being the primary site yield limitation, it had only allowed the crop to reach a yield potential equivalent to what looks to now be a suboptimal P rate in crop season four at this site. This means that the response to K in these results may have been constrained by a lack of basal P.

The historical gilgai lines mentioned in the P trial section certainly add to yield variability in the sites without applied P and/or K, and when combined with low site yields, have meant that obtaining statistically significant differences in yield have been more challenging.

The yield benefits from the high K treatment (100K) in this chickpea crop (29-43%, depending on yield data used) were a much higher percentage difference than had occurred in previous sorghum crops (Figure 4). As discussed for the P trials, this may reflect either low N availability limiting yields of the cereal crops and/or a higher requirement for K by the chickpea crops.

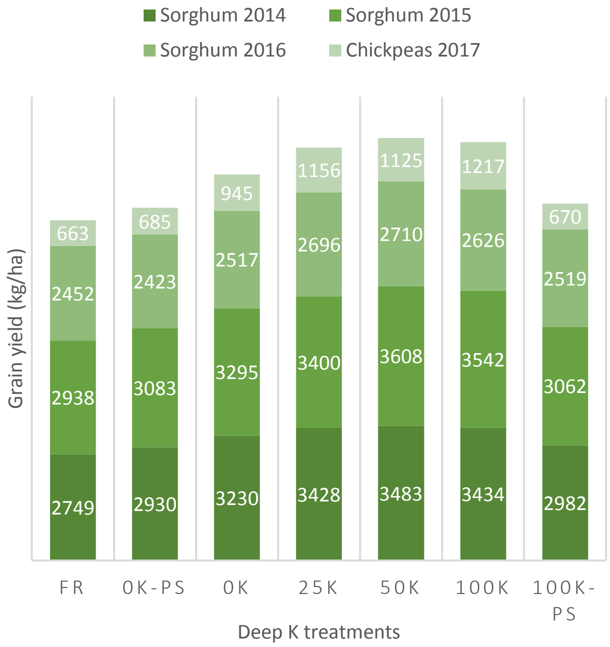


Figure 4. Accumulated yield response to K treatments for four successive crops grown on the trial site

Evaluating the data across all four years of crop results (Figure 5) shows a small but consistent response to additional deep-banded K. There is very little difference between the 50K and 100K treatments with total additional grain production of 939 kg/ha and 832 kg/ha achieved respectively for these treatments.

Each of the K applications has provided additional profit over 0K four years after initial treatment, however whilst the 25 and 50K rates had covered their treatment costs in the second year, 100K had not generated a positive return until year three. After four years the 25K rate had the highest return on investment generating $4.30 in additional profit for every dollar spent (Table 6).

Interplot variation caused by old gilgai lines across plots with no additional P prior to flowering; 100K-PS plot on the left and FR plot on the right. The application of deep P and K effectively eliminated these crop differences

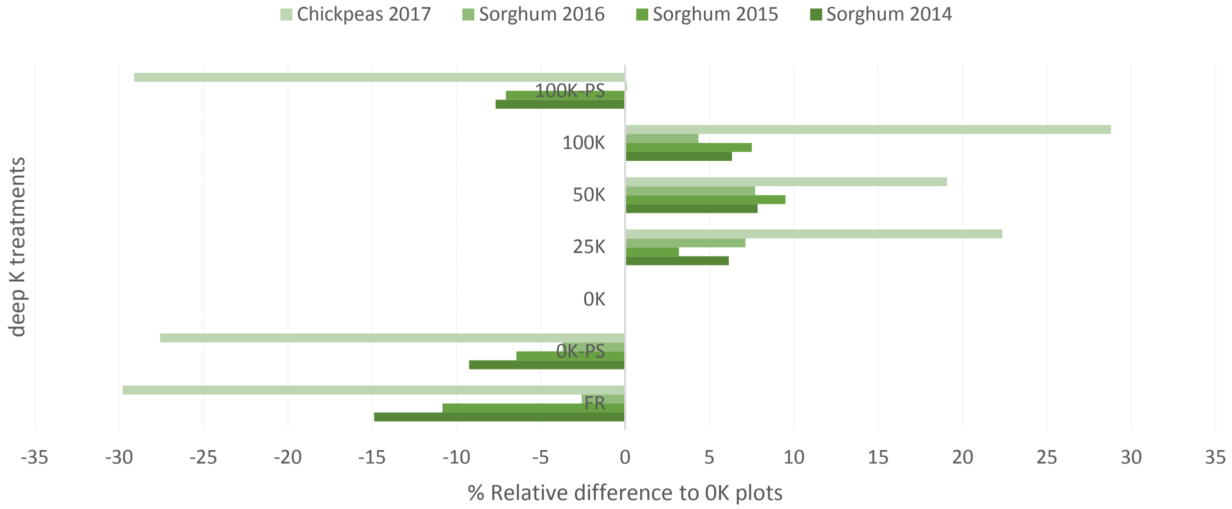


Figure 5. Relative response of grain yield to the deep-banded K treatments as a percentage of the 0K plots

Table 6. Cumulative Additional Profit ($/ha) vs 0K

K rate (kg/ha)	2014 Sorghum	2015 Sorghum	2016 Sorghum	2017 Chickpea	ROI
25	-$6	$21	$66	$234	4.3
50	-$17	$62	$110	$254	3.2
100	-$79	-$17	$10	$228	1.8

Assuming K applied as MOP (50K) @ $500/t, $30/ha application cost, sorghum price of $250/t, and chickpea $800/t

Sulfur trial

Consistent with previous data, the chickpea yield data for the S trial (Table 7) has shown no response to residual rates of banded sulfur fertiliser. The main significant difference in this trial is between plots that have no background P and K fertiliser (FR, 0S-PK, 30S-PK) and those that do (0S, 10S, 20S and 30S). While there was no response between the different rates of S fertiliser, crop yields declined up to 40% when the P and K were not added. This data provides additional evidence that the site was severely P and K limited, and that applying other macronutrients will have little or no impact on yields unless those constraints are addressed.

The FR plots show slightly higher yields than the 0S-PK and the 30S-PK treatments, and while not significantly different, it is the first time in four years that this has occurred (Figure 6 and Figure 7). The main difference between the –PK plots and the FR plots was the addition of ripping and extra nitrogen and zinc when the treatments were applied in 2013. This combination gave the –PK plots a yield advantage in the first three sorghum crops (800 kg/ha for 0S-PK and 951 kg/ha for 30S-PK) over the FR treatment, however in the fourth year the advantage seems to have gone. While tempting to suggest this pattern is consistent with response to the basal N application, providing gains in grain but not grain legume crops, the real cause cannot be determined.

Table 7. Comparison of mean grain yields across treatments in S trial for chickpeas 2017

Treatments	Mean grain yields (kg/ha)	Least significant difference P(0.05)	Relative difference to '0S'	
			(kg/ha)	(%)
FR	1062	ab	-277	-21
0S-PK	928	a	-411	-31
0S	1339	c	0	0
10S	1360	c	21	2
20S	1298	bc	-41	-3
30S	1278	bc	-61	-5
30S-PK	823	a	-516	-39

Means with the same letter are not significantly different (lsd=257)

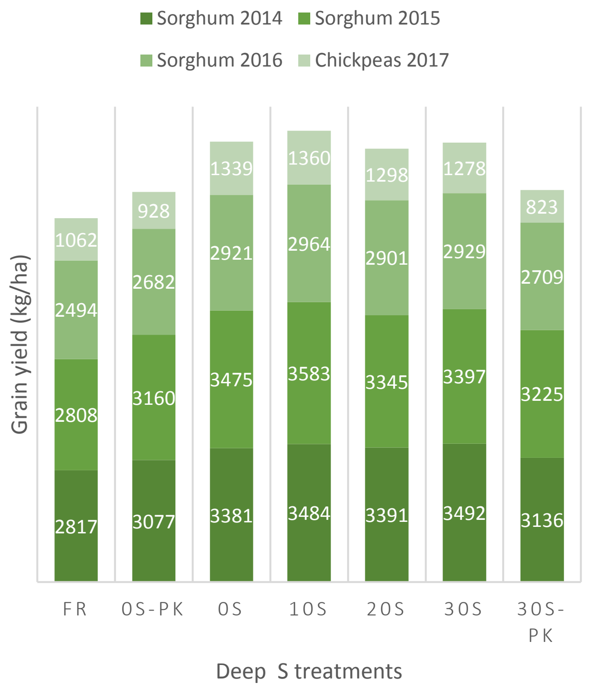


Figure 6. Accumulated yield response (kg/ha) to S treatments for four successive crops grown on the trial site

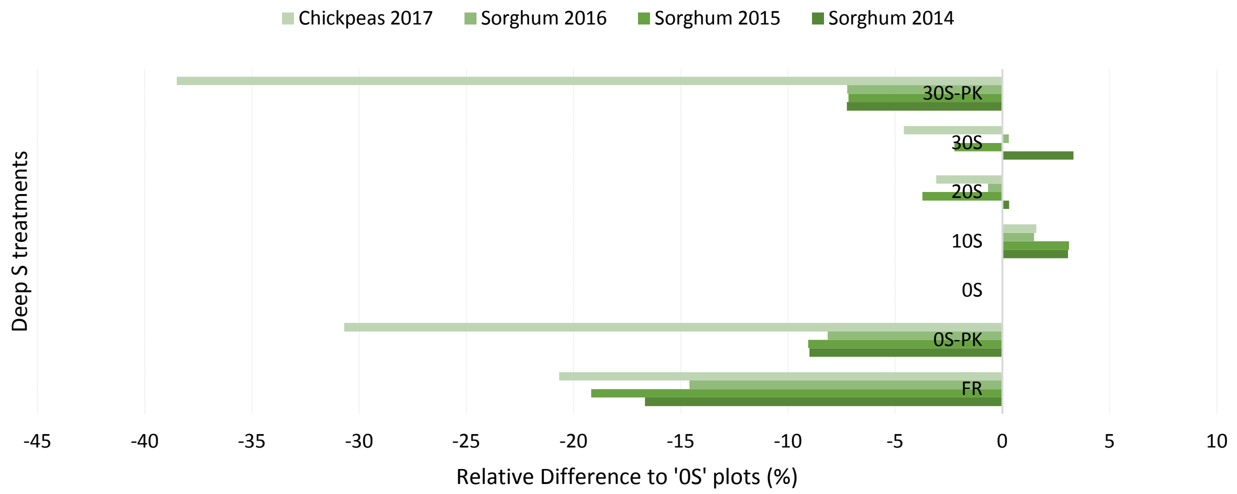


Figure 7. Relative response of grain yield to the deep-banded S treatments as a percentage of the 0S plots

Implications for growers

The 2017 crop results from this trial site have highlighted the differences that can occur between species of crops in response to critical levels of nutrition. The average yield response in the P trial for sorghum over the first three years at this site was 17%, compared to the first chickpea crop at the site effectively doubling its yield (100% increase). This dramatic difference between crop performance highlights two messages about long term nutrient management.

The first message is that nitrogen availability can have a dominating impact on the yield of cereal species. If N is low, the responses to added P and K may not be expressed as the crops remain N deficient . Protein levels for the last sorghum crop at this site were low (8.1%) which indicates nitrogen levels in the soil were either depleted or unavailable (trapped in the dry surface soil layers). This may be one of the main reasons for the chickpea crop having such dramatic improvement in response to the deep P and K applications, compared to the previous sorghum crops.

The second message is that while grain legumes can fix their own N and so ensure that the response to P and K is more likely to be evident, their grains also have a much higher content of P and K compared to cereals (10 kg/t versus 3.5 kg/t for K, 3 kg/t versus 1.8 kg/t for P). Therefore, while overcoming a P and K nutrient limitation by deep banding will have a more consistent effect on yields of grain legumes such as chickpeas compared to crops like wheat or sorghum, the rate of export of applied P and K means fertiliser rundown will potentially occur faster with higher legume frequencies.

Another major outcome of this trial is the evidence that the deep banding of both P and K fertilisers can continue to produce economic responses after four successive crops over four years. Given the strength of the chickpea response in year four, it may be possible that economic crop responses will continue into year five and year six. If it is possible to get six years of crop responses to one deep-banded application then the economics of deep banding will be even more compelling than they already are.

Acknowledgements

It is greatly appreciated to have the continued support of trial co-operators, by hosting this trial site. This work is funded by the Grains Research and Development Corporation, University of Queensland and the Department of Agriculture and Fisheries under UQ00063 'Regional soil testing guidelines for the northern grains region'.

Trial details

Location:	Dysart
Crop:	Chickpeas (Kyabra$^{\phi}$)
Soil type:	Grey Vertosol (Brigalow scrub) on minor slopes
In-crop rainfall:	94 mm
Fertiliser:	Nil

Selected trial site soil fertility characteristics:

Depth (cm)	Nitrates	Sulfur (KCl-40)	Col P	BSES P	Exc. K	ECEC
0-10	2	1.7	5	8	0.25	35.6
10-30	1	1.6	1	3	0.12	28.8
30-60	1	2.6	1	4	0.09	31.4

Comparison of plots in the S trial at flowering: FR in the foreground, 30S in the middle distance, 0S-PK in the background; plots without background PK have a smaller canopy

Seasonal differences in response to deep-applied phosphorus in chickpea and wheat—Central Queensland

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[1]Department of Agriculture and Fisheries
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RESEARCH QUESTION: *What differences can occur in crop response to the deep-banding application of phosphorus under different environmental conditions?*

Key findings

1. Response to deep phosphorus (P) applications at Dululu site varied by up to 14% between 2016 and 2017 seasons.
2. Response to deep P applications at Comet River varied by up to 24% between 2016 and 2017 seasons.
3. No response to deep P applications at Emerald site.

Background

Over the last four 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 is particularly evident in the non-mobile nutrients of phosphorus (P) and potassium (K). In some established zero tillage production systems there is a marked difference between the nutrient concentration in the top 10 cm of the soil profile and the deeper layers (10-30 cm and 30–60 cm), that cannot be explained by natural stratification. It would seem that this pattern of soil analysis 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 an application of P or K placed deeper in the soil can provide a grain yield benefit and whether that benefit (response) can be maintained over several years. These results are being used to define the economic benefit of adding these non-mobile nutrients over successive cropping cycles.

What was done?

This report collates the data from three P trials that have had winter crops harvested in 2017 (Table 1).

Soil analysis indicates that plant available P is stratified between the surface (0-10 cm) and subsurface (10-60 cm) depths (Table 2). Electrical conductivity increases at depth with a significant gypsum layer present below 30 cm.

Table 1. Location and cropping history of three deep P research sites

Site name	Original treatment date	Number of crops since treatment (2017 inclusive)	2017 winter crop	Planting date	Harvest date
Dululu	23/11/15	2	Chickpeas	25/4/17	26/9/17
Comet River	10/11/15	2	Wheat	27/4/17	20/9/17
Emerald	5/2/15	3	Chickpeas	8/6/17	10/10/17

Table 2. Soil phosphorus tests for Dululu, Comet River and Emerald deep-placed P sites

Site	Dululu			Comet River			Emerald		
	Colwell P	BSES P	Ex K	Colwell P	BSES P	Ex K	Colwell P	BSES P	Ex K
0-10 cm	17	21	0.23	22	24	0.46	30	71	0.95
10-30 cm	3	5	0.12	5	5	0.12	6	46	0.49
30-60 cm	1	4	0.09	< 2	3	0.10	2	37	0.42

Table 3. Experimental treatments for deep placed P experiments

Treatment number	1	2	3	4	5	6	7
P rate (as mono ammonium phosphate (MAP))	FR	0	40	0	10	20	40
K rate (as potassium chloride)	-	0	0	50	50	50	50
S rate (as ammonium sulfate)	-	20	20	20	20	20	20
N rate (as urea, MAP and ammonium sulfate)	-	80	80	80	80	80	80
Zn rate (as zinc chelate)	-	2	2	2	2	2	2

Chloride concentrations are not limiting for root growth in the 1.2 m profile analysed (data not shown).

Nutrient application rates for the experiments are listed in Table 3. A 'Farmer Reference' (labelled FR) treatment is included as an untreated control providing baseline data on yield and nutrient uptake. The deep P treatments were applied using a fixed tine implement that delivered the P and K 25 cm deep and the N and S 10–15 cm deep. Fertiliser bands were 50 cm apart. The treated areas were positioned within existing controlled traffic tram lines, and the width of these tram lines differed from site to site. Plot lengths varied from 28 to 32 m. Treatments were set up across two planter widths allowing a starter P to be applied to one side and not the other by growers at sowing. The starter P treatments equates to grower practice for product and rate. All sites have the same treatment structure, but differ in relation to plot size and the number of replicates (Table 4).

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

Table 4. Summary of trial structure for P trials

Site	Plot size	Replicates	Total number of plots
Dululu	5.4m x 28m	4	64
Comet River	6m x 32m	6	96
Emerald	6m x 32m	4	72

Results

The results for each trial site will be presented separately. The 2017 winter crop represents the second (Dululu and Comet River) or third (Emerald) crop grown at these sites since the initial treatments were applied. Included in this current year data is a comparison of crop results from the previous season.

Contrasting seasons and crops at Dululu, 2016 wheat versus 2017 chickpea

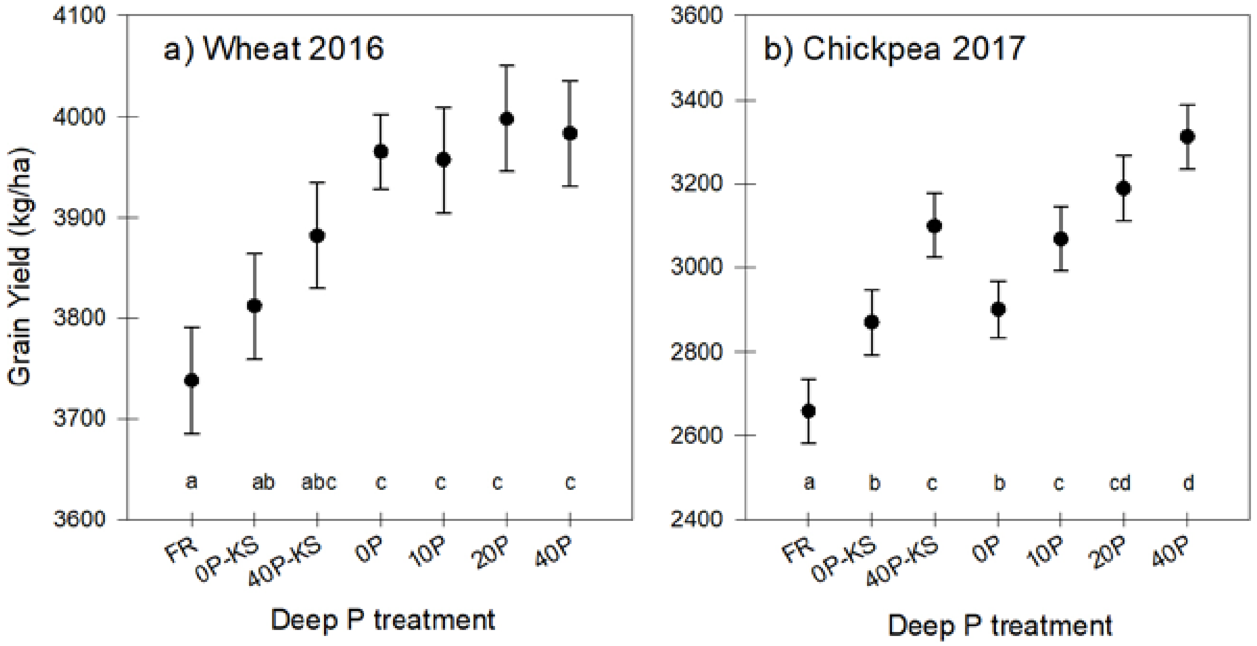

Figure 1. Grain yields at Dululu deep P site for a) wheat in 2016 and b) chickpea in 2017
Error bars are standard error for each mean; letters indicated lsd at 5%; note different yield scale in each year

Dululu

Chickpea grain yield showed a clear significant difference between the 0P plots and the three rates of applied P (10P, 20P, 40P and 40P-KS) (Figure 1b). The largest yield increase was at the highest rate of P (40P), which improved yield by over 400 kg/ha (14%) compared to the 0P rate and 650 kg/ha (25%) relative to the starting condition (FR). Differences between the 40P and 40P-KS were also significant, with the yield response to deep P dropping by half when background K and S fertiliser had not been added. The 0P and the 0P-KS treatments were also significantly different, reinforcing that the background basal nutrients (most likely K) were having a significant impact on yield.

The comparison between the 2016 wheat crop (Figure 1a) and the 2017 chickpeas (Figure 1b) showed contrasting results. The wheat crop in 2016 showed no significant differences between deep P rates in the presence of basal nutrients (0P, 10P, 20P and 40P were all the same), while the 2017 chickpea crop showed a linear increase in yield with increasing P rates. These differences in crop performance may be partly explained by the incidence and amount of in-crop rainfall and the status of nutrients in the top 10 cm of the profile.

The wheat crop in 2016 experienced good in-crop rainfall in the first six weeks of crop life which is generally considered the critical period for setting grain number (Figure 2). By keeping

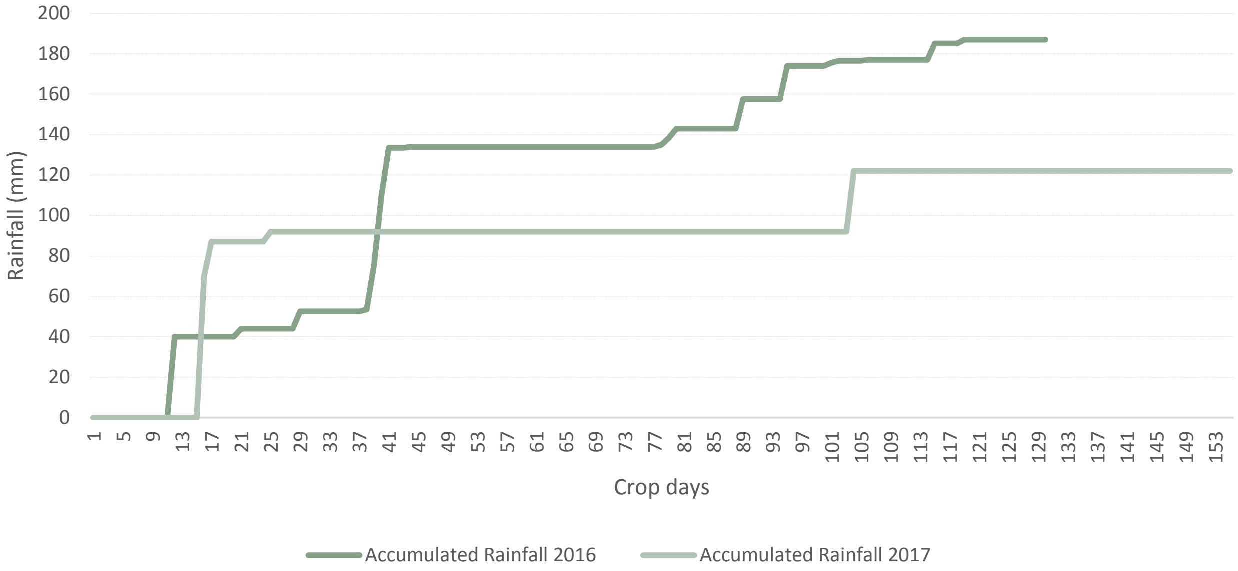

Figure 2. In-crop rainfall for 2016 and 2017 winter growing seasons at the Dululu deep P site

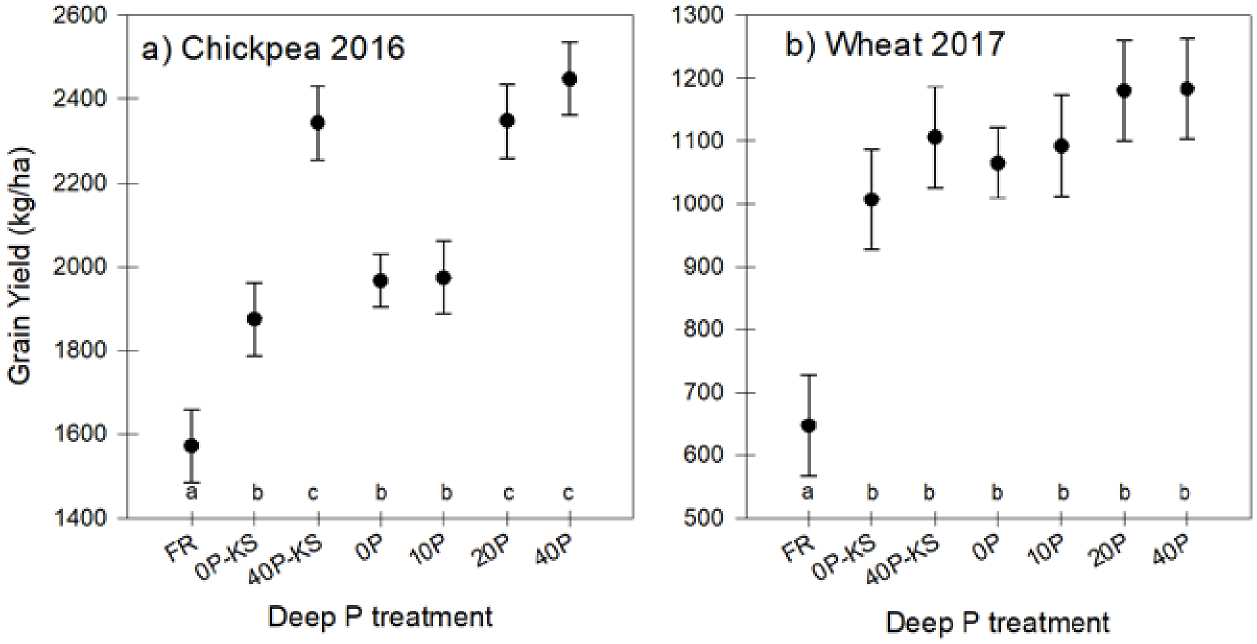

Figure 3. Grain yields at Comet River deep P site for a) chickpea in 2016 and b) wheat in 2017

Error bars are standard error for each mean; letters indicated lsd at 5%; note different yield scale in each year

the soil surface wet, in-crop rainfall meant the plant root system had easy access to nutrients contained in the top 10 cm of the profile. Continued in-crop rainfall meant that the plant could access surface soil nutrients almost continually throughout the crop life cycle, which ensured that it had no absolute requirement to forage deeper in the profile for water and nutrients. This meant that the deep placement bands may have been largely untouched by the plant root system, or that in the absence of deep P bands the crop was still able to gather enough P from the surface 10 cm layer.

Compare this scenario with that of the chickpea crop in 2017. The critical period for setting grain yield in chickpea is at flowering, which started from 57–65 days after sowing (DAS). During this period the surface soil would have been largely dry as the last in-crop rainfall was 40 days earlier. This meant that the crop was accessing moisture from deeper in the profile during the critical flowering period and therefore relying on the deep-banded P treatments to meet crop P demands.

The sensitivity of the two crops to soil P availability would also have been a factor in the differences in crop performance between 2016 and 2017. Analysis of grain samples has showed that chickpea grain contains at least 3 kg P/t while cereals such as wheat are closer to 2 kg/t or less. This suggests that chickpeas have a greater need for available P during grain filling, with that P having to come from current soil uptake, or from P accumulated in crop biomass.

Comet River

The Comet River site was planted to wheat in the 2017 winter season and experienced very tough conditions. Plant populations were between 40 and 50 plants/m^2 on 50 cm rows and a lack of follow-up rainfall after planting meant that very few plants developed secondary roots. Consequently machine-harvested yields were low, making it more difficult to see significant differences. The only significant difference in the yield data (Figure 3b) was between the FR plots and all other treatments.

The contrast between crop responses for chickpeas in 2016 and this wheat crop in 2017 were again striking (Figure 3a vs 3b). The 2016 chickpea crop showed a strong response to the deep-banded P treatments, particularly the 20P and 40P rates (with or without basal K and S). The highest rate of P produced a 24% improvement in yield (492 Kg/ha) over the 0P plots.

While it is tempting to again conclude that chickpeas have proven to be the most responsive to deep-banded P applications in comparison to cereal crops such as wheat, it is worth paying particular attention to the contrasting seasonal conditions experienced by the two crops (Figure 4) and the soil fertility characteristics for the site (Table 2).

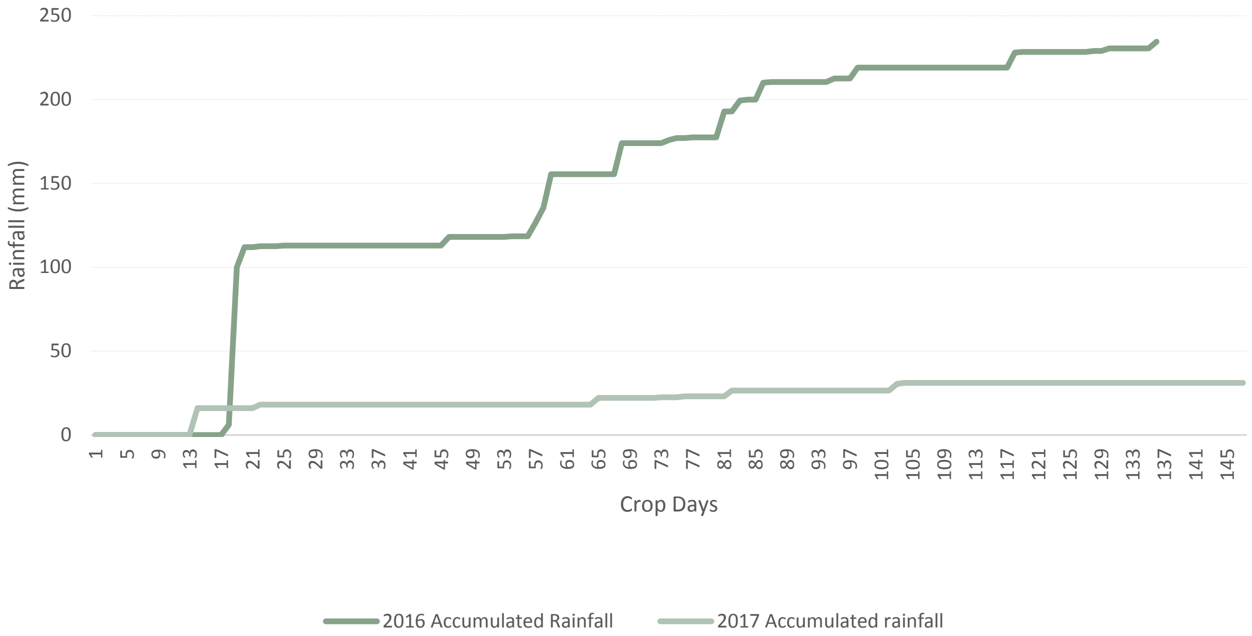

Figure 4. In-crop rainfall for 2016 and 2017 winter growing seasons at the Comet River deep P site

The most noticeable point about the rainfall distribution in the 2017 wheat crop was the lack of it. Secondary root development was very limited meaning most plants had only a primary root system. The implication of this was that the wheat plants did not have the capacity to develop a root system of sufficient size or surface area. The plant may have been able to access the deep bands of fertiliser but simply could not grow enough root mass around these fertiliser bands to effectively take advantage. The surface soil would have been dry for most of the crop's life so access to any of the surface nutrient would have been limited.

In contrast, the chickpea crop of 2016 had the advantage of good in-crop rainfall, with significant falls after sowing and then again from around the start of flowering (57-65 DAS). In theory, the plant should have been able to access nutrients out of the surface profile and not needed to use the deep bands of fertiliser, however the yield results suggest the deep fertiliser bands have been accessed by the plant. This could be partly due to deep planting the chickpeas (10-15 cm), which meant the seed would have been placed below the relatively nutrient-rich surface layer. Chickpeas have a tap rooted structure, which means initial root development is down rather than sideways or up. Some shallower roots may have established themselves in the surface soil later in the crop life cycle but it would have been difficult to get enough root mass into the surface layer after rainfall to take full advantage of the higher P status.

Emerald

The Emerald site was planted to chickpeas in 2017 and because of the dry winter season was irrigated by overhead sprinklers prior to planting to avoid deep planting and to obtain a close to a full planting profile. The chickpea grain yield (Figure 5b) would suggest that there were no significant differences between the deep-banded treatments. This is an unusual outcome as eight out of the ten P trial sites across the CQ region have given significant responses. The most unusual aspect of this data was that the results were so uniform. All treatments yielded within 60 kg/ha of each other, including the FR plots which normally always yield significantly less than all other treatments.

Another unusual aspect of the chickpea results was a significant difference between the starter P blocks. Plots planted with starter averaged 1762 kg/ha while the non-starter blocks averaged 1680 kg/ha (lsd = 47, at the 5% level). This is an unexpected result given that this site had a relatively high Colwell P concentration in the top 10 cm (30 mg P/kg, Table 2). Data from the 2016 wheat crop showed some contrast with 2017 chickpea crop, with some significant differences existing between FR and the 0P-KS plots in 2016 (Figure 5a).

As with the other two sites, the contrast in seasonal rainfall patterns between 2016 and 2017 (Figure 6) was marked; with implications for the relative ease of access to the nutrient-rich top 10 cm of the soil profile. The 2017 crop rainfall pattern suggests a relatively dry season,

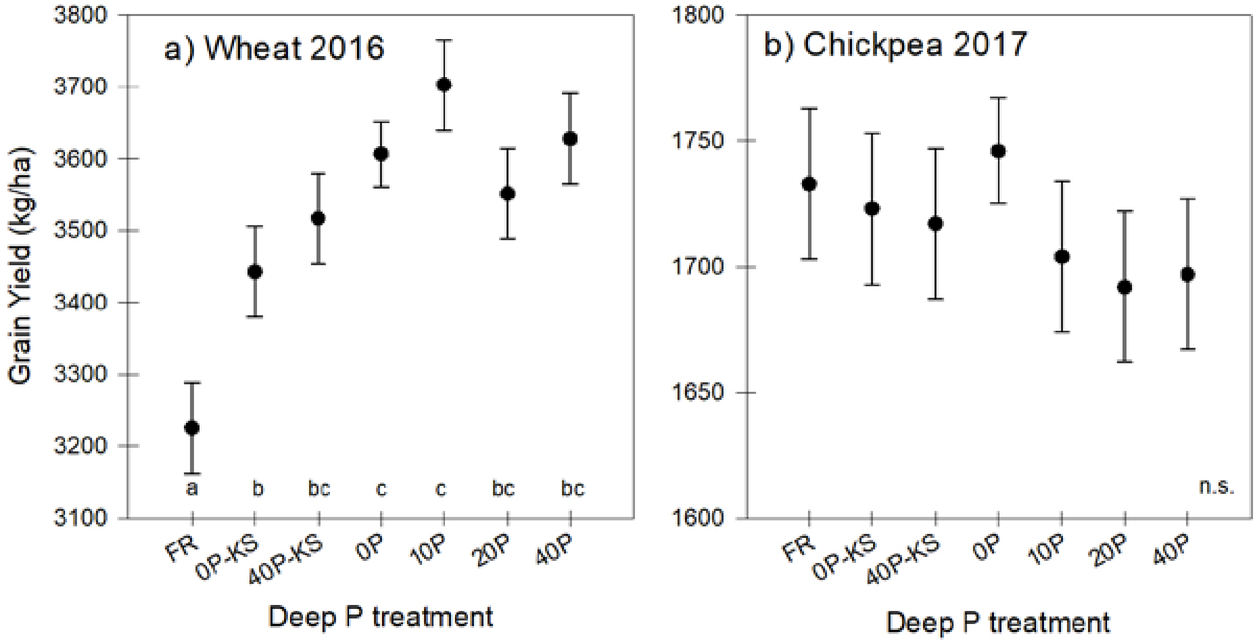

Figure 5. Grain yields at Emerald deep P site for a) wheat in 2016 and b) chickpea in 2017
Error bars are standard error for each mean; letters indicated lsd at 5%; note different yield scale in each year

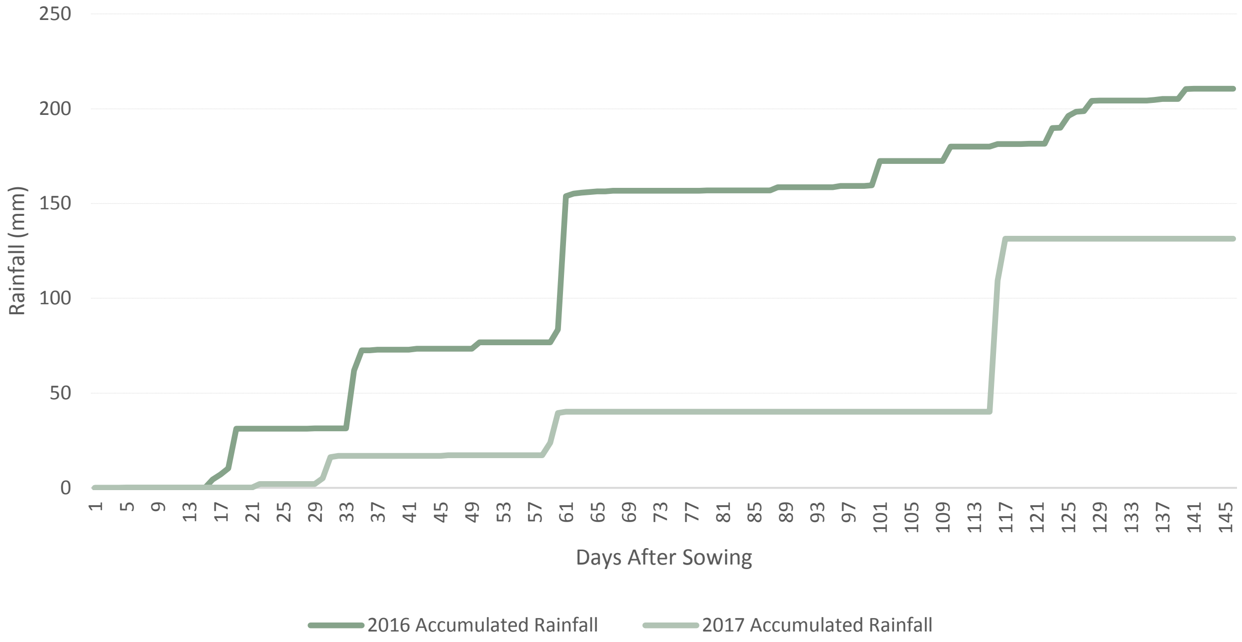

Figure 6. In-crop rainfall for 2016 and 2017 winter growing seasons at the Emerald deep P site

with only 23 mm falling at the start of flowering (Figure 6) but basically nothing else until close to harvest. The surface profile would have been dry and effectively inaccessible for most of the flowering and grain filling phase, so the crop would have had little access to surface nutrients except immediately after planting.

In 2016, where there was no response to the deep P-banding, the in-crop rainfall pattern would suggest that access to the surface profile would have been consistent throughout the life of the wheat crop (Figure 6). The wheat plant would have been able to access at least some of the Colwell P that was measured in the surface soil (Table 1), and given the high concentration, that may have been enough for the crop to not need any of the deep-banded nutrient.

Analysis of total dry matter samples suggested that the 2017 chickpea crop had been able to access soil P across the whole trial site. Dry matter analyses for the chickpea crops at the Emerald (no response to deep P) and Dululu (deep P responsive) sites from 2017 suggest much better access to soil P reserves at the Emerald site (Figure 7).

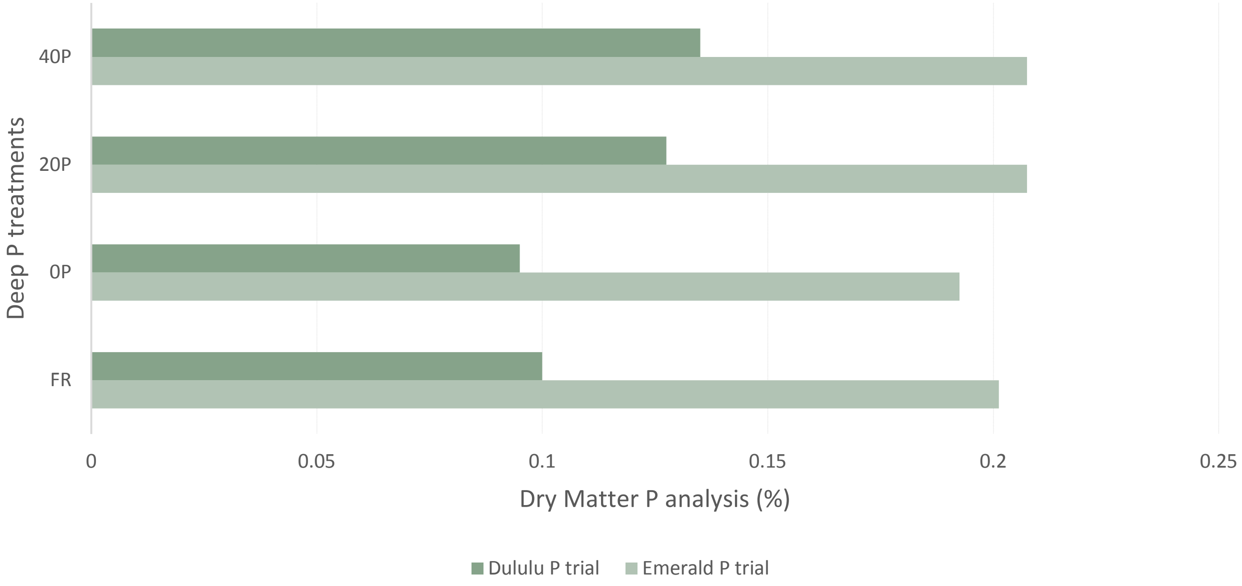

Figure 7. Comparison of P content in total dry matter for chickpeas across Dululu and Emerald P trials in 2017

Biomass P concentrations in the Emerald crop were uniform across all treatments and at levels that would indicate at least moderate P status, while the chickpea crop at the Dululu site showed not only considerably lower biomass P concentrations but also some clear differences in P concentration between treatments.

The source of crop P at the Emerald site is not clear. Despite Colwell P profiles that were similar to other P sites in all bar the top 10 cm layer, and a growing season in which access to topsoil layers should have been limited, the crop still managed to access enough P to meet demands. While it is tempting to suggest this must have come from the surface soil, it is also worth noting the higher BSES P concentrations in the subsoil layers at the Emerald site (Table 2). Whilst not high in relative terms, the BSES P was approximately ten times greater than at the other trial sites in those subsoil layers. If these P reserves were more soluble than experienced in other situations (e.g. as a result of a history of fertiliser P applications and conventional tillage), this may have allowed improved subsoil P access. Understanding the lack of P responsiveness at the Emerald site needs further investigation.

Economic analysis

For the Dululu site, there was no significant benefit to either the background treatments or deep-P treatments in the first year's wheat crop (Table 5). However the yield increase in the second year's chickpea crop resulted in $72/ha additional profit with the background tillage and basal nutrient treatment (50K, 20S, 80N, 0.5Zn). Deep-P treatments then contributed between $100 and $200/ha in extra profit above the background nutrition. Whilst all treatments have currently managed to improve profit it is expected that higher P rates will have a longer duration of providing yield benefits.

Table 5. Cumulative change in profit vs FR for Dululu and Comet River deep P sites

Site	Dululu			Comet River		
P rate	2016 Wheat	2017 Chickpea	ROI	2016 Chickpea	2017 Wheat	ROI
0	-$ 121	$ 72	0.4	$ 136	$ 270	1.4
10	-$ 156	$ 173	0.8	$ 112	$ 272	1.2
20	-$ 176	$ 249	1.0	$ 315	$ 476	1.9
40	-$ 244	$ 278	0.9	$ 402	$ 402	1.3

Assuming P applied as MAP 22P/11N @ $800/t , K and S applied as SOP 42K/18S also at $800/t, N as urea $400t (reducing by 0.5 * P rate to account for N in MAP) zinc @ $2000/t ($1/ha) and a $30/ha application cost grain prices $800 chickpea and $300 wheat

At Comet River, both chickpea and wheat crops responded strongly to the background tillage and basal nutrient treatment with the yield benefit in the first year more than covering all background nutrient costs (50K,20S 80N 0.5Zn). After two crops, the background treatment alone has provided an additional $270/ha in profit. The 20 or 40P treatments generated an additional profit of $150-200/ha. Whilst 20P currently has the highest Return on Investment (ROI), generating $1.90 in profit for every dollar spent, we would expect the 40P treatment to last for longer, and its ROI to increase in coming years.

Implications for growers

The results from the three deep-banded P trials over the last two years demonstrates the variability that can occur in the responses to deep placed nutrients. Yield responses can vary from 0–24% at the same site for the same treatment across two different seasons. It is imperative that growers understand these variables and to what extent they can influence results from deep fertiliser applications.

Crop species, in-crop rainfall and starting soil nutrients can all have a large influence on the scale of response to deep-banded nutrients. Basically all of these variables are based around the central concept of plant uptake. Availability of water and nutrients in the profile, the size of the root system and its structure and the critical timing of when plants are setting up yield, all play roles in determining nutrient uptake.

It is critical for growers and agronomists to understand which zone of the soil profile is depleted in macronutrients and by how much. Soil testing in the appropriate increments (0–10 cm, 10–30 cm etc.) is the best way to get an understanding of where the nutrient depletion is in the profile, and this then governs what variables will influence the efficiency of nutrient uptake across 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 available nutrient concentrations in the surface and subsurface layers, and to quantify any potential constraints to yield. They are then encouraged to evaluate the responses on their soils using an appropriate program of strip-trials and on-farm exploration to validate responses for themselves.

Acknowledgements

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

Trial details

Location:	Dululu, Comet River, Emerald
Crop:	Wheat and chickpeas
Soil type:	Grey, Brown Vertosols (Brigalow scrub) on minor slopes
In-crop rainfall:	122 mm (Dululu) 31 mm (Comet River) 131 mm (Emerald)
Pre-plant fertiliser:	Nil (Dululu and Emerald) 200 kg/ha urea (Comet River)

Seasonal differences in response to deep-applied potassium in chickpea and wheat—Central Queensland

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RESEARCH QUESTION: *What differences can occur in crop response to the deep banding application of potassium under different environmental conditions?*

Key findings

1. Response to deep K applications at the Dululu site varied significantly between 2016 and 2017 seasons.
2. There have been no significant responses to deep K applications at Comet River in either 2016 or 2017 seasons.

Background

Over the last four years the UQ00063 project (Regional soil testing guidelines) has been monitoring a series of nutrition 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. Subsurface depletion is particularly evident for the non-mobile nutrients phosphorus (P) and potassium (K). In some established zero tillage production systems there is a marked difference between the nutrient concentration in the top 10 cm of the soil profile and the deeper layers (10-30 cm and 30-60 cm), that cannot be explained by natural stratification. It would seem that this pattern of soil analysis is becoming more evident across CQ and 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 either P, K or sulfur (S) that is deep-placed in these more depleted layers can provide a grain yield benefit and whether that benefit can be maintained over several years. These results can also be used to define the economic benefit of adding these non-mobile nutrients over a crop rotation, rather than the conventional approach of assessing the profitability against the next crop to be sown.

Data from these sites is also contributing to the understanding of the pathways of macro nutrient uptake and how responses to deep-banded fertiliser can be impacted by seasonal constraints and differences in crop species.

What was done?

This report collates the data from two K trials that have had winter crops harvested in 2017 (Table 1).

The treatments within each of these K trials were very similar, with the main differences being in relation to plot size (Table 2). There were eight main treatments (Table 3), which included four K rates; 0, 25, 50, and 100 kg of K/ha. All of these treatments had background fertiliser applied at the same time to negate any other potentially limiting nutrients. This background fertiliser included; 80 kg of nitrogen (N), 20 kg of P, 20 kg of sulfur (S) and 2 kg of zinc (Zn). The other treatments included 0K and 100K with background N and Zn, but without P and S (0K-PS, 100K-PS). The last two treatments were a farmer reference (FR), and an extra 0K plot to give two controls for each replicate. The FR treatments had nothing applied except what the farmer applied in normal commercial practice.

Table 1. K trials sites for 2017 winter cropping season

Site Name	Original treatment date	Number of crops since treatment (2017 inclusive)	2017 winter crop	Planting date	Harvest date
Dululu	23/11/15	2	Chickpea	25/4/17	26/9/17
Comet River	10/11/15	2	Wheat	27/4/17	20/9/17

Table 2. Summary of trial structure for K trials at each site

Site	Main Treatments	Extra treatments	Split for starter treatment	Plot size	Number of replicates	Total number of plots
Dululu	0K, 25K, 50K, 100K, 100K-PS, 0K-PS, FR	0K	No	5.4m x 28m	6	48
Comet River	0K, 25K, 50K, 100K, 100K-PS, 0K-PS, FR	0K	No	6m x 32m	6	48

Table 3. Summary of nutrient application rates for K trials

Treatment label	N (kg/ha)	P (kg/ha)	K (kg/ha)	S (kg/ha)	Zn (kg/ha)
0K	80	20	0	20	2
0K	80	20	0	20	2
25K	80	20	25	20	2
50K	80	20	50	20	2
100K	80	20	100	20	2
0K-PS	80	0	0	0	2
100K-PS	80	0	100	0	2
FR	0	0	0	0	0

All plots had starter P applied with the seed at planting. Commercial granular fertiliser products were used at all three sites (Table 4). The deep K treatments were applied using a fixed tine implement which delivered the P and K at 25 cm deep and the N and S at 10-15 cm deep. The bands of fertiliser were placed 50 cm apart in plots that were positioned within existing controlled traffic tram lines, and the width of these tram lines differed from site to site. Plot lengths varied from 28 m to 32 m. The bands were placed in the same direction as the old stubble rows. There were six replicates at each of these two sites.

Table 4. List of commercial granular products used in nutrient treatments

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

The collection of data was done in the same way for both trials. Plant counts, starting soil water and starting nitrogen (N) measurements were taken post emergence. Total dry matter measurements were taken at physiological maturity and yield measurements were taken with a plot harvester when commercial harvesting started in the same paddock. A harvest sample was taken from each plot and a grain sample was kept from the plot for nutrient analysis. Both the dry matter samples and the grain samples were ground and subsampled for wet chemistry analysis.

Results

The results for each trial site are presented separately in this section. The 2017 winter crop represents the second crop grown at these sites since the initial treatments were applied. Included in this report is a comparison of this year's results to crop responses from the previous season.

Dululu

Table 5. Mean grain yields for chickpeas in 2017 trial

Treatments	Mean grain yields (kg/ha)	Least significant difference (P=5%)	Relative difference to '0K' plots (kg/ha)	(%)
FR	2552	a	-272	-9.6
0K-PS	2616	a	-208	-7.4
0K	2825	b	0	0.0
25K	2987	c	163	5.8
50K	3063	c	238	8.4
100K	3276	d	451	16.0
100K-PS	2839	b	14	0.5

Means with a common letter are not significantly different (lsd=107)

There was more than 700 kg/ha yield response to combinations of tillage, basal fertiliser and K, compared to the FR treatment (2552 kg/ha, Table 5). This response consisted of a non-significant effect of tillage and basal N/Zn application (0K-PS); small but significant responses to adding P and S to the basal fertiliser (0K: 2825 kg/ha), or adding K in the absence of P and S (100K-PS: 2839 kg/ha).

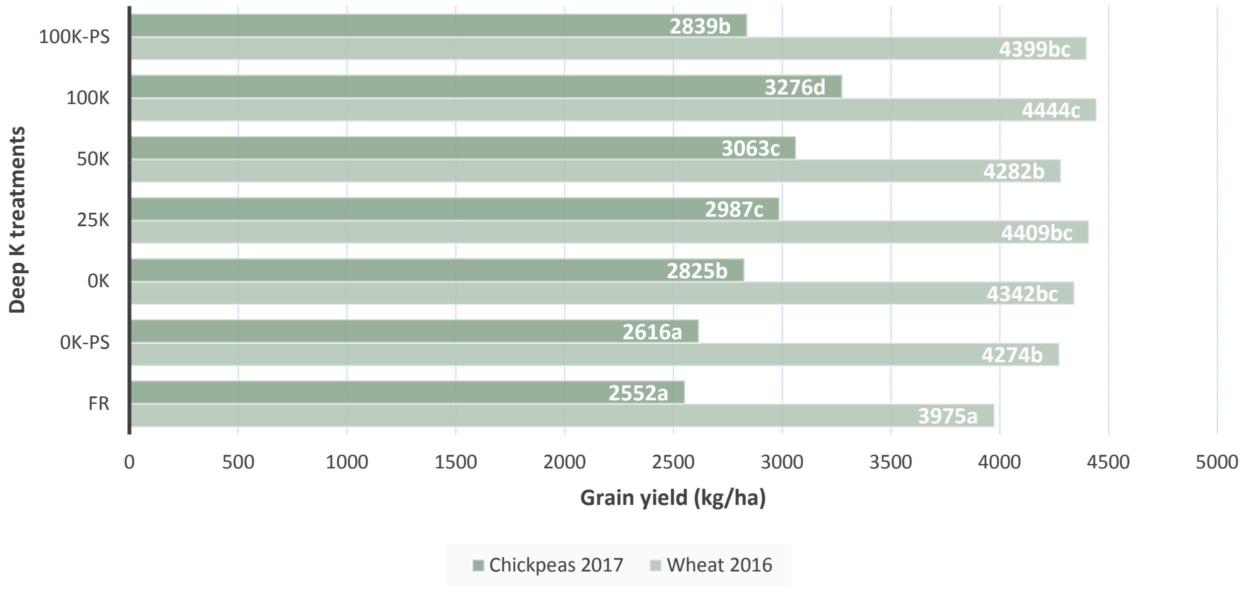

Figure 1. Comparison of mean yields across deep K treaments in 2016 and 2017 seasons at Dululu

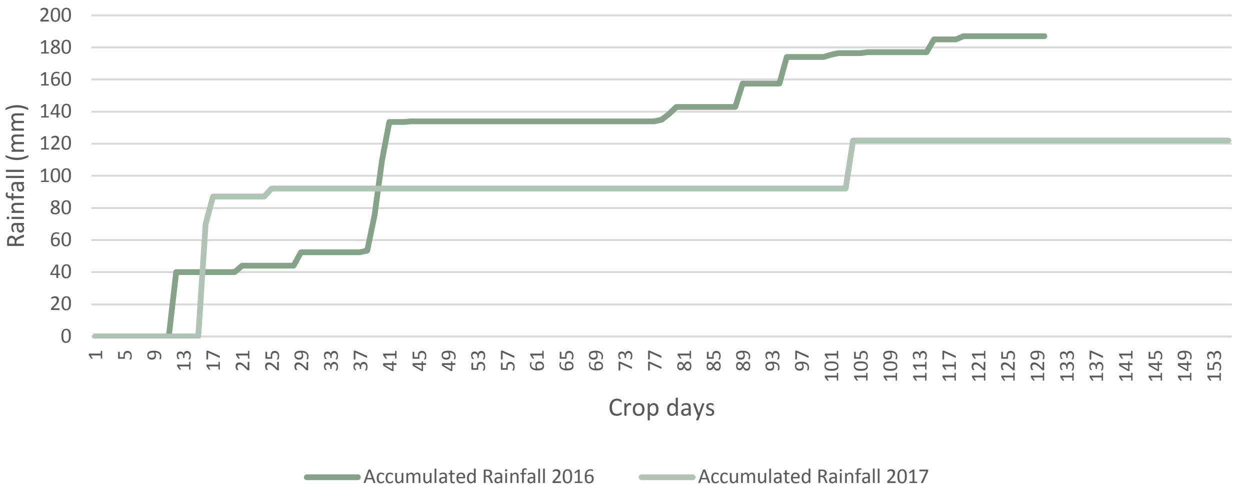

Figure 2. Comparison of the pattern of in-crop rainfall for the two winter crops grown at Dululu

There was also a linear response to increasing K rate in the presence of P and S equivalent to an additional 4.4 kg grain/kg applied K. The yield with the highest rate applied (100K) improved yield by over 451 kg/ha (16%) compared to the 0K rate.

The yield difference between the 100K and 100K-PS indicated that the background fertiliser (most likely P) is also having a major impact on yield, and in fact is the primary yield limitation at the site. Responses to K simply do not occur unless P and S are present.

The comparison between the wheat crop in 2016 and the chickpea crop in 2017 (Figure 1) show quite different responses in each year. All treatments in the wheat crop in 2016 showed significantly higher yields than the FR benchmark, but there were no differences between K rates or the presence or absence of basal P and S. In contrast, the chickpea crop in 2017 showed strong yield improvements in relation to the deep-banded P, K and S applications.

The yield benefit witnessed in the 2017 chickpea crop was more than enough to cover application and treatments costs, and represented a profit of up to $240/ha after two years (Table 6).

Table 6. Cumulative benefit ($/ha) vs 0K at Dululu

K rate (kg/ha)	2016 Wheat	2017 Chickpea
25	-$35	$73
50	-$98	$71
100	-$99	$240

Assuming K applied as MOP @ $500/t, $30/ha application cost, wheat $300/t and chickpea $800/t

Table 7. Selected soil fertility characteristics for the Dululu trial site sampled prior to the 2016 crop

Depth (cm)	Nitrates	Colwell P	Sulfur (KCl-40)	Exc. K	BSES P	ECEC
0-10	7	17	4	0.23	21	22
10-30	22	3	7	0.12	5	28
30-60	18	1	18	0.09	4	29

Contrasting seasons and crops at the Dululu K site; 2016 wheat versus 2017 chickpeas

These differences in crop performance may be partly explained by the incidence and amount of in-crop rainfall (Figure 2) and the status of nutrients in the top 10 cm of the profile (Table 7). However, it is also worth noting that chickpeas have generally been more sensitive to low soil K than grain crops at most K trial sites, and the K requirements to fill grain are also very different. Cereal grains typically have about 2.5 to 3.5 kg K/t while chickpea grain contains up to 10 kg K/t.

The site K status (Table 7) shows marginal K availability in the 0-10 cm layer for a soil with a moderate CEC of 22 cmol/kg, but exchangeable K that is effectively half what we are currently estimating as the critical exchangeable K for crop responses in the 10-30 cm layer, and that declines further in the 30-60 cm layer. This stratification of nutrients can interact with seasonal constraints to affect plant response to deep-banded nutrients. In other words, this looks to be a site where the less access the roots have to the top 10 cm (e.g. in seasons with infrequent in-crop rainfall events), the worse the crop K status is likely to be. Similar observations can be made with respect to available P in those layers.

The wheat crop in 2016 experienced good in-crop rainfall in the first six weeks of crop life which is generally considered the critical period for setting grain number and ensuring adequate plant P status through the use of starter P fertiliser. The critical times for obtaining both P and K to support growth and biomass accumulation occurred from that period onwards, with K uptake mainly occurring over the next 30-40 days in cereals. The starting wet soil conditions, combined with continued in-crop rainfall, meant that the plant could access surface soil nutrients (especially K) almost continually throughout the crop's life cycle. Whilst the plant may well have accessed nutrients from the bands, uptake was not required to support the seasonal yield potential and would have simply represented a sparing of background soil reserves.

Compare this scenario with that of the chickpea crop in 2017, where the critical period for setting grain yield is at flowering, which started from 57–65 days after sowing (DAS). During this period the surface soil would have been largely dry as the last in-crop rainfall was 40 days earlier, and so nutrient reserves in the 0-10 cm layer would have been largely inaccessible. This meant that the crop was accessing moisture from deeper in the profile during the critical flowering period and therefore would have been relying on deep P and K bands in otherwise depleted subsoil layers to acquire the nutrients needed to set yield potential.

Comet River

The Comet River site was planted to wheat in the 2017 winter season and experienced very tough conditions. Plant populations were between 40 and 50 plants/m^2 on 50 cm rows and a lack of follow up rainfall after planting meant that very few plants developed secondary roots.

Consequently machine harvested yields were low and variable, with lack of moisture being the prime yield determinant at this site.

There were no significant differences between the increasing rates of deep-banded K in grain yield (Table 8); however the FR plots yielded significantly less than all other treatments except for the 0K without background fertiliser. This would indicate that the ripping effect from the original treatments did not cause a significant difference but the addition of background P fertiliser (for 0K, 25K, 50K and 100K) has given a significant yield advantage of between 380–630 kg/ha over the baseline (FR) treatment.

Table 8. Mean grain yields for wheat in 2017 at Comet River

Treatments	Mean grain yields (kg/ha)	Least significant difference P(0.05)	Relative difference to '0K' plots (kg/ha)	(%)
FR	719	a	-383	-34.8
0K-PS	980	ab	-122	-11.1
0K	1102	bc	0	0.0
25K	1132	bc	30	2.8
50K	1217	bc	115	10.5
100K	1358	c	256	23.2
100K-PS	1303	c	202	18.3

Means with a common letter are not significantly different (lsd=261)

Interestingly, the highest rate of K without background P and S did not show the same response as the zero rates of K without background P and S. This is a contradictory result but it is difficult to put too much emphasis on this interaction when the crop was so water-limited.

There was a trend for increasing yields with increasing K rate. Relative yields for the 100K treatments were 23% better than the 0K plots; this amounted to a difference of 256 kg/ha. Given the variability across the site, these differences were too small to give any statistical differences (Table 8) but is still useful data in the ongoing monitoring of this site.

When comparing the 2016 and 2017 crop seasons, there were some similarities in the fact that in neither season was there any consistent significant response to the deep-banded K treatments (Figure 3)—despite the trend for increasing yields with increasing K rates in 2017. The 2016 chickpea crop did show significant yield responses compared to the FR treatment, and there was evidence of low P and low K at the site. While the tillage effect was not significant (i.e. 0K–PS), there was both a response to K in the absence of P and S (100 K-PS produced yields ~500 kg/ha higher than FR), and a response to adding basal P and S in the absence of K (i.e. 0K treatment yielded 870 kg/ha more than FR—a 34% yield increase). However in this instance, the effects of adding P and S and K were not additive (i.e. there was no further response to adding K once P and S had been applied).

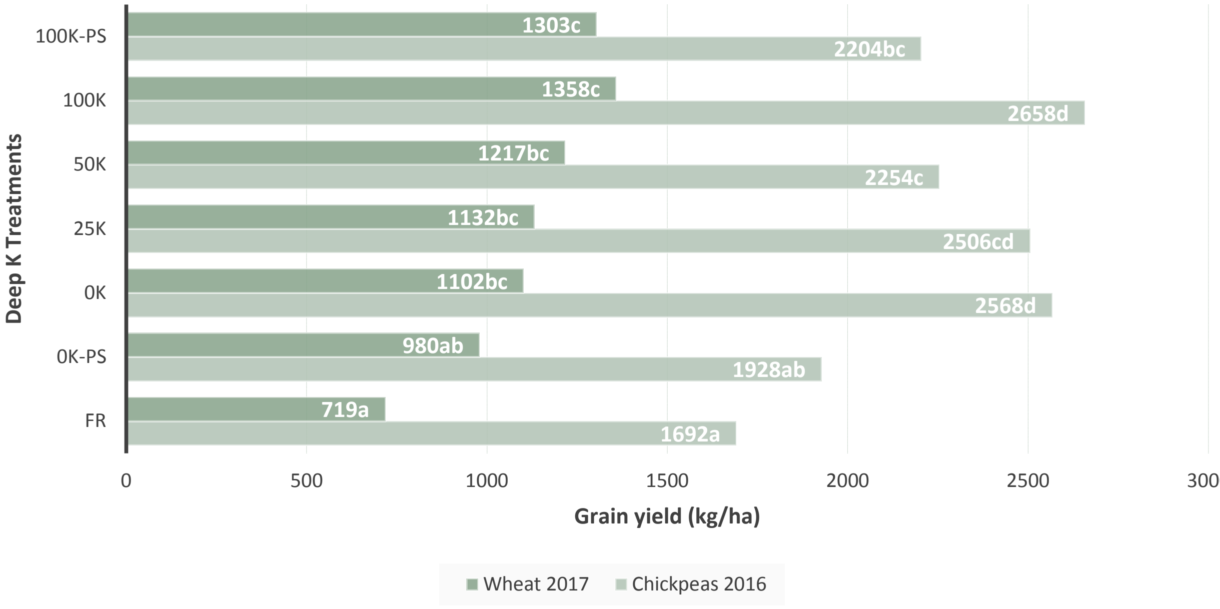

Figure 3. Comparison of mean grain yields across two seasons for the Comet River K trial

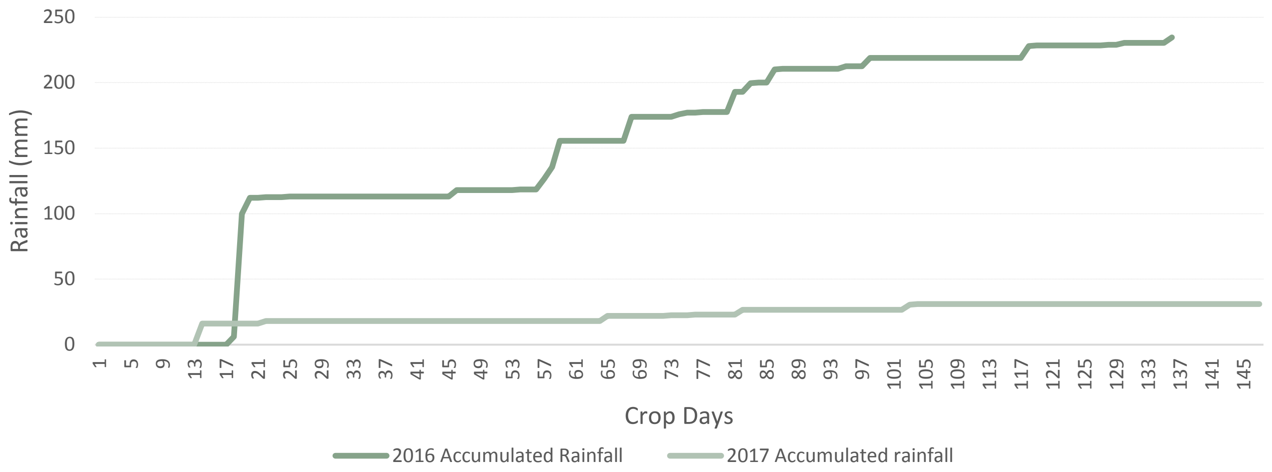

Figure 4. Comparison of the pattern of in-crop rainfall for the two winter crops grown on the Comet River site

Contrasting seasons and crops at Comet River K trial site; 2016 chickpeas versus 2017 wheat

Yield data from the K trial suggests that the sites primary limitation in 2016 was P. Observations of P application partially or wholly overcoming a K limitation have been observed at other sites, and seem to be related to the development of a more vigorous root system that is more effective at extracting K from soil with low background reserves. While not sustainable in the long term (i.e. soil K reserves get even lower), this type of response can confound the interpretation of short term fertiliser responses.

As with the site at Dululu, the seasonal rainfall patterns (Figure 4) interacting with the soil nutrient status in different profile layers (Table 9) provide a plausible explanation for the different crop responses. This site shows reasonable P status (Colwell P 22 mg/kg) and quite high K status (0.46 cmol K/kg) in the 0-10 cm layer. However both drop to clearly yield-limiting levels in the 10-30 cm and beyond, similar to the site at Dululu; so if crops were not able to forage for nutrients in the relatively enriched 0-10 cm layer significant P and K limitations would be expected.

The seasonal rainfall patterns provide a sharp contrast in amounts and distribution that would have clearly affected access to that top 10 cm layer. The chickpea crop of 2016 had the advantage of good in-crop rainfall amounts both early in the season and during the flowering (57–65 DAS), pod set and grain filling periods. In theory the crop should have been able to access nutrients out of the surface profile and not needed to use the deep bands of fertiliser,

Table 9. Selected soil fertility characteristics for the Comet River site

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

but the observation of a significant P response (see trial report: *Seasonal differences in response to deep-applied phosphorus in chickpea and wheat—Central Queensland*), suggest that chickpea may not have been as effective at exploiting that shallow layer as the wheat crop was at the Dululu site. This is consistent with the coarser tap root of chickpea and the much slower root proliferation compared to cereal species.

The most noticeable point about the rainfall distribution in the 2017 wheat crop was the lack of it. Secondary root development was very limited; most plants had to survive on a primary root system, meaning that the crop did not have the capacity to develop a root system of sufficient size or surface area. This would have seriously limited the ability to effectively exploit deep soil moisture or nutrients, and also would have had limited ability to proliferate roots in and around deep bands to effectively take advantage of the nutrients in them. The surface soil would have been dry for most of the crop's life so access to any of the surface nutrient would also have been limited.

Whilst not statistically significant, the trend for a K response in 2017 but not one to deep P was interesting. Diffusive supply of P through soil to plant roots is much less efficient than that of K, so to effectively exploit a deep P band there would need to be more roots around that concentrated P source than there would be to see significant K uptake from a deep K band. Therefore the 2017 result may simply reflect the lack of secondary root growth, and hence root density in and around the P and K bands in the 10-30 cm layer. Further collection of data from this site will help clarify the relative P and K limitations at this site and soil type.

Implications for growers

The results from the two deep-banded K trials over the last two years demonstrates the variability that can occur in the responses to deep placed nutrients. Yield responses can vary significantly at the same site for the same treatment across two different seasons, due to differences in seasonal patterns of rainfall and root access to different profile layers. It is imperative that growers understand these variables and to what extent they can influence results.

Crop species, in-crop rainfall and starting soil nutrients can all have a large influence on the scale of response to deep-banded nutrients. At both sites it is apparent that K is not the most limiting nutrient and therefore response to deep K will be limited unless the deficiency in the most limiting nutrient (in this case P) has been overcome.

To summarise, most of these variables relate to the plants' requirement and ability to take up nutrient. Where the plants are taking water from in the profile, the size of the root system and its structure and the critical timing of when plants are setting up yield all play a role in determining the effective acquisition of nutrients.

It is critical for growers and agronomists to understand which zone of the soil profile is depleted in macronutrients and by how much. Soil testing in the appropriate increments (0-10 cm, 10-30 cm etc.) is the best way to get an understanding of where the nutrient depletion is in the profile, and this then governs what variables will influence the efficiency of nutrient uptake across seasons.

The advantage these and other sites are showing is that, while significant responses may not be evident in one season due to rainfall and root access, the excellent residual value of both deep P and K mean those nutrients will still be available for crops in following years.

Acknowledgements

It is greatly appreciated to have the continued support of trial co-operators, by hosting this trial site. This work is funded by the Grains Research and Development Corporation, University of Queensland, and the Department of Agriculture and Fisheries under UQ00063 'Regional soil testing guidelines for the northern grains region'.

Trial details

Location:	Dululu, Comet River
Crop:	Wheat and Chickpeas
Soil type:	Grey, Brown Vertosols (brigalow scrub) on minor slopes
In-crop rainfall:	122 mm (Dululu) 31 mm (Comet River)
Pre-plant fertiliser:	Nil (Dululu) 200 kg/ha of urea (Comet River)

Impact of deep phosphorus and potassium application over four years—Darling Downs

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RESEARCH QUESTIONS: *Does putting phosphorus (an immobile nutrient) in the soil at 15-20 cm deep increase grain yields in lower rainfall environments? | How does starter phosphorus interact with deep-placed phosphorus? | For soil with low subsoil potassium, does applying potassium at 15-20 cm deep in the soil, either with or without phosphorus, increase grain yields?*

Key findings

1. Combinations of deep-placed phosphorus and potassium on soil with low subsoil test values increased cumulative grain production by 23% over four crops.
2. Starter phosphorus application with seed at sowing is advocated, with yield reductions measured in three of four crops when starter phosphorus was not applied.
3. An integrated nutrient management approach is required for soils with multiple fertility limits.

Background

As the length of time we have been cropping land increases, immobile nutrients such as phosphorus (P) and potassium (K) are being taken up by plants from the soil in the 10-30 cm and lower layers, however crop residues are depositing P onto the surface. This is creating a stratified distribution of higher nutrient availability in the surface and lower availability below. Root activity in the soil surface can be limited through faster loss of soil moisture and limited in-crop rainfall. Potentially, deeper soil layers can support periods of root activity for longer as they are not as prone to evaporative moisture loss. This research is questioning if placing immobile nutrients deeper into the soil can increase grain yield.

What was done

Soil analyses were conducted from samples taken in a paddock near Jimbour on the Darling Downs indicating levels of plant available P and K were more available at the soil surface 0-10 cm than in the subsurface 10-30 cm and 30-60 cm depths (Table 1). Potassium was marginal for the site with exchangeable K of approximately 0.2 cmol/kg below 10 cm.

Table 1. P soil test results (mg/kg) for Jimbour West deep-placed P and K site

	Colwell P	BSES P	Exchangeable K
0-10 cm	37	97	0.47
10-30 cm	8	12	0.20
30-60 cm	4	7	0.22

Various rates of other nutrients were applied for the P and K experiments (Table 2) including nitrogen (N), sulfur (S) and zinc (Zn) to eliminate any other potential deficiencies. A 'Farmer Reference' (labelled FR) treatment was included as an untreated control providing baseline data on yield and nutrient uptake. Deep-placed fertiliser was applied perpendicularly to the crop sowing direction, at a depth of ~15-20 cm in bands 50 cm apart. Plots were two planter widths across, allowing a starter P to be applied to one side and not the other by the grower at sowing. The starter P treatments equate to grower practice for product and rate. Starter application was applied as standard practice to the K experiment. There were six replicates in each experiment. Urea was applied to balance the nitrogen input through a tine positioned between the bands of deep P and K. Treatments were established in January 2014.

Table 2. Experimental treatments for Jimbour West

a) Deep-placed P treatment nutrient application rates (kg P/ha)

Treatment	1	2	3	4	5	6
P rate (as mono ammonium phosphate (MAP))	FR	0	10	20	30	60
K rate (as potassium chloride)	-	50	50	50	50	50
S rate (as ammonium sulfate)	-	10	10	10	10	10
N rate (as urea, MAP and ammonium sulfate)	-	60	60	60	60	60
Zn rate (as zinc chelate)	-	0.5	0.5	0.5	0.5	0.5

b) Deep-placed K treatment nutrient application rates (kg K/ha)

Treatment	1	2	3	4	5	6	7
K rate (as potassium chloride)	FR	0	100	0	25	50	100
P rate (as MAP)	-	0	0	20	20	20	20
S rate (as ammonium sulfate)	-	10	10	10	10	10	10
N rate (as urea, MAP and ammonium aulfate)	-	60	60	60	60	60	60
Zn rate (as zinc chelate)	-	0.5	0.5	0.5	0.5	0.5	0.5

Table 3. Agronomic details for crops at the Jimbour West site

Crop	Barley 2014	Mungbean 2014-15	Sorghum 2015-16	Chickpea 2017
Date sown	16-May-14	12-Jan-15	13-Jan-16	5-Jun-17
Variety	Sheppard⚘	Green Diamond	MR-Taurus	PBA Seamer⚘
Crop type	Barley	Mungbean	Sorghum	Chickpea
Row spacing	42 cm	42 cm	1m solid	42 cm
Planting rate / population	40 kg/ha	300,000	70,000	55 kg/ha
Starter product	SuPreme Z™	SuPreme Z™	SuPreme Z™	SuPreme Z™
Starter rate	35 kg/ha	40 kg/ha	40 kg/ha	37 kg/ha
Maturity biomass date	25-Sep-14	27-Mar-15	14-Apr-16	11-Oct-17
Harvest date	16-Oct-14	08-Apr-15	16-May-16	30-Oct-17
In-crop rainfall	117 mm	174 mm	247 mm	90 mm

Four crops have been grown and harvested since the deep application of P and K in 2014 with agronomic management details shown in Table 3. Above ground biomass was measured at maturity. Grain yield was measured using a plot harvester and corrected to receival standard moisture content.

Results

P experiment

In terms of yield, starter treatment was statistically significant on three crops (Table 4), while deep-placed treatments have been significant for every crop. There was no significant interaction between starter and deep-treatment for any crop.

Not applying starter P significantly decreased crop yield by 140, 48 and 225 kg/ha in the barley, mungbean and chickpea crops respectively (Table 5).

Table 4. Statistical significance for crops in 2016 and 2017 seasons

Crop	Barley 2014	Mungbean 2014-15	Sorghum 2015-16	Chickpea 2017
Starter P	$p < 0.05$	$p < 0.05$	n.s.	$p < 0.05$
Deep P	$p < 0.001$	$p < 0.01$	$p < 0.05$	$p < 0.001$
Starter P * Deep P	n.s.	n.s.	n.s.	n.s.

Table 5. Grain yield kg/ha with and without starter in 2016 and 2017 seasons

Crop	Barley 2014	Mungbean 2014-15	Sorghum 2015-16	Chickpea 2017
No starter	4590	539	2660	1930
Plus starter	4730	587	2610	2205

The sorghum yield was reduced by 50 kg/ha with the use of starter P, however the effect is not significant if just the FR and 0P treatments are analysed as a subset (data not shown). Under the same analysis, the starter application remains significant for the other three crops. There are contrasting responses at the site between the cereal and pulse crops with deep

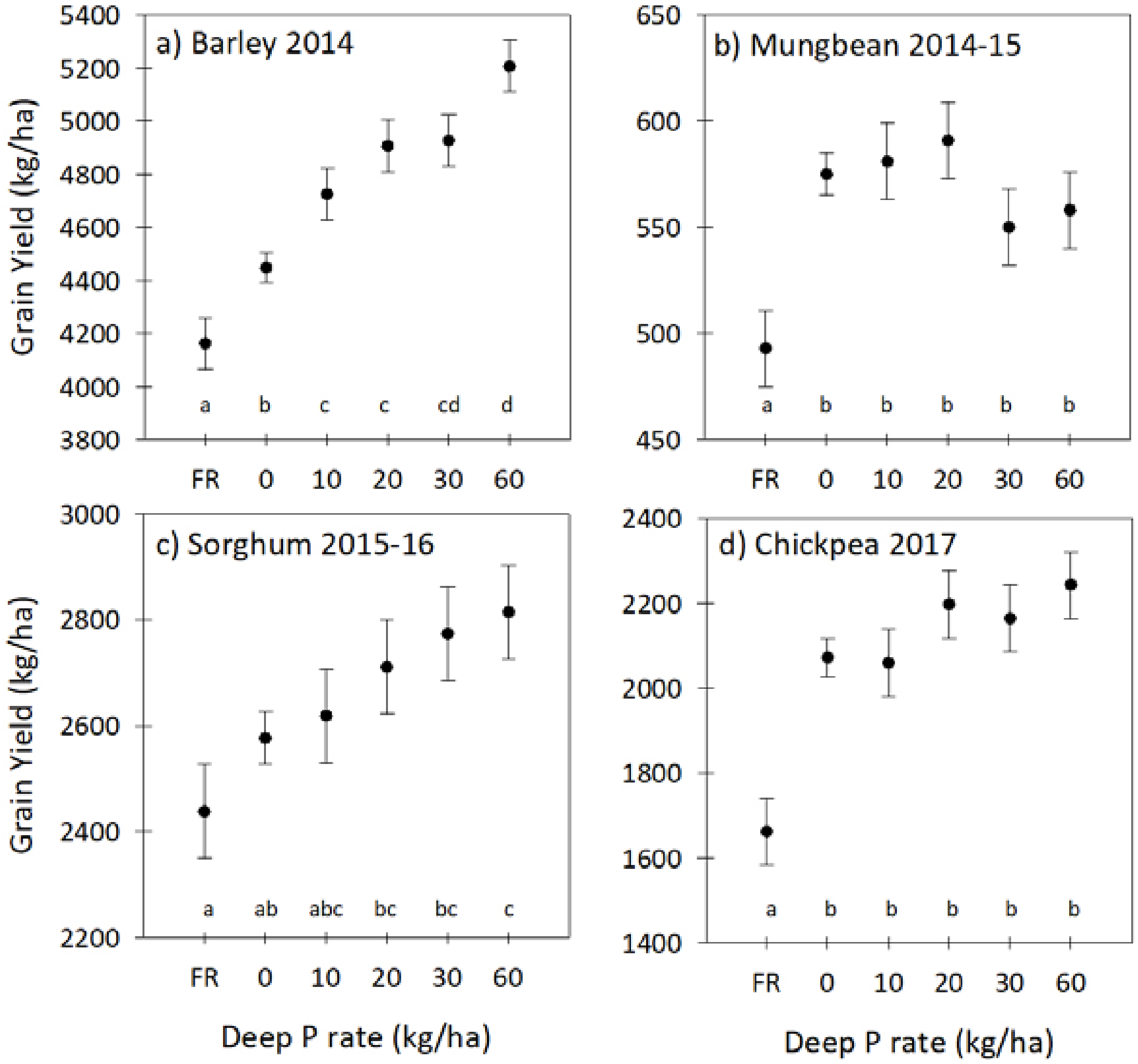

Figure 1. Grain yield (kg/ha) from deep-placed P treatments at Jimbour West for a) barley in 2014, b) mungbean in 2014-15, c) sorghum in 2015-16 and d) chickpea in 2017
Error bar are standard error for each mean. Letters indicated lsd at 5%; note different yield scale each year

P treatments. Yield increases with deep-placed P were measured in barley and sorghum (Figure 1; a and c). In the 2014 barley crop, the combination of deep tillage and basal nutrients (NKSZn) increased the yield by 285 kg/ha (7%) compared to untreated control 'Farmer Reference' plots. Applying 10-30 kg P/ha at depth increased yield by an average of 690 kg/ha, with further yield increases at P rates greater than 30 kg/ha (Figure 1a). Sorghum yield in 2016-17 was higher with any deep P treatment over 10 kg P/ha.

The pulse species did not demonstrate any significant effect to the deep P treatments for 2014-15 mungbean (Figure 1b) and 2017 chickpea (Figure 1d). The mungbean crop, while having a reasonable in-crop rainfall total (174 mm), it was very unevenly distributed during the growing season. The chickpea yield in 2017 had no significant difference between any of the deep placed P rates. These two results suggest the pulse species are responding to the other nutrients applied, principally potassium. Analysis of the deep-placed P treatments excluding the FR did not indicate any statistical significance in either year.

Cereal crops (barley, wheat and sorghum) have a relatively straightforward mechanism to grain yield, with biomass related directly to grain yield via harvest index. Plotting the amount of phosphorus taken up at maturity for the cereal crops (barley and sorghum) against grain yield indicated 200 kg/ha yield per kilogram of P (Figure 2). Increased P supply through deep placement has increased biomass production, and the amount of P taken up as measured at maturity.

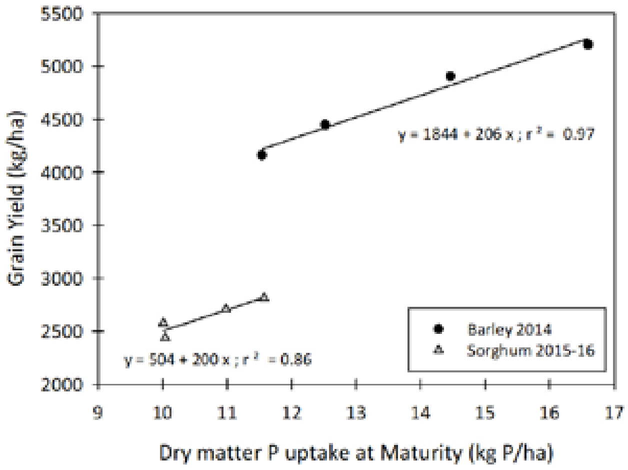

Figure 2. Dry matter P uptake at maturity vs grain yield for cereals at the Jimbour West experiment

K experiment

Grain yields have been significantly affected in the K experiment in three of four crops, although the results are not always straightforward. Barley yield in 2014 (Figure 3a) was increased across a number of treatments. Firstly, the combination of deep-tillage and basal nutrient (the 0K-P treatment) increased yield by 438 kg/ha. This increase is probably due to nitrogen as there was no change in yield between the 0K-P and 100K-P (so no K effect without P). The 0K and 25K treatments were also the same, suggesting the P application had no influence. Once the K application was 50 kg/ha or greater, yields were higher again with a 750 kg/ha increase with 50 kg K/ha plus N, P, S and Zn.

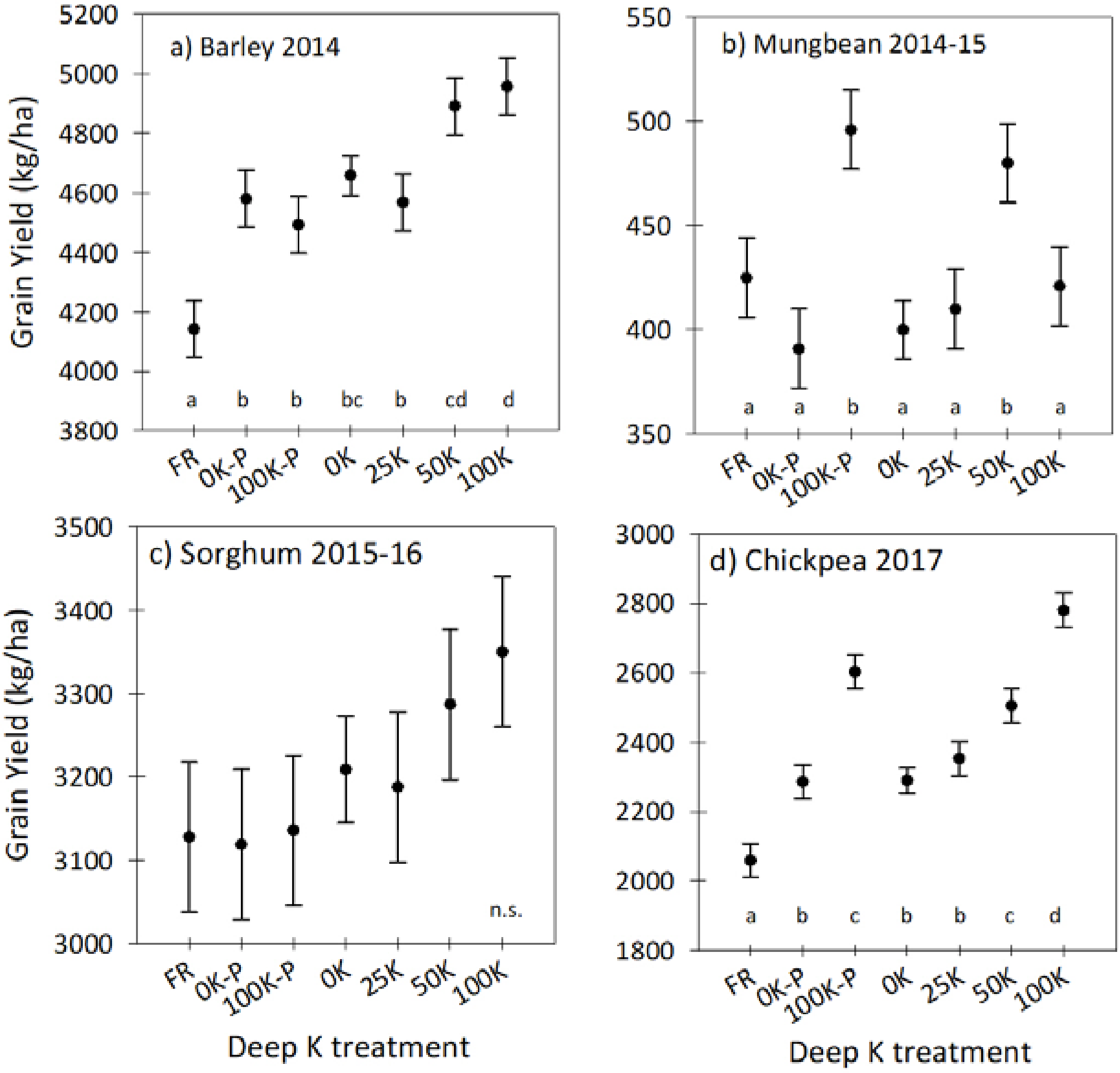

Figure 3. Grain yield (kg/ha) from deep-placed K treatments at Jimbour West for a) barley in 2014, b) mungbean in 2014-15, c) sorghum in 2015-16 and d) chickpea in 2017
Error bar are standard error for each mean. Letters indicated lsd at 5%; note different yield scale each year

Mungbean in 2014-15 (Figure 3b), while having statistically significant responses, is difficult to interpret as the effects are inconsistent across the treatments. While the comparison between the 0K-P and 100K-P is valid with yield being increased, the lack of response to the same 100K with P treatment provides no clear result. Sorghum in 2015-16 (Figure 3c) was not significantly affected by any treatment.

Chickpea grain yield in 2017 (Figure 3d) had several factors additively increasing yield, similar to the barley in 2014 (Figure 3a). Yield in the 0K-P was higher by 226 kg/ha (11%) than the FR, so the combination of previous deep-tillage and basal nutrient boosted yield. Adding 100 kg K/ha without P increased yield by another 317 kg/ha (15%). Phosphorus application without K had no yield effect as the 0K and 25K treatments had the same yield as the 0K-P. Applying K with P increased the grain yield in the 50K and 100K treatments. The highest chickpea yield was 2780 kg/ha; 720 kg/ha (35%) more than the untreated Farmer Reference baseline.

Implications for growers

Farming soils with low subsoil plant available P and K have additional nutritional management challenges over those having to manage a single nutrient such as nitrogen. At this site, an integrated approach using deep-tillage to put immobile P and K below 15 cm has delivered substantial cumulative increases in grain yield (Table 6).

An application of P as a starter with the seed at sowing is still recommended, as significant reduction in grain yield often results when starter P is omitted. The role of starter P in cereal grains to establish early vigour and set yield potential has been well communicated.

Table 6. Cumulative difference in grain yield over four crops compared to untreated control

Deep P rate (kg/ha)*	Change in cumulative yield (kg/ha) versus Farmer Reference
0	914 (10.4%)
10	1227 (14.0%)
20	1648 (18.8%)
30	1658 (18.9%)
60	2065 (23.5%)

*Treatments include additional N, K, S and Zn to support P response research

Each of the deep-P treatments has provided significant improvement to gross margins. The response at 0P rate suggests that there were significant benefits to background tillage, N, K, S and Zn treatments, however P provided additional benefit on top of this. The final economics of the different treatments will be dependent on response duration, with higher rates having higher upfront costs, but also expected to have a greater duration. Whilst 20P and 60P have currently provided similar increases in gross margin, 60P cost $140/ha more upfront and over the four years has generated approximately $150 more in returns (Table 7).

Results at this research site suggest yield responses to potassium application at depth are possible if other limiting nutrients are also applied, particularly for grain legumes which have higher K demand. The pathway to yield for pulse species and the interaction between crop P status and the ability of root systems to forage for K is an on-going area of research.

Increased grain yield will have implications for nitrogen management, with higher yields requiring a greater nitrogen supply.

This research has been conducted under controlled experimental conditions. Before commencing a large scale nutrient application

Table 7. Nutrient costs and cumulative difference in gross margin ($/ha) versus farmer reference from four crops at deep-placed P experiment at Jimbour West

Deep-P Rate	Cumulative additional income	Treatment nutrient costs ($/ha)					Cumulative gross margin change
		Ammonium sulfate	MOP	Zinc	MAP	Urea	
0	$549	$14	$50	$1	$0	$43	$441
10	$654	$14	$50	$1	$40	$39	$510
20	$845	$14	$50	$1	$80	$35	$665
30	$809	$14	$50	$1	$120	$30	$593
60	$996	$14	$50	$1	$240	$17	$673

Assuming urea $400/t, MAP $800/t, ammonium sulfate $350/t, MOP $500/t, Trace Zn $2000/t, application cost of $30/ha, wheat $300/t, chickpea $800/t, barley $270/t, and mungbean $1200/t program, growers are urged to appropriately soil test their fields to establish nutrient available levels for the surface and subsurface layers, and to quantify any potential constraints to yield. They are then encouraged to evaluate the responses on their soils using an appropriate program of strip-trials and on-farm exploration to validate responses for themselves.

Acknowledgements

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

Trial details

Location: Jimbour West

Weather: Average temperatures and median rainfall are presented in Figure 4

Soil type: Grey Vertosol (Cecilvale)

Soil parameters:

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

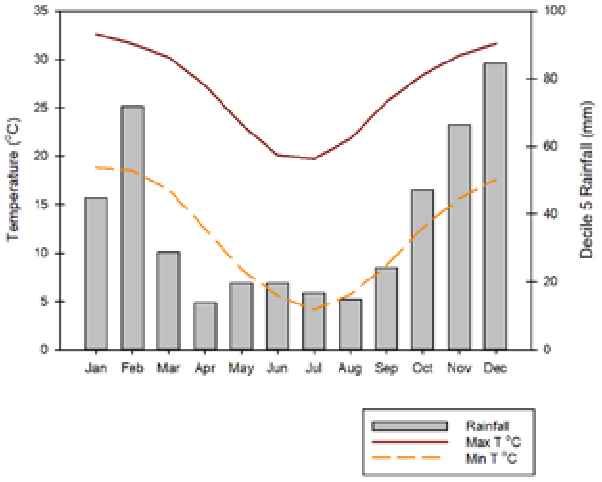

Figure 4. Average maximum and minimum temperatures and meadian rainfall for Dalby (source: Bureau of Meterology data)

Aerial view of the Darling Downs trial site

Cereals have generally increased yields but pulses are inconsistent with deep placed phosphorus—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? | How does starter phosphorus interact with deep-placed phosphorus?*

Key findings

1. Starter phosphorus application significantly increased grain yield in three of eight harvested trials. Responses to starter application were all in wheat crops. Not applying starter reduced yield.
2. Deep-placed phosphorus (P) treatment (tillage, P and basal nutrients) increased cumulative yield by up to 1770 kg/ha (20%) with three crops at Wondalli which have provided a positive return easily accounting for treatment costs. The Condamine sites have cumulative yield gains of 10-15%.

Background

As the length of time we have been cropping land increases, immobile nutrients such as phosphorus (P) and potassium (K) are being taken up by plants from the soil in the 10-30 cm layer. Return of crop residue is depositing these nutrients onto the surface. This is creating a stratified distribution of higher nutrient availability in the surface and lower availability below. Root activity in the soil surface can be limited through faster loss of soil moisture and limited in-crop rainfall. Potentially 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.

What was done

Soil analyses were taken at three trial sites on the Western Downs indicating plant available P was stratified between the surface 0-10 cm and subsurface 10-30 cm/30-60 cm depths (Table 1).

Table 1. Soil phosphorus tests for Western Downs deep-placed P sites

	Wondalli		Condamine South		Condamine North	
	Colwell P	BSES P	Colwell P	BSES P	Colwell P	BSES P
10 cm	11	96	13	25	18	66
30 cm	<2	13	4	6	6	22
60 cm	<2	13	3	5	7	17

Electrical conductivity increased at depth with a significant gypsum layer present below 30 cm. Chloride concentration was not limiting for root growth in the 1.2 m profile analysed (data not shown).

Deep P application rates were identical for the three experiments (Table 2). FR represents 'Farmer Reference', an untreated control providing baseline data on yield and nutrient uptake. Deep P fertiliser was placed perpendicular to sowing direction, at a depth of roughly 20 cm in bands 50 cm apart. A basal zinc (Zn) application was applied into the P fertiliser trench. Urea was applied to balance the nitrogen (N) input to 60 kg N/ha at Wondalli and 40 kg N/ha at Condamine through a tine positioned between the bands of deep P. Deep P plots were two planter widths across, allowing a 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 each experiment. Treatments were applied during May 2013 at Wondalli, and December 2013/January 2014 at Condamine.

Table 2. Experimental deep P treatments

Treatment number	1	2	3	4	5	6
Deep-P rate (as mono ammonium phosphate)	FR	0	10	20	30	60
S rate (as ammonium sulfate)	-	10	10	10	10	10
Zn rate	-	0.5	0.5	0.5	0.5	0.5

Crop management and agronomic management for sites are detailed in Table 3. Phosphorus uptake at maturity was calculated from the above ground biomass cut at maturity x 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.

At Wondalli due to late night operations, two LongReach varieties were inadvertently sown over the trial area—LongReach Spitfire$^{\phi}$ was planted over three and a half replications and Sunvale on the remaining two and a half replications. The mid-June sowing for Sunvale would be thought of as late in the district (Douglas Lush, pers comm). Full details are explained in the 2016 edition of 'Queensland Grains Research'. For simplicity, the results here relate to the LongReach Spitfire$^{\phi}$ yields.

Table 3. Agronomic details for Wondalli, Condamine South and North sites

Wondalli				
Date sown	9-Dec-13	9-Jun-15	26-May-16	26-Apr-17
Crop	Sorghum	Wheat	Chickpea	Wheat
Variety	G22	LongReach Spitfire$^{\phi}$/ Sunvale	PBA HatTrick$^{\phi}$	Sunbri
Row spacing (m)	Double skip	0.375	0.75	0.375
Planting rate (kg/ha)	N/A	40	50	40
Starter product	Starter Z	MAP	MAP plus Zn	SuPreme Z™
Starter rate (kg/ha)	20	40	40	40
Maturity biomass date	19-Mar-14	12-Oct-15	Abandoned	1-Nov-17
Harvest date	24-Apr-14	18-Nov-15	N/A	1-Nov-17
In-crop rainfall (mm)	224	159	258	185

Condamine South				
Date sown	8-May-14	13-May-15	14-May-16	29-Apr-17
Crop	Chickpea 14	Wheat 15	Chickpea 16	Wheat 17
Variety	PBA HatTrick$^{\phi}$	Suntop	Kyabra	EGA Eaglehawk$^{\phi}$
Row spacing (m)	0.66	0.33	0.75	0.33
Planting rate (kg/ha)	88	45	70	43
Starter product	Starter Z	DAP	Starter Z	Starter Z
Starter rate (kg/ha)	20	22	20	20
Maturity biomass date	1-Oct-14	25-Sept-15	Abandoned	6-Oct-17
Harvest date	1-Oct-14	21-Oct-15	N/A	26-Oct-17
In-crop rainfall (mm)	143	158	314	177

Condamine North			
Date sown	Abandoned	10-Sep-15	6-Jan-17
Crop	Wheat	Sorghum	Mungbean
Variety	-	Dominator	Jade-AU$^{\phi}$
Row spacing (m)	-	1.0	0.50
Planting rate / popln	-	80,000 sown	19 kg/ha
Starter product	-	Starter Z	Starter Z
Starter rate (kg/ha)	-	20	20
Maturity biomass date	-	21-Jan-16	27-Mar-17
Harvest date	-	22-Jan-16	26-Apr-17
In-crop rainfall (mm)	-	167	182

Results

From the 11 site years sown at the three sites, eight have been successfully harvested. The wheat emergence in 2014 at Condamine North was very uneven, while the chickpea in 2016 at both Wondalli and Condamine South were abandoned due to very wet seasonal conditions.

There was no significant interaction between starter and deep treatment P(0.05) at any site in any year (Table 4). Starter treatment has been significant in three crops (all wheat) at two sites (Wondalli and Condamine South). Yield was reduced by not applying starter with reductions of 368 and 176 kg/ha for Wondalli in 2015 and 2017 respectively. At Condamine South the yield was 218 kg/ha lower without starter.

Deep-placed P treatments significantly influenced yield in six of the eight harvested crops (Table 4), with wheat being the most

Table 4. Statistical significance of treatments for Wondalli, Condamine South and North sites

Site	Crop	Starter	Deep P	Starter * Deep P
Wondalli	Sorghum (2013-14)	n.s.	p<0.001	n.s.
	Wheat (2015)	p<0.001	p<0.001	n.s.
	Wheat (2017)	p<0.001	p<0.01	n.s.
Condamine South	Chickpea (2014)	n.s.	p<0.05	n.s.
	Wheat (2015)	n.s.	p<0.001	n.s.
	Wheat (2017)	p<0.01	p<0.001	n.s.
Condamine North	Sorghum (2015-16)	n.s.	n.s.	n.s.
	Mungbean (2016-17)	n.s.	n.s.	n.s.

n.s. not signifcant

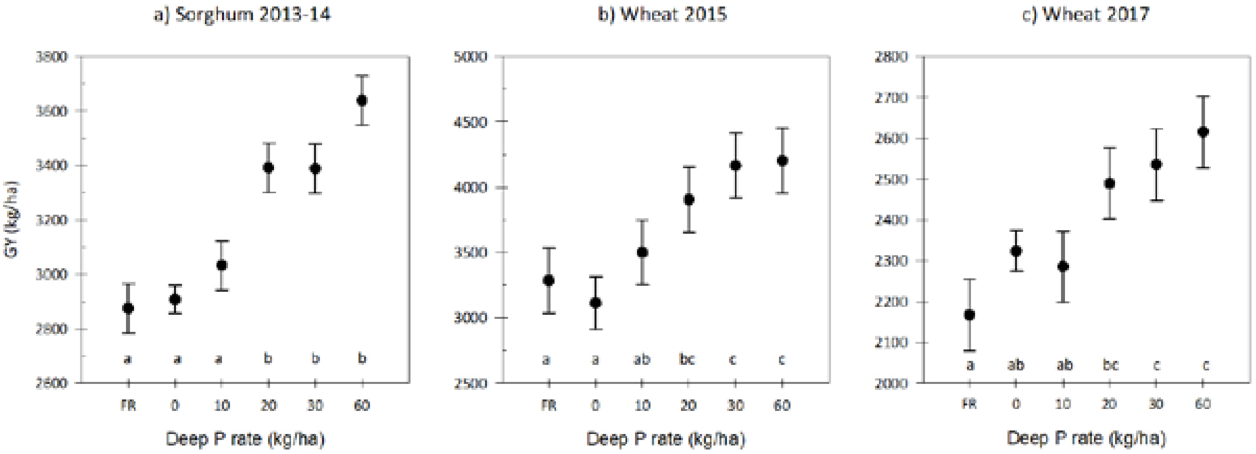

Figure 1. Grain yield (kg/ha) from deep-placed P treatments at Wondalli for a) sorghum in 2013-14, b) wheat in 2015, and c) wheat in 2017; note different yield scale in each year

Error bar are standard error for each mean; letters indicate lsd at 5%

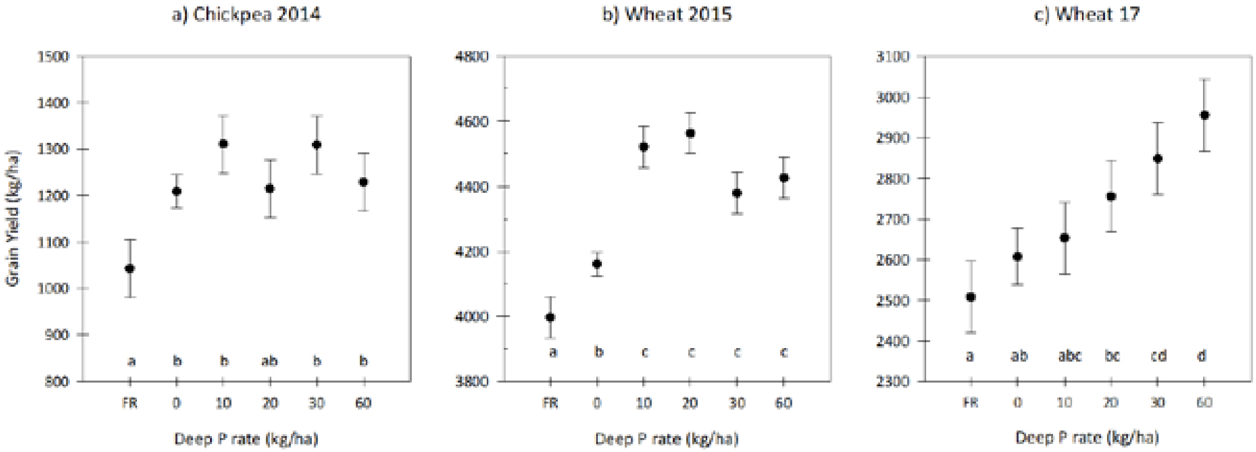

Figure 2. Grain yield (kg/ha) from deep-placed P treatments at Condamine South for a) chickpea in 2014, b) wheat in 2015, and c) wheat in 2017; note different yield scale in each year

Error bars are standard error for each mean; letters indicated lsd at 5%

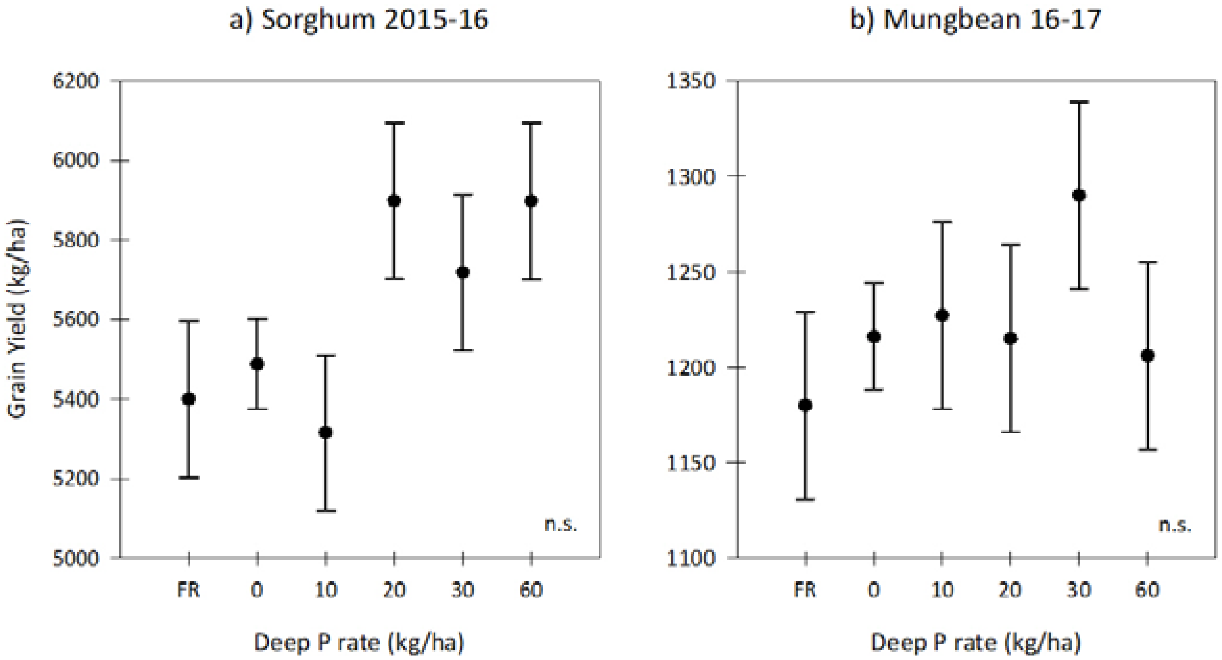

Figure 3. Grain yield (kg/ha) from deep-placed P treatments at Condamine North for a) sorghum in 2015-16 and b) mungbean in 2016-17; note different yield scale in each year
Error bars are standard error for each mean

commonly sown species. All harvested crop yields have been significantly increased with deep P at Wondalli (Table 4, Figure 1). For sorghum in 2013-14 (Figure 1a), yields with deep P at 20 kg P/ha or greater were significantly increased over the untreated, 0 and 10 kg P/ha treatments. Wheat yields increased with deep P rate in both 2015 (Figure 1b) and 2017 (Figure 1c). Deep-placed P at 20 kg P/ha or greater again has the highest yields.

At the Condamine South site, deep treatments were statistically significant for all crops (Table 4) but effects were not as conclusive as they were for Wondalli. With the chickpea in 2014 (Figure 2a), there were no effects of deep P rate on yield. The differences are most likely due to a combination of deep tillage and basal nutrient application—the FR treatment was different to all others. Yields for the following 2015 wheat crop (Figure 2b) show an increase

Figure 4. Aerial image from Condamine North site taken 09 March 2017

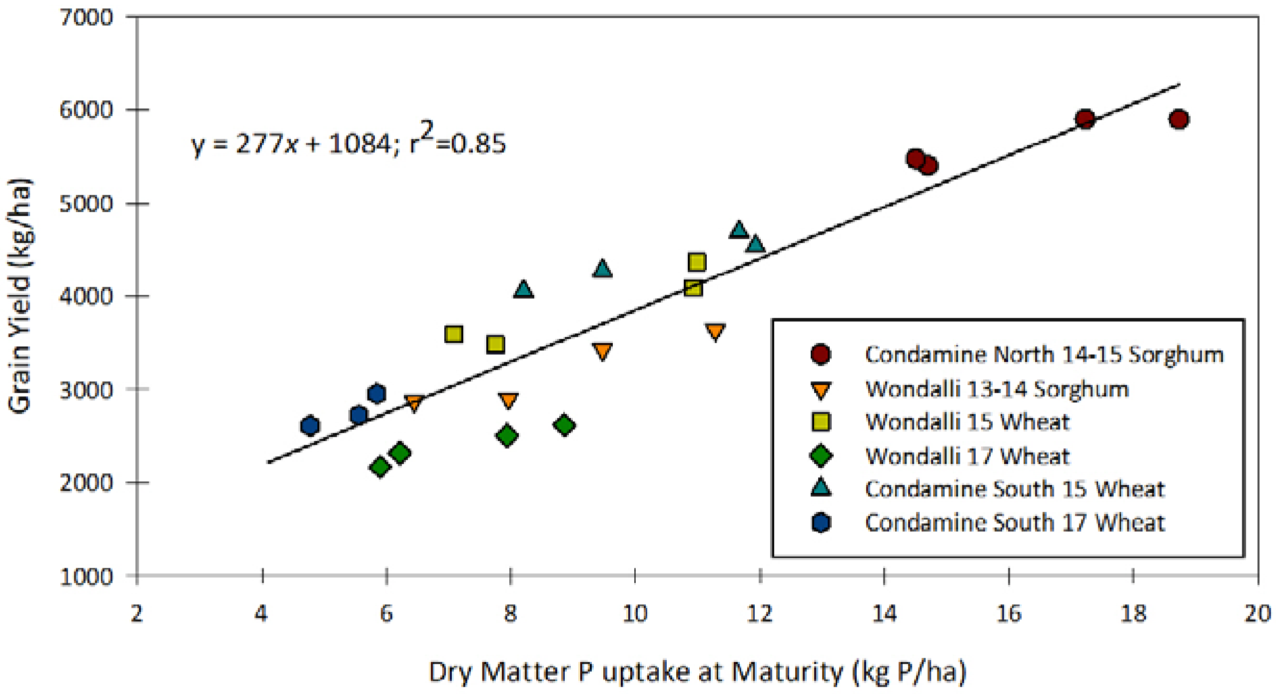

Figure 5. Maturity dry matter P uptake (kg P/ha) versus grain yield (kg/ha) in cereal crops grown at Western Downs deep-P sites

with the 0P treatment versus FR, and then an additional yield increase with deep P 10 kg P/ha or greater. The 2017 wheat (Figure 2c) shows a linear response with increasing deep P rate.

The Condamine North site had no significant effects of deep placed P in either sorghum (Figure 3a) or mungbean (Figure 3b).

Micro-relief on the site, probably due to gilgais, added site variability during the mungbean growing season (Figure 4).

Cereal crops (wheat and sorghum) have a relatively straightforward mechanism to grain yield, with biomass related directly to grain yield via harvest index. By plotting the amount of phosphorus taken up at maturity for the cereal crops (wheat and sorghum) against grain yield, the relationship of 277 kg/ha grain per kg of P taken up was found (Figure 5). Increased P supply through deep placement has increased biomass production, and the amount of P taken up as measured at maturity.

Implications for growers

An application of P as a starter application is still recommended, as sites in this study have demonstrated significant reduction in grain yield when starter was not used. The role of starter P in cereal grains to establish early vigour and set yield potential has been well outlined.

Deep-placement of P has increased grain yield in a majority of cereal crops harvested. The pathway to yield for pulse species and the interaction P nutrition has on this is an on-going area of research.

Cumulative grain yields at the three sites demonstrate the potential for increased grain production over multiple years (Table 5). Increased grain yield will have implications for nitrogen management, with higher yields requiring a greater nitrogen supply.

Table 5. Cumulative difference in grain yield (kg/ha) versus Farmer Reference at three deep-placed P experiments

Deep P rate (kg/ha)	Wondalli (3 crops)	Condamine South (3 crops)	Condamine North (2 crops)
0	-88 (-1.1%)	400 (5.3%)	125 (2.1%)
10	460 (5.5%)	880 (11.7%)	-37 (-0.6%)
20	1225 (14.7%)	826 (10.9%)	534 (8.1%)
30	1482 (17.8%)	736 (9.8%)	429 (6.5%)
60	1769 (21.3%)	703 (9.3%)	524 (8.0%)

After three crops each of the deep P treatments at Wondalli and Condamine South, have provided a positive return easily accounting for treatment costs (Table 6). The $200/ha return for 0P at Condamine South suggests there has been a response to one or more of the background treatments of deep tillage and basal nutrient application. After two crops, both 20 and 30P have generated positive returns at the Condamine North site, whilst 60P has also generated yield benefits at this site with its treatment cost was ~$120/ha more than 30P. The final economics of the different treatments will be dependent on response duration, with higher rates having higher upfront costs, but also expected to have a greater duration.

Table 6. Cumulative difference in gross margin ($/ha) versus Farmer Reference at three deep-placed P experiments

Deep P rate (kg/ha)	Wondalli (3 crops)	Condamine South (3 crops)	Condamine North (2 crops)
0	-$10.63	$202.00	$45.61
10	$57.44	$366.67	-$39.25
20	$305.06	$277.40	$81.50
30	$301.45	$339.71	$77.50
60	$325.65	$171.82	-$89.75

Assuming MAP costs $800/t, application cost of $30/ha, wheat $300/t, sorghum $300/t, chickpea $800/t and mungbean $1200/t

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

Acknowledgements

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

Trial details

Location:	Wondalli and Condamine
Soil type:	Grey Vertosol (Wondalli and Condamine North) Brown Vertosol (Condamine South)

Example of selected soil characteristics (Wondalli):

Depth (m)	pH (CaCl2)	pH (H2O)	EC (1:5)	Ca	Mg	Na	K	ECEC
				(cmol/kg)				
0.0-0.1	7.9	8.7	0.17	22.3	4.8	1.14	1.33	29.6
0.1-0.3	8.1	9.1	0.19	20.5	6.8	2.09	1.05	30.4
0.3-0.6	8.0	8.6	0.65	17.5	8.4	4.01	0.92	30.8
0.6-0.9	7.7	8.1	2.44					
0.9-1.2	6.9	7.2	2.24					

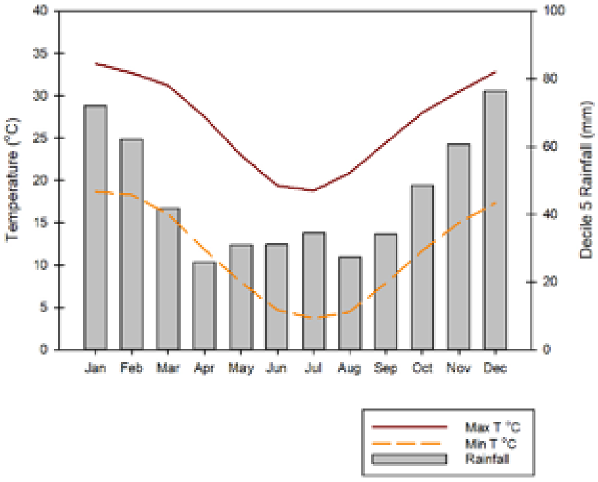

Figure 6. Average weather data (temperature and rainfall) for Texas, Queensland (source: Bureau of Meterology data)

Increased wheat yields two years after deep phosphorus application—Maranoa

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

Key findings

1. For the 2017 season, starter application increased yield (compared to no starter) at the wheat-on-wheat site, but had no response on the chickpea-on-wheat site.
2. Deep-placed phosphorus (P) treatment (tillage, P and basal nutrients) increased yields at both sites under tough seasonal conditions.
3. Wheat yield has increased with deep placed P in all years.

Background

As the length of time we have been cropping land increases, immobile nutrients such as phosphorus (P) are being taken up by plants from the soil in the 10-30 cm and lower layers, however crop residues are depositing P onto the surface. This is creating a stratified distribution of higher nutrient availability in the surface and lower availability below. Root activity in the soil surface can be limited through faster loss of soil moisture and limited in-crop rainfall. Potentially, deeper soil layers can support periods of root activity for longer as they are not as prone to evaporative moisture loss. This research is questioning if placing immobile nutrients deeper into the soil can increase grain yield.

What was done

Soil analyses taken at two experiment sites near Roma in 2015 showed levels of plant available P were more available at the soil surface 0-10 cm than in the subsurface 10-30 and 30-60 cm depths (Table 1). Electrical conductivity increased at depth with a significant gypsum layer present below 30 cm, and the chloride concentrations were not limiting for root growth in the 1.2 m profile analysed (data not shown).

Nutrient application rates were identical for the two experiments (Table 2). Deep-placed fertiliser was applied perpendicularly to the crop sowing direction, at a depth of roughly 20 cm in bands 50 cm apart. A basal zinc (Zn) application was made into the P fertiliser trench. A 'Farmer Reference' (labelled FR) treatment was included as an untreated control providing baseline data on yield and nutrient uptake. Urea was applied to balance the nitrogen input to 40 kg N/ha through a tine positioned between the bands of deep P. Deep P plots were split so that a starter P application could be applied to one side and not the other by growers at sowing. The starter P treatments were grower practice for product and rate. There were six replicates in each experiment. Treatments were established in December 2015.

Table 1. P soil test results (mg/kg) for both Mt Bindango deep placed P sites

Site	Mt Bindango North		Mt Bindango South	
	Colwell P	BSES P	Colwell P	BSES P
0-10 cm	19	48	20	46
10-30 cm	3	16	5	28
30-60 cm	< 2	18	2	27

Table 2. Experimental treatments (deep P nutrient application rates) (kg/ha)

Treatment	1	2	3	4	5	6	7
P rate (as mono ammonium phosphate)	FR	0	10	20	30	40	60
N rate (from MAP and urea)	-	40	40	40	40	40	40
Zn rate (zinc chelate)	-	2.0	2.0	2.0	2.0	2.0	2.0

Table 3. Agronomic details for crops in 2016 and 2017 seasons

Site	Mt Bindango North		Mt Bindango South	
Crop	Wheat	Wheat	Chickpea	Wheat
Date Sown	18-Jun-16	16-May-17	22-May-16 (moisture seeking)	12-May-17
Variety	Ventura	Baxter$^{\text{\textcircled{p}}}$	Kyabra$^{\text{\textcircled{p}}}$	Baxter$^{\text{\textcircled{p}}}$
Row spacing (cm)	50	50	75/100	50
Planting rate (kg/ha)	60	42	65	42
Starter product	Granulock® Z	Granulock® Z	Granulock® Z	Granulock® Z
Starter rate (kg/ha)	48	33	35	33
Maturity biomass date	05 Oct 2016	29 Sept 2017	05 Oct 2016	29 Sept 2017
Harvest date	03 Nov 2016	29 Sept 2017	26 Oct 2016	29 Sept 2017

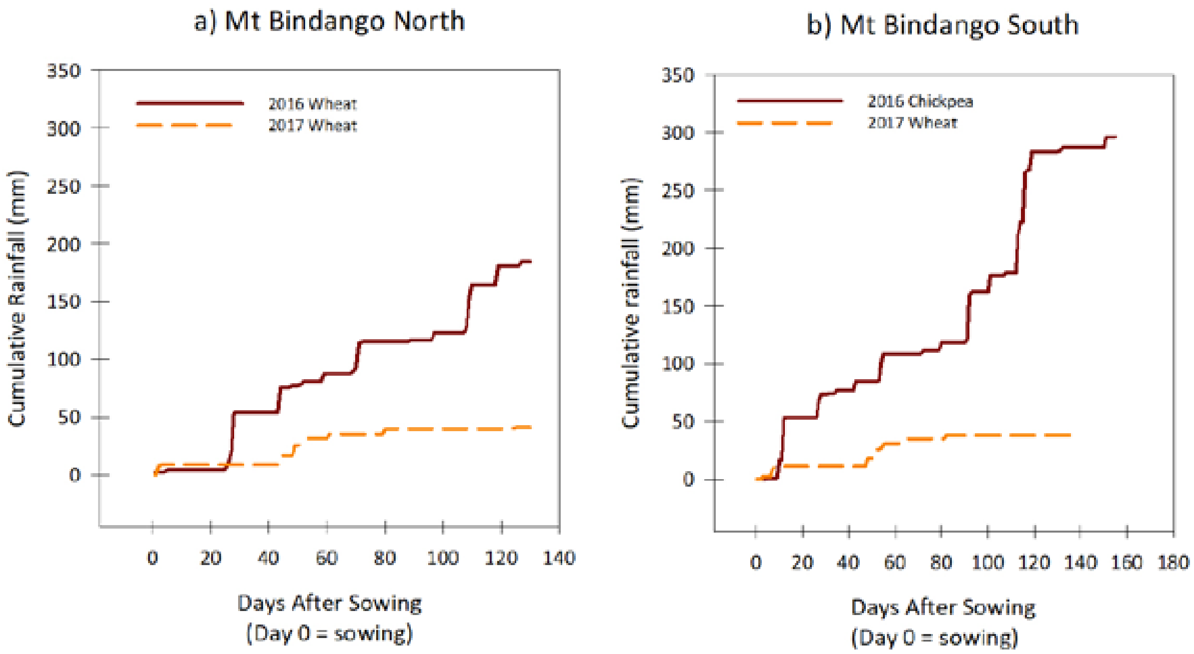

Figure 1. Cumulative rainfall (mm) with days after sowing for each crop year at both sites

Agronomic management details are in Table 3. Above ground biomass was measured at maturity from selected treatments (FR, 0, 20 and 60 kg P/ha). Grain yield was measured using a plot harvester and grain yield corrected to receival standard moisture content.

In-crop rainfall differed between the dry year in 2017 (with <50 mm received) and higher rainfalls in 2016 (Figure 1).

Results

At the northern site (Mt Bingango North), both starter ($p<0.05$) and deep treatments ($p<0.001$) significantly increased grain yield in both wheat crops (Table 4), while the southern site (Mt Bindango South) only had statistical significance for deep treatment ($p<0.05$) in the 2017 wheat. There was no significant interaction between starter and deep treatment for any of the crops.

Table 4. Statistical significance for crops in 2016 and 2017 seasons

Site	Mt Bindango North		Mt Bindango South	
Crop	Wheat 2016	Wheat 2017	Chickpea 2016	Wheat 2017
Starter	p<0.05	p<0.05	n.s.	n.s.
Deep	p<0.001	p<0.001	n.s.	p<0.05
Starter*Deep	n.s.	n.s.	n.s.	n.s.

Table 5. Grain yield with/without starter in 2016 and 2017 seasons

Site	Mt Bindango North		Mt Bindango South	
Crop	Wheat 2016	Wheat 2017	Chickpea 2016	Wheat 2017
No Starter	4425	1727	2043	2310
Plus Starter	4680	1894	2185	2480

Not applying starter significantly decreased crop yield by 255, 167 and 250 kg/ha in the three wheat crops (Table 5), but no significance was measured in the chickpeas. This result is averaged over all deep-P treatments, however the effect is still present if just the FR and 0P treatments are analysed as a subset (data not shown).

Yield increased with deep placed P at the northern site in both crop years (Figure 2). In the 2016 crop, applying 10-30 kg P/ha at depth increased yield by 580 kg/ha, with further yield increases at P rates >40 kg/ha (Figure 2a). Results from 2017 (Figure 2b) has shown a similar pattern of response, with increasing grain yields with increasing deep P rate, but at smaller yields than in 2016. Cumulative yield increase from two crops with 20 kg P/ha placed at depth is 752 kg/ha.

Wheat grain yield in 2017 (Figure 3b) was increased at the southern site with >20 kg/ha deep P, contrasting the nil response from chickpea in 2016 (Figure 3a). As with the northern site, P rates of 40 kg/ha or greater had the largest effect increasing grain yield by 340 kg/ha (15%).

The change in P uptake at maturity in the wheat above ground biomass provided a basis for the increase in grain yield (Figure 4). For each extra kilogram of P taken up by the crop, an additional 237 kg of grain was produced.

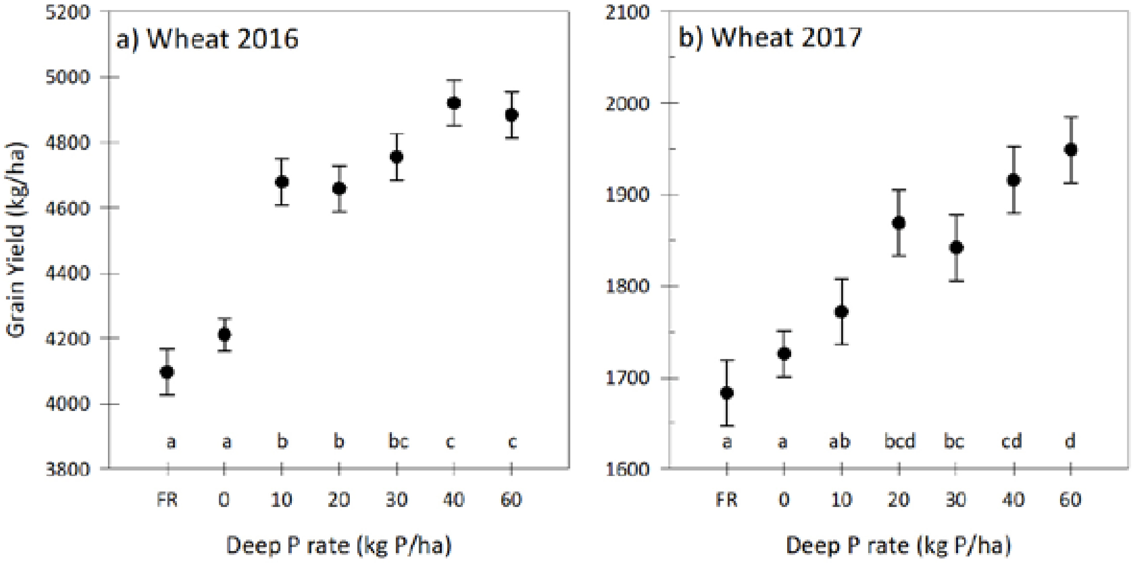

Figure 2. Grain yields (kg/ha) from deep-placed P treatments at Mt Bindango North in 2016 and 2017

Error bar are standard error for each mean; letters indicated lsd at 5%; note different yield scale each year

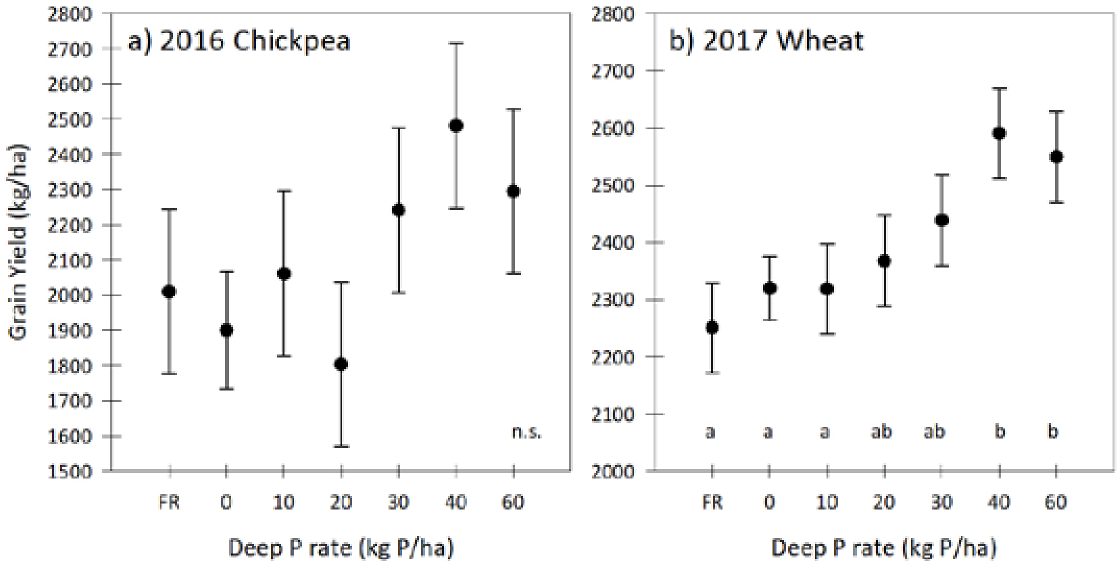

Figure 3. Grain yields (kg/ha) from deep-placed P treatments at Mt Bindango South in 2016 and 2017

Error bar are standard error for each mean; letters indicated lsd at 5%

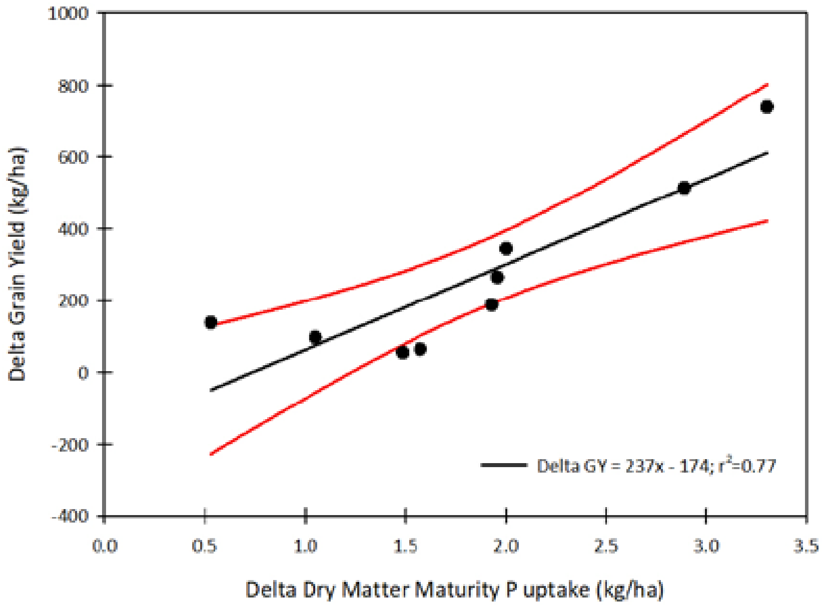

Figure 4. Change in DM P uptake at maturity vs change in grain yield for wheat at two sites in the Maranoa

Implications for growers

Grain yield increases with either starter application, or deep-placed P have been measured in wheat for two contrasting growing seasons in the Maranoa. Further work in understanding the drivers of yield in chickpea is on-going, with another chickpea crop scheduled for the northern site in 2018. The southern site is intended to have wheat again in 2018.

The cumulative increases in grain yield, particularly for wheat in these experiments suggests deep-placing phosphorus can boost yield despite contrasting seasonal conditions (Table 6). Increased cereal grain yield however will also have implications for nitrogen management, with higher yields requiring a greater nitrogen supply to meet water limited potential.

Table 6. Cumulative difference in grain yield (kg/ha) compared to Farmer Reference at two deep-placed P experiments in the Maranoa

Deep P rate (kg/ha)	Mt Bindango North (2 crops)	Mt Bindango South (2 crops)
0	158 (2.7%)	36 (0.8%)
10	672 (11.6%)	110 (2.8%)
20	752 (12.9%)	-27 (-0.6%)
30	818 (14.1%)	420 (9.9%)
40	1054 (18.3%)	420 (9.9%)
60	1057 (18.3%)	585 (13.5%)

Each of the deep-P rates at the northern site has more than paid for its treatment cost within the first two seasons (Table 7); the duration of response will determine the overall profitability of each of these treatments, with an expectation that higher rates will provide longer lasting benefits.

Table 7. Cumulative change in gross margin ($/ha) compared to Farmer Reference in response to deep-placed P in the Maranoa

Deep P rate (kg/ha)	Mt Bindango North (2 crops)	Mt Bindango South (2 crops)
0	$5.81	-$74.08
10	$105.64	-$12.08
20	$100.34	-$184.61
30	$95.73	$102.00
40	$112.34	$294.45
60	$30.84	$63.97

Assuming a MAP cost of $800/t an application cost of $30/ha, wheat price of $300/t and a chickpea price of $800/t

The negative results at 0, 10 and 20P at the southern site are largely driven by a negative response in the chickpea crop in the first year, interestingly none of the higher rates had this same negative, and have all managed to more than cover their treatment costs.

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 available nutrient levels for the surface and subsurface layers, and to quantify any potential constraints to yield. They are then encouraged to evaluate the responses on their soils using an appropriate program of strip-trials and on-farm exploration to validate responses for themselves.

Acknowledgements

The team would like to thank to trial co-operator for hosting this trial. Thanks also to the Grains Research and Development Corporation, University of Queensland and the Department of Agriculture for funding project UQ00063 'Regional soil testing guidelines for the northern grains region'.

Trial details

Location: Hodgson
Soil type: Mt Bindango North - Open Downs (Roma Downs)

Example of selected soil characteristics:

Depth (m)	pH (CaCl2)	pH (H2O)	EC (1:5)	Ca	Mg	Na	K	ECEC
				(cmol/kg)				
0.0-0.1	6.9	7.4	0.082	21.9	7.2	1.14	0.67	30.9
0.1-0.3	7.2	7.8	0.082	27.1	7.9	0.49	1.34	36.8
0.3-0.6	6.9	7.1	1.358	31.1	8.3	0.47	2.24	42.1
0.6-0.9	7.4	7.7	2.080	33.2	8.3	0.41	3.00	44.9
0.9-1.2	5.4	5.6	1.600	22.9	8.5	0.47	3.7	35.6

Soil type: Mt Bindango South - Open Downs (Roma Downs)

Example of selected soil characteristics:

Depth (m)	pH (CaCl2)	pH (H2O)	EC (1:5)	Ca	Mg	Na	K	ECEC
				(cmol/kg)				
0.0-0.1	7.1	8.0	0.182	34.9	6.0	1.18	1.23	43.33
0.1-0.3	7.4	8.6	0.270	34.2	7.2	0.69	3.44	45.51
0.3-0.6	8.0	8.9	0.408	30.5	8.2	0.64	6.63	45.93
0.6-0.9	7.3	8.0	2.133					
0.9-1.2	7.3	7.9	1.875					

Chickpeas growing in deep phosphorus trial site at Maranoa

How can you get more deep-placed phosphorus into crops to boost grain yield?

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RESEARCH QUESTIONS:

1. *Can plants take up more deep placed nutrient if it is applied in narrower band spacing (0.25 m), or can application cost be saved through wider bands (1.0 m)?*
2. *Will using fluid form be better than granular?*
3. *How do different high analysis fertilisers compare for performance in-crop?*
4. *What is the interaction between phosphorus and zinc fertilisers when applied at depth?*

Key findings

1. Early season phosphorus responses in 2015 barley were impressive—12% increase with tillage and basal and another 12% with 40 kg P/ha.
2. Dry conditions reduced grain yield responses at one site.
3. Excellent chickpea grain yield responses in 2017 to increasing phosphorus rate.

Background

Research across central and southern Queensland since 2013 has reliably shown deep-placement of phosphorus (P) can increase cereal and some legume grain yields due to greater P uptake by plants.

These regional experiments have used a constant fertiliser band spacing of 0.50 m with varying rates of fertiliser P applied from 0 to 60 kg P/ha. The 0.50 m band spacing was chosen from earlier exploratory placement experiments that suggested 0.25 m bands are equivalent to 0.50 m, and both were better than 1.00 m. However these experiments used a constant rate of application, so different band spacing were also characterised by different in-band P concentrations—a key determinant of the rate of diffusive supply to crop roots.

Plant P uptake from P fertiliser is a combination of several influences: the diffusion gradient of P (in-band concentration), how much of the soil is treated (how many bands), the amount of roots a plant can use to access the fertiliser, the Arbuscular Mycorrhizal Fungi (AMF) status of the soil, and sensitivity of the plant. The diffusion gradient for applied P fertiliser is a combination of fertiliser band spacing (lineal m/ha) and application rate.

Grass crop species (wheat, barley, sorghum) with fibrous root systems have been able to utilise 0.50 m bands, whilst coarsely rooted pulse crops have been less reliable at utilising deep-placed P and K bands.

Experiments on the Western Downs (Lundavra and Westmar/Inglestone) with deep-placement that used triple superphosphate (TSP) as the P source were not as responsive for maturity P uptake and grain yield as experiments set up later that used mono-ammonium phosphate (MAP). One theory is that on soils with higher alkalinity levels, TSP is not as plant available so crops cannot recover P as effectively. This research is attempting to assess how different P fertiliser products, at varying rates, at different band spacing combinations alter crop response and fertiliser recovery, over a range of crop species with contrasting rooting characteristics.

There is an antagonistic effect between plant P and zinc (Zn) uptakes with high rates of fertiliser P reducing Zn acquisition. To counteract this, a background Zn has been applied onto the fertiliser P band at rates of 0.5 to 2.0 kg/ha depending on the Zn source used. However, several experiments (particularly with sorghum), have suggested that crop zinc levels in the above-ground biomass at maturity were decreasing with increasing P application rates and may still be below suggested critical levels. An experiment to explore the interaction between applied P and Zn in fertiliser was established.

What was done

Five experiments were deployed (Table 1) covering topics exploring rate x band spacing interactions for P, phosphorus product comparisons between granular and liquid forms, and the relationship between P and Zn application rates.

Table 1. Experimental program summary

No.	Locality	Experiment	Established
1	Jimbour West #1	P rate x band spacing	March 2015
2		P product x rate	May 2017
3	Jimbour West #2	P rate x band spacing x form	March 2016
4		P rate x Zn product	Dec 2015
5	Lundavra	P product x rate	June 2017

Jimbour West site #1 details (experiments 1–2)

Soil analyses taken from the site suggested both P and K were low (Table 2) and crops should respond to P and K application.

Experiment 1 (Table 3) compares three band spacing (0.25, 0.50 and 1.00 m) each with different P application rates and an untreated control ('No treatment'), which was left as a representation of district practice and unamended soil. Plot size was 10 m long (8 m treated) x 24 m wide. There were six replicates. Mono-ammonium phosphate (MAP 10N 22P) was used as the P source, with liquid potassium sulfate (KTS 30K 25S) and zinc sulfate (17 Zn) applied as basal nutrients.

Experiment 2 (Table 1) was established in May 2017 using a different experimental approach to explore differences in crop response to four P products: triple superphosphate (TSP 0N 20P), MAP, diammonium phosphate (DAP 18N 20P) and Flowphos 15 (10N 15P). Each product was applied at 0, 10, 20, 30, 40, 60 and 80 kg P/ha. Urea was applied to balance N application to constant addition across all treatments. The experiment was duplicated at Lundavra (Table 1, experiment 5) on the Western Downs.

Three crops have been grown on the Jimbour West site 1 (Table 4). Experiment 2 (P product comparison) was put in between cotton mulching and sowing the barley. Given the very short time between establishing experiment and sowing, crop emergence was heavily compromised and no data was collected/reported. The initial data collection is intended to be in winter 2018 after the site has had additional time to re-consolidate.

Table 4. Crop agronomic details at Jimbour West #1

Crop	Barley	Cotton	Barley
Date sown	21-May-15	13-Oct-16	1-Aug-17
Variety	Sheppard$^{(D)}$	748BRF3	Compass$^{(D)}$
Row spacing (m)	0.375	1.5	0.375
Population	50 kg/ha (sown)	14 seeds/m	90 kg/ha (sown)
Starter product	SuPreme Z™	MAP 2% Zn	Nil
Starter rate (kg/ha)	30	30 k	
Maturity biomass date	21-Sep-15	16-Feb-17	
Harvest date	23-Oct-15	31-Mar-17	15-Dec -17
In-crop rainfall (mm)	104.5	97	101

Table 2. Soil test results for Jimbour West #1

Depth	pH1:5 (H2O)	pH1:5 (CaCl2)	Col P (mg/kg)	BSES P (mg/kg)	Ex Ca (cmol/kg)	Ex Mg (cmol/kg)	Ex Na (cmol/kg)	Ex K (cmol/kg)
0-10 cm	7.1	6.0	37	97	19.2	14.2	0.75	0.47
10-30 cm	7.5	6.6	8	12	16.2	14.7	1.6	0.20
30-60 cm	8.1	7.0	4	7	17.7	19.4	3.77	0.22

Table 3. Treatment details for experiment 1 - phosphorus rate x band spacing at Jimbour West #1—Factorial plus added control structure for P rate x band spacing

Basal treatment	P rate (kg/ha)	No band spacing	Band spacing (m)		
			0.25	0.50	1.00
No treatment	None	✓	✗	✗	✗
Tillage + Basal	0	✗	✓	✓	✓
Tillage + Basal	10	✗	✓	✓	✗
Tillage + Basal	20	✗	✓	✓	✓
Tillage + Basal	40	✗	✓	✓	✓
Tillage + Basal	80	✗	✗	✗	✓

Table 5. Soil test results for Jimbour West site #2

Depth	pH1:5 (H2O)	pH1:5 (CaCl2)	Col P (mg/kg)	BSES P (mg/kg)	Ex Ca (cmol/kg)	Ex Mg (cmol/kg)	Ex Na (cmol/kg)	Ex K (cmol/kg)
0-10 cm	7.4	6.6	17	30	17.0	13.3	1.3	0.37
10-30 cm	7.9	6.7	4	12	18.0	15.3	2.4	0.28
30-60 cm	8.4	7.5			18.7	18.7	4.6	0.27

Jimbour West site #2 details (experiments 3–4)

Two experiments were established between Dec 2015 and Mar 2016 to compare fluid versus granular MAP (Table 1, experiment 3), and the effect of zinc application rates with increasing P application rates (Table 1, experiment 4). The soil test values for the site suggested low P without the K being low enough to restrict growth (Table 5).

Treatment structure for experiment 3 was main plots were factorial combination of five application rates (0, 20, 20, 40 and 80 kg P/ha) x three band spacing (0.25, 0.5 and 1.0 m). Each combination of application rate x band spacing plot was spit into granular (MAP) vs fluid (Flowphos 15). Plot size was 10 m long (8 m treated) x 24 m wide, with six replicates. Urea was used to balance N application to 60 kg/ha.

To explore the interaction between applied P and Zn in fertiliser, three granular products monoammonium phosphate (MAP 10N 22P 0Zn), Granulock® Z (10N 22P 1Zn) and Granulock® Z Extra (12N 20P 2Zn) with different Zn concentrations were each applied equivalent to 0, 10, 20, 60 and 60 kg P/ha Treatments were applied in December 2015. Plot size was 10 m long (8 m treated) x 24 m wide, with four replicates. Urea was used to balance N application to 60 kg/ha. Fertilisers were applied on a 0.50 m spacing for all products and rates.

Chickpea was sown as the first crop into the experiment (Table 6) in 2017, however emergence was slightly uneven due to use of disk openers to chase slightly deeper moisture. Variation in emergence was captured using drone platform and used to position biomass samples at points in the plot that had a similar time of emergence.

Table 6. Agronomic details for experiment 6

Crop	Chickpea
Date Sown	20-May-17
Variety	PBA Seamer⊕
Row spacing (m)	0.375
Population	60 kg/ha sown
Starter product	Granulock® Z Extra
Starter rate	20 kg/ha
Maturity biomass date	20-Oct-17
Harvest date	31-Oct-17
In-crop rainfall (mm)	126

Lundavra site details (experiment 5)

This was the second of two experiments established between May and June 2017 to compare different P fertiliser sources with increasing P application rates. Treatments have been outlined previously in Jimbour West site #2. The soil test values for the site suggested stratified P distribution with decreasing plant availability at depth (Table 7).

Sorghum was sown as the first crop in October 2017 (Table 8).

Table 8. Agronomic details for Lundavra experiment 5

Crop	Sorghum
Date sown	25-Oct-17
Variety	MR-Taurus
Row spacing (m)	Double skip
Population	50000/ha sown
Starter product	Granulock® Z Extra
Starter rate	20 kg/ha
Maturity biomass date	17-Jan-18
Harvest date	30-Jan-18
In-crop rainfall (mm)	154

Table 7. Soil test results for Lundavra P product comparison experiment

Depth	pH1:5 (H2O)	pH1:5 (CaCl2)	Col P (mg/kg)	BSES P (mg/kg)	Ex Ca (cmol/kg)	Ex Mg (cmol/kg)	Ex Na (cmol/kg)	Ex K (cmol/kg)
0-10 cm	7.1	6.1	55	87	11.8	4.1	0.56	0.77
10-30 cm	8.5	7.3	4	8	17.2	7.2	1.72	0.32
30-60 cm	9.1	7.9	2	5	15.1	9.4	3.75	0.22

Results

Jimbour West site#1 - experiment 1 P rate x band spacing

Significant treatment effects on yield were seen only in the first barley crop (Table 9). No treatment effect on yields were measured in the two following crops due to very tough seasonal conditions with low rainfall in both years (Table 4). The 2015 season had good seasonal conditions until anthesis but was warm and dry following that reducing grain yield potential.

Table 9. Statistical significance for treatment effects on grain/lint yields for crops in experiment 1

Crop	Barley 2015	Cotton 16-17	Barley 2017
Treatment	$p < 0.001$	n.s.	n.s.

Increasing P rate significantly increased grain yield in the 0.25 and 0.50 m band spacing, but had no effect on the 1.00 m band (Table 10). Yield increases were generally 3-10% (150-500 kg/ha grain).

Table 10. 2015 Grain yield contrast analysis for each band spacing in experiment 1

Band spacing	0.25 m	0.50 m	1.00 m
P rate	$p<0.001$	$p<0.05$	n.s.
0	4600 a	4565 a	4584
10	4749 ab	4584 a	
20	5100 c	4982 b	4584
40	4857bc	4880 b	4778
80			4761

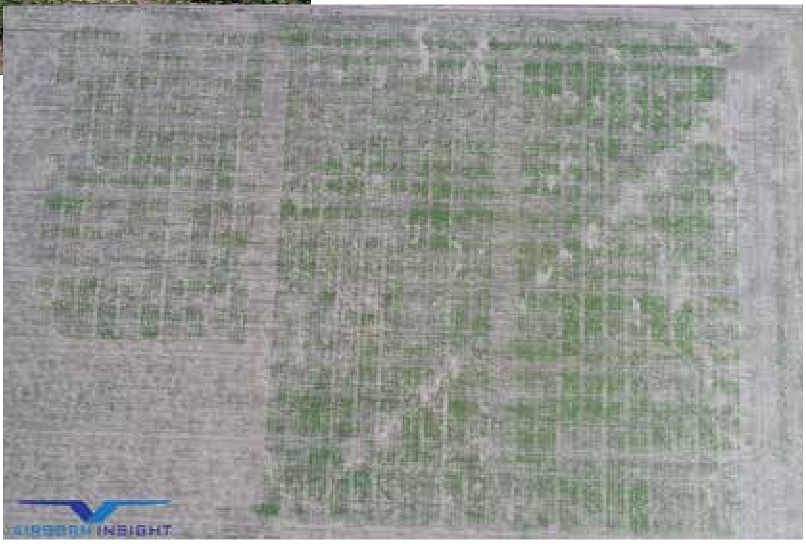
Significance ratings are not across band spacing analysis; each significance is only for the same band spacing

Jimbour West site #2—experiment 3 P rate x band spacing x form

This was the first crop sown following establishing the experiment. Visual effects were seen with increased crop growth from both tillage and the P application (see image below left).

While this field has been under controlled traffic management for many years, a legacy effect of racetrack (round-and-round) tillage practices was visible using proximal (drone) imagery (see image below right).

Chickpea growth on 11 August 2016 with edge effect of untreated zone clearly visible to the right of the picture



Drone image on 27 Sept 2016. The left bay is the P x Zn rate experiment, the middle and right bays are the P rate x band spacing x form experiment plots

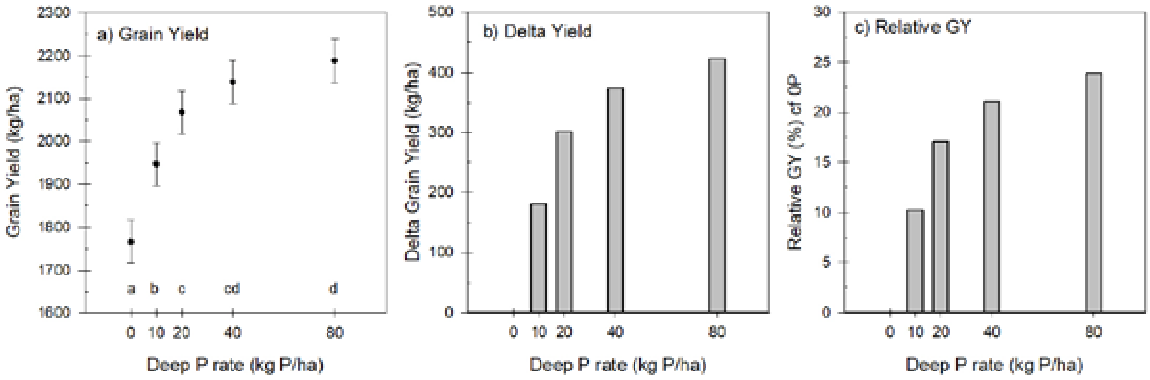


Figure 3. Effects of P application rate on a) grain yield (kg/ha), b) change in grain yield (kg/ha) vs 0P, and c) relative change in grain yield for chickpea grown in 2017

The experimental layout and treated plots were clearly visible as is the 45° angle of the diagonal roadway. The compaction in this zone must be below the rip layer created during the establishment of the experiment. Plots under the compacted diagonal zone were removed prior to statistical analysis. Visual and Normalised Difference Vegetation Index (NDVI) data from within treated plot data area was used to guide biomass sampling and harvest operations. Correlation between sample area NVDI and biomass at maturity values were good (r2=0.70, data not shown).

Effects on grain yield for 2017 were only from deep P application rate ($p < 0.001$), with no significant difference seen in other factors or their interactions. Increasing P rate to 40 kg P/ha produced maximum grain yield of 2150 kg/ha (Figure 3a). This response was probably accentuated by the very long fallow preceding sowing, reducing population of arbuscular mycorrhizal fungi for the AMF-sensitive chickpea species. At the 40 kg P/ha rate, increase in grain yield was close to 400 kg/ha (Figure 3b) or just over 20% (Figure 3c).

Jimbour West site #2—experiment 4 P rate x Zn product

P rate was the only significant effect on grain yield ($P<0.001$) when comparing the three products. Large increases in yield were observed (Table 11), but results were at odds with nearby trial results. Why the 0P plots in this experiment were 400 kg/ha lower than the control (0P) in the adjacent P rate x band spacing is hard to explain. The grain yields with 30 and 60 kg P/ha rates were very similar to the yields measured for the 40 and 80 kg P/ha rates (Figure 3), and for the chickpea grown close by at other research sites, suggesting maximum yield for the season was achieved.

Table 11. P rate response of grain yield in P rate x Zn product experiment in 2017

P rate	Mean grain yield (kg/ha)	Change in yield (kg/ha)	Relative change (%)
0	1359		
10	1712	353	26
20	1860	501	37
30	2023	664	49
60	2151	792	58

While there are no significant differences in grain yield, there are difference seen in dry matter at maturity between products in relation to Zn vs P uptake (Figure 4). MAP had a very flat response with Zn uptake increasing very little as P uptake increased. This contrasts the increased Zn uptake from the Granulock® products, with the higher Zn concentration in Granulock® Z Extra generating a steeper uptake slope compared to Granulock® Z.

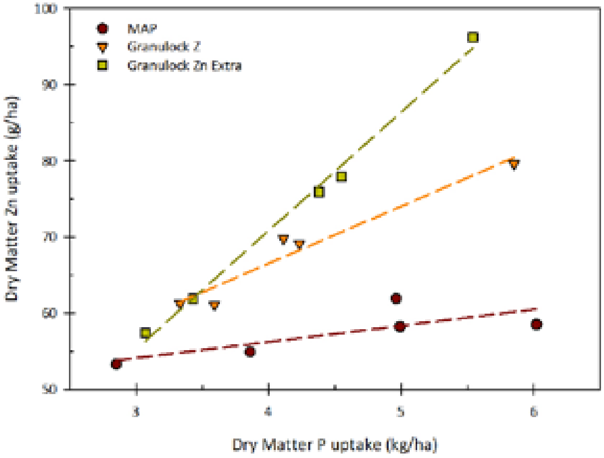


Figure 4. Chickpea maturity dry matter P uptake (kg/ha) vs Zn uptake (g/ha) for three products at five application rates in 2017

Lundavra site—experiment 5 P rate x P product

Neither deep P rate or P product had any effect on grain yield at Lundavra in 2017-18. Excellent seasonal conditions kept yield potential high with trial average of 3200 kg/ha (Table 12) rating very highly on a double skip sowing configuration.

Table 12. Grain sorghum yield (kg) for P rate x P product 2017-18

P rate	P product					Grand total
	Control	TSP	MAP	DAP	F15	
0	3141					**3141**
10		3157	3250	3110	3317	**3208**
20		3320	3187	3010	3200	**3179**
30		3070	3130	3197	3263	**3165**
40		3223	3173	3180	3207	**3196**
60		3283	3243	3280	3290	**3274**
80		3433	3087	3420	3057	**3249**
Grand total	**3141**	**3248**	**3178**	**3199**	**3222**	**3202**

Phosphorus uptake in the crop was measured for all MAP plots at both anthesis and maturity (Table 13). Results suggest that approximately 80% of maturity P uptake was in the plant at anthesis.

Table 13. Sorghum P uptake in dry matter at anthesis and maturity at Lundavra 2017-18

P rate	Anthesis P uptake (kg/ha)	Maturity DM P up (kg/ha)	% total uptake at anthesis
0	6.2	8.1	77%
10	7.3	10.5	69%
20	7.5	9.1	83%
30	7.0	9.4	74%
40	6.8	9.3	73%
60	9.6	10.8	89%
80	8.2	8.1	102%
Grand total	**7.1**	**8.9**	**80%**

Preliminary analysis suggests no difference in P uptake between P products (data not shown).

Implications for growers

Deep-placing P has increased yields in combination with the tillage disturbance and basal nutrients. There are no clear recommendations on appropriate band spacing to suit different crop root system architecture. Spacings of 0.25 and 0.50 m have provided yield increases in one crop where 1.00 m had no effect.

Continued work in refining experimental technique to explore interaction of rate and band spacing is on-going.

Field work to separate performance of fluid versus granular P, and different high analysis forms (TSP, MAP, DAP) has not differentiated yield responses between differing form or products. Recommendation to use MAP-based product remains. Zinc addition at 1% with increased plant Zn uptake as P uptake improved. Product with 2% Zn concentration had a steeper Zn uptake i.e. more Zn per kg P uptake.

Acknowledgements

Thanks to the trial co-operators for hosting these trials. This work is funded by University of Queensland, the Department of Agriculture and Fisheries and the Grains Research and Development Corporation under UQ00078 'Deep placement of nutrients'.

Trial details

Jimbour West

Soil type: Grey Vertosol (Cecilvale)

Depth (m)	pH (CaCl2)	pH (H2O)	EC (1:5)	Ca	Mg	Na	K	ECEC
				(cmol/kg)				
0.0-0.1	6.0	7.1	0.05	19.2	14.2	0.75	0.53	34.7
0.1-0.3	6.6	7.5	0.08	16.2	14.7	1.6	0.18	32.7
0.3-0.6	7.0	8.1	0.16	17.7	19.4	3.77	0.19	41.1
0.6-0.9	8.2	9.1	0.31	16.7	21.5	5.57	0.22	44.0
0.9-1.2	8.2	9.1	0.44	17.0	24.0	6.99	0.31	48.3

Lundavra

Soil type: Brown Dermosol (Wynhari)

Depth (m)	pH (CaCl2)	pH (H2O)	EC (1:5)	Ca	Mg	Na	K	ECEC
				(cmol/kg)				
0.0-0.1	6.13	7.13	0.07	11.8	4.1	0.56	0.77	17.25
0.1-0.3	7.30	8.50	0.11	17.2	7.1	1.72	0.32	26.42
0.3-0.6	7.90	9.10	0.18	15.1	9.4	3.75	0.22	28.44
0.6-0.9	7.77	9.00	0.30	11.8	9.7	6.30	0.20	27.99
0.9-1.2	5.40	6.63	0.55	9.0	8.7	7.45	0.17	25.30

Soils research

The management of soil organic matter has remained the focus of the Department of Agriculture and Fisheries' Regional Agronomy team in the soils domain. Soil organic matter (SOM) is critical for healthy soils and sustainable agricultural production; however levels under cropping systems are continuing to decline. Growers are looking for 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.

Two projects were funded in 2012; one by the Grains Research and Development Corporation (GRDC), and the second by the federal Department of Agriculture, Fisheries and Forestry (DAFF). Demonstration sites were set up to investigate the impact a range of farm management strategies had on soil organic carbon levels. These were aimed at helping growers understand the functions of soil organic matter in grain production systems, and how current farming systems affect soil carbon levels.

The demonstration sites investigated the potential of increasing soil organic matter:

- By establishing productive pastures on long-term cropping country
- Under cropping by comparing manure versus fertiliser
- By applying nitrogen fertiliser to maximise production on established grass pastures.

One site focused on applying nitrogen to maximise production on established grass pasture and was finalised late 2016; a summary of the results was included in the 2016 Queensland Grains Research publication. The two remaining sites were finalised in 2017 and are summarised in the following section.

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, hence reducing SOM contributions.
- A pasture phase is economically viable (particularly under high livestock values), however the pasture needs to be utilised, which is difficult 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 its 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.

This work investigating soil organic matter has now been finalised. However, with investment from the Grains Research and Development Corporation new research investigating the economics of ameliorating soil constraints in the northern region will begin late 2018. Results from this research will be reported in future publications.

Increasing soil organic matter under cropping: manure versus fertiliser—Warra

Jayne Gentry and David Lawrence
Department of Agriculture and Fisheries

RESEARCH QUESTION: *What is the soil carbon benefit of using feedlot manure as compared to granular fertiliser within a dryland grain cropping system?*

Key findings

1. Averaged soil organic carbon (SOC) levels (across all treatments) increased within the five year period with the implementation of a higher production farming system.
2. There were no statistically significant differences in SOC between treatments.
3. The nil treatment was significantly different to all fertilised treatments in both grain yield and dry matter production.
4. In the first year, grain yield responded to the amount of nutrients rather than the source.
5. The choice between manure and granular fertiliser should be on price, convenience, or a preference for organic options.

Background

It has been thought by some grain growers that applying manure (used primarily as a phosphorus source) would boost soil organic matter (SOM) and soil organic carbon (SOC) levels. This trial aimed to determine the impact of applying manure versus conventional fertiliser on the soil surface and deep in the soil profile on soil organic matter, yield and profitability.

What was done

The current commercial treatment of 5 t/ha stockpiled feedlot manure spread on the soil surface was varied to compare the impact of incorporating the manure, using a higher rate of manure, and comparing manure applications with traditional fertilisers. An analysis determined that approximately 342 CK55S kg/ha provided equivalent nutrients as 5 t/ha of the feedlot manure.

Treatments were replicated three times:

- Nil fertiliser
- 5 t/ha manure (surface-applied)
- 5 t/ha manure (incorporated)
- 10 t/ha manure (surface-applied)
- fertiliser equivalent to 5 t/ha manure (with seed at sowing)
- fertiliser equivalent to 10 t/ha manure (with seed at sowing)
- fertiliser equivalent to 5 t/ha manure (deep placement at ~20 cm)

The trial paddock was recently purchased by the co-operator and had been cropped for over 80 years with no record of fertilisers. Hence the paddock had very low carbon and nutrient levels; and most likely low yields and dry matter production.

All manure and fertiliser treatments were applied as one-off applications early in 2013 and then again in 2016. Fertiliser rates were calculated following analysis of the manure at the site on a dry weight basis of 3.6 t/ha. The plots were all 1.6 km long and planted with commercial equipment to fit with normal farm practices. The following crops were fertilised (the whole trial receiving the same fertiliser rate as determined by the co-operator to maximise yield potential) and planted by the co-operator; sorghum in 2013, chickpea in 2014, sorghum in 2015, and chickpea in 2016.

Results

Adding nutrients via manure or granular fertiliser initially increased sorghum grain yields (P(0.05)) for all treatments, except the incorporated manure (5 t/ha). The only treatment that further increased yields above the existing commercial practice at the site (5 t/ha manure spread on the surface) was the deep placement of fertiliser (Figure 1). The ‘equivalent fertiliser’ applied at normal depth with the seed produced the same result as the manure, indicating that grain yield responded to the amount of nutrients and where they were placed, rather than the source. These treatment differences were similarly reflected in total dry matter measurements. It appeared that the dry season favoured this deep placement, which may have allowed the roots to access nutrients such as phosphorus while the soil surface was too dry for root activity.

Grain and biomass data for the following three crops showed the nil treatment to be significantly lower than all other treatments. The accumulated grain and dry matter production across the life of the project was similarly lower (P(0.05)) for the nil treatment (Figure 2).

Total organic carbon (TOC) levels under remnant vegetation on these brigalow soils in the Warra district are typically 3.0-3.5% for the 0-10 cm layer. However, the mean starting total organic carbon levels on this soil were low 0.78% for 0-10 cm and 0.65% for 10-30 cm. Low TOC levels are common where these soils have been cropped for 80-100 years. Despite a long cropping history, there had been no fertiliser applications on this site until the trial began.

The trial was resampled and analysed in 2017 after the two manure/fertiliser treatments were applied and the four crops grown and harvested. There were no statistically significant differences in changes in SOC or carbon stocks between the treatments over this time (Table 1). This was not surprising as there were no statistically significant differences between treatment yields or dry matter production except for the nil treatment. Differences in SOC are difficult to detect due to natural variability and the potential changes are very small over a five year time frame.

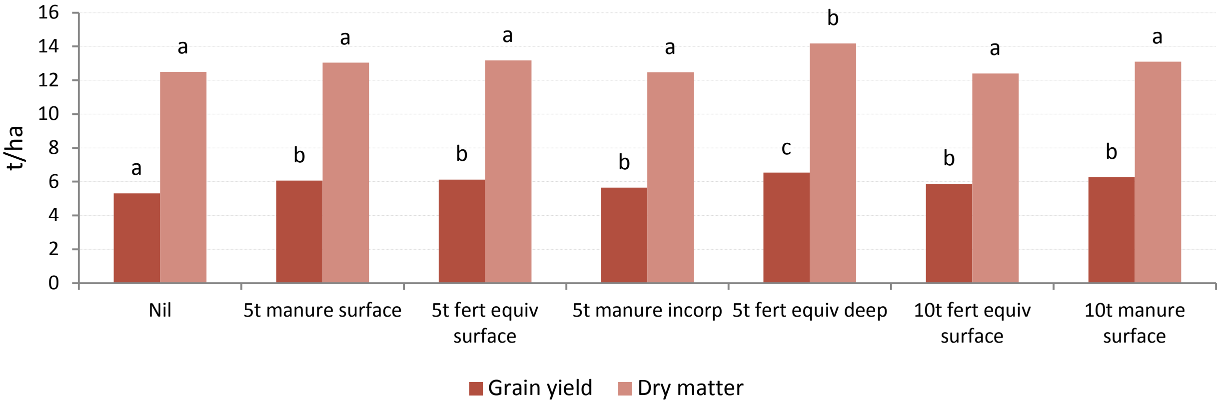


Figure 1. Sorghum 2013/14 grain yield and dry matter
Values with common letters are not significantly different; P(0.05)

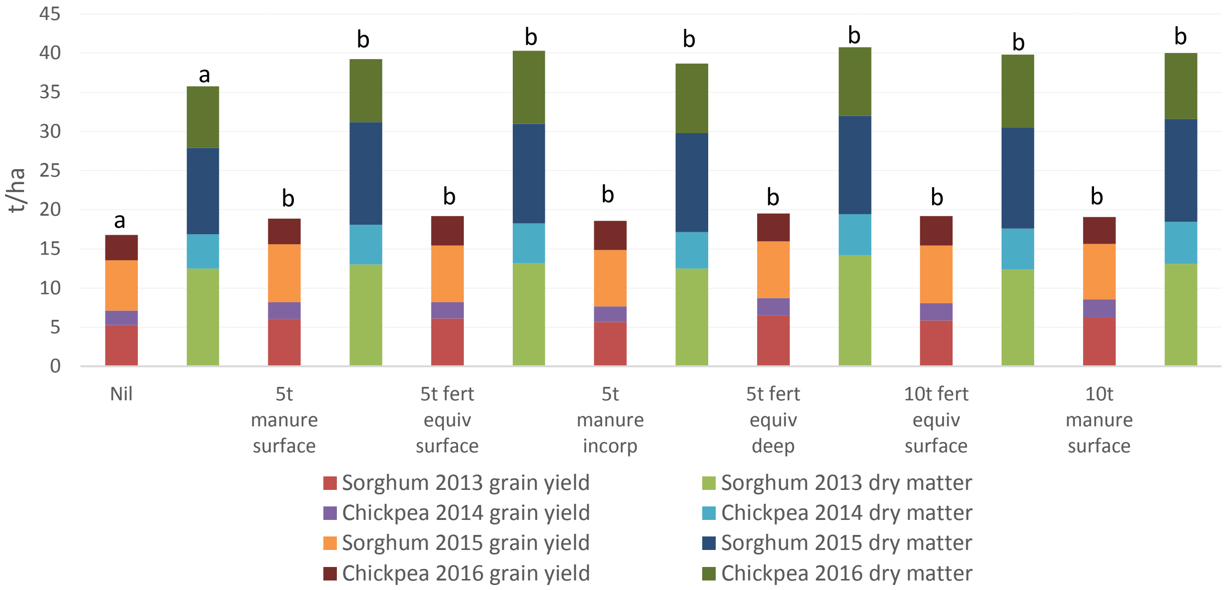


Figure 2. Cumulative grain yield and dry matter (2013, 2014, 2015, 2016)
Values with common letters are not significantly different; P(0.05)

Table 1: Soil organic carbon stock (t/ha) in 0-30 cm* at beginning (2012) and end of trial (2017)

		SOC (t/ha)	Standard error
Starting mean (2012)		*31.65*	*1.10*
2017	control	31.89	1.24
Manure	5t/ha (surface)	31.44	1.32
	10t/ha (surface)	34.40	1.63
	5t/ha (incorp)	33.35	2.01
Fertiliser	5t-eqv (surface)	30.89	3.08
	10t-eqv (surface)	35.05	2.76
	5t-eqv (deep)	32.33	0.98

***Bulk density (0-10 cm) =1.30; (10-30 cm) = 1.52**

However, soil organic carbon levels in the 0–10 cm layer across the trial increased by 0.11% (P(0.02)). Total carbon stocks to 30 cm also significantly increased by 1.16 t/ha, equating to a 5.4% rise (P(0.001)). This suggests that the new management of the paddock (with low starting SOC and nutrient status), successfully built SOC by maximising dry matter production and yield through good crop nutrition. The fractions of SOC were also tested, and as expected with increases in SOC in a four year time frame, there was a large proportion of particulate organic carbon in the final soil samples.

Many farmers consider manure to be a better option for 'organic matter' as they expect it to boost soil organic carbon directly. However, we saw no direct SOC benefit and our estimates of the nitrous oxide emissions (Figure 3) suggest that it may be less desirable than inorganic fertilisers that have lower emissions when applied appropriately. The nitrous oxide emissions for the two (2013 and 2016) manure and fertiliser treatments were calculated from the analysis of the manure sample and the use of standard emission factors from the Australian National Greenhouse Accounts National Inventory Report 2012 (manure spread on non-irrigated crops emission factor of 0.01 and fertiliser on non-irrigated crops emission factor of 0.003).

Considering that there have now been two applications of these treatments over the life of the trial, the manure treatments have produced four-fold greater CO_2-e emissions than the synthetic fertiliser treatments.

Implications for growers

As expected from the minimal dry matter responses, none of the treatments had a significant effect on soil organic carbon. While 5-10 t/ha of feedlot manure applied every three years is not a large amount of additional dry matter, local growers remain very interested in the long-term impacts on crop performance and soil carbon. Growers need to know if manure applications at these commercial rates have little or no direct impact on soil organic carbon, as it will assist them to make more informed decisions on the most appropriate method of

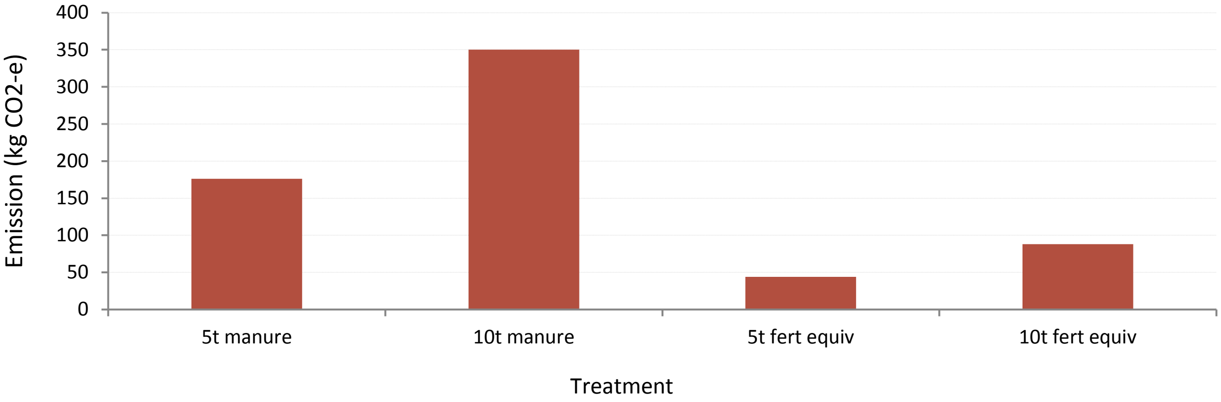


Figure 3. Calculated nitrous oxide emissions

Harvesting sorghum in the soil organic matter trial

applying the nutrients that their crops need. While many farmers currently consider manure to be a better option for ‘organic matter’ as they expect it to boost soil organic carbon directly, our estimates suggest that it may be less desirable than inorganic fertilisers that have lower nitrous oxide emissions when applied appropriately.

The SOC levels of a low input cropping system (with no fertiliser inputs) indicated a potential drop of 2% from initial levels when cropping began on this soil (80+ years). This past cropping system had ‘mined’ the nutrients from the SOM over the years. However, this trial has indicated that changing to a high input system (maximising production through stubble retention and providing adequate crop nutrition) has increased SOC levels over a five year time frame. This supports the message that good agronomy will maintain or increase SOC levels.

Acknowledgements

The team would like to thank the co-operators for hosting this trial and the Department of Agriculture and Fisheries and the Grains Research and Development Corporation for investing in this project (DAQ00182).

Trial details

Location:	Warra, Queensland
Crop:	Sorghum (2013), chickpea (2014)
Soil type:	Black Vertosol
Fertiliser:	as per treatment list

Increasing soil organic matter: establishing productive pasture on long-term cropping country—Brigalow

Jayne Gentry and David Lawrence
Department of Agriculture and Fisheries

RESEARCH QUESTION: *What is the soil carbon benefit of establishing a productive pasture on long-term cropping country comparing grass only, grass plus legume, and grass plus nitrogen?*

Key findings

1. There was a large increase in dry matter with the addition of 100 N kg/ha each year to grass.
2. Soil organic carbon increased in the 0–10 cm layer in the grass + 100 kg N/ha.

Background

The establishment of a productive sown grass pasture phase is the most promising practice available to mixed farmers looking to improve their soil organic carbon (SOC) levels on degraded cropping land. However, these pastures must be well grown with good nutrient supplies to make a major contribution. Nitrogen is required in most old cropping soils that have low levels of available nitrogen due to their declining soil carbon levels. This nitrogen can be supplied to the system by the inclusion of a legume in the pasture mix or by the addition of nitrogen fertiliser. This trial compared the effectiveness of three different approaches on increasing pasture production and ultimately soil carbon.

SOC benefits will be greatest where pastures are established quickly and produce large quantities of dry matter. However, pasture establishment is often unsatisfactory and the increased time out of production waiting for a good pasture to graze is costly. The best method to rapidly establish a productive pasture is to ‘plant it like a crop’; that is plant into soil moisture into a paddock where weeds have been controlled effectively.

What was done

The treatments were:

- Short-term grass only (Bambatsi panic)
- Short-term grass-legume (Bambatsi panic and Burgundy bean)
- Short-term grass only (Bambatsi panic) plus 100 kg N/ha/yr

The pastures were planted with research equipment into replicated plots approximately 15 m x 6 m in February 2013. Unfortunately the trial was flooded a few weeks later, however it was replanted in November 2013. Urea fertiliser was surface applied to the relevant plots at 100 kg N /ha, typically in September/October each year. All pasture plots were slashed to mimic livestock grazing.

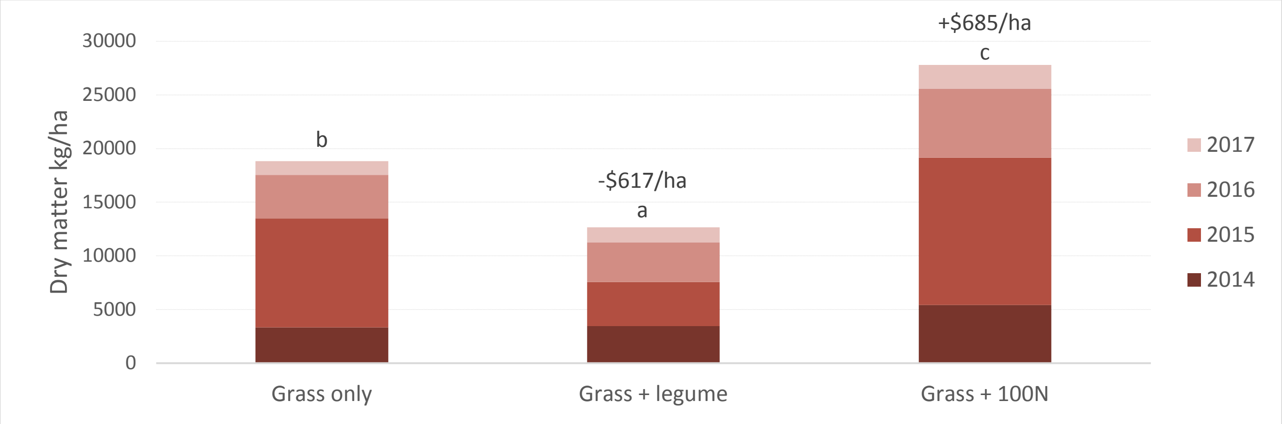


Figure 1. Dry matter production
Values with common letters are not significantly different; P(0.05)

Table 1. Change in carbon stock

Treatment	SOC (0-10 cm)			SOC (10-30 cm)			Carbon stocks 0-30 cm (t/ha)		
	Start (2014)	Finish (2017)	% change	Start (2014)	Finish (2017)	% change	Start (2014)	Finish (2017)	% change
Grass	0.84 a	0.95	13 a	0.58	0.67	16 a	29.1	33.1	14 a
Grass + legume	0.84 a	0.98	17 a	0.58	0.79	36 a	28.9	37.6	30 a
Grass + 100 N	0.74 b	1.00	35 b	0.57	0.73	28 a	27.4	36.0	31 a

Bulk Density (0-10 cm) = 1.28; bulk density (10-30 cm) = 1.59); values with common letters are not significantly different; P(0.05)

Results

Total dry matter production over the life of the trial was significantly higher (P(0.001)) in the pure grass + 100N compared to the mixed grass/legume pastures and the grass only treatments (Figure 1). It is interesting to note the potential dry matter production in a good season when adequate nitrogen was available to maximise growth; almost 14 t/ha of dry matter was produced in 2015 year under the grass + 100 kg N/ha treatment.

The total dry matter production after four years was 15 t/ha higher in the grass + 100N compared to the mixed grass/legume pastures and 9 t/ha higher than the grass only treatment. This was expected as the legume did not have sufficient time to begin to provide a nitrogen benefit to the grass hence producing less dry matter. In the longer term, the grass/legume mix should provide higher production with a self-replacing source of nitrogen, but not higher than the grass + 100N. It is calculated that over the duration of the four year trial the grass + 100 kg N/ha/yr treatment had the potential to generate an additional $685/ha in profit as compared to the grass only treatment. In comparison the grass-legume treatment was $617/ha behind the grass only treatment due to the lower biomass[1].

The starting total organic carbon levels averaged across the trial (0.82% for 0–10 cm; 0.58% for 10-30 cm) were low but typical for a paddock in the area that had been cropped for 100 years. It should be noted that the starting levels for the grass + 100 kg N/ha treatment were significantly lower than the other two treatments (Table 1), as SOC can naturally be highly variable. Under remnant vegetation they would be expected to be 3.0-3.5% in the 0-10 cm layer of the soil.

Differences in SOC are difficult to detect due to natural variability (especially under pasture) and potential changes are very small over a five year time frame, however the SOC significantly increased in the 0–10 cm layer in the grass + 100 kg N/ha treatment (Table 1). Although not statistically significant, a trend was seen in the total carbon stocks for the grass + legume and the grass + 100 kg N/ha treatments after four years. The fractions of SOC were also tested, and as expected in a four year time frame there was a large proportion of particulate organic carbon in the final soil samples.

Implications for growers

Well grown pasture phases will slow the decline, and/or increase total organic carbon in the soil. However, there is strong evidence that pastures must be productive with good nutrient supplies to make a major contribution. Consequently, a source of nitrogen (legumes, fertilisers, manures) will be needed in most old cropping soils that have low levels of available nitrogen due to their declining soil carbon levels. The fastest way to build carbon is under a grass only system with annual applications of nitrogen, as legumes are slower to establish and produce less biomass in the same time period. This work suggests that impacts will take several growing seasons (three in this case) to show increases in SOC.

Acknowledgements

The team would like to thank the co-operators for hosting this trial and the Department of Agriculture and Fisheries and the Grains Research and Development Corporation for investing in this project (DAQ00182).

Trial details

Location:	Brigalow, Queensland
Crop:	Bambatsi panic, bambatsi panic + burgundy bean
Soil type:	Black Vertosol
Fertiliser:	as per treatment list

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[1] Calculated using 12:1 Food Conversion Efficiency (FCE), a live weight beef price of $3/kg, and assuming 40% of additional dry matter is consumed it is possible to estimate the economic benefit of these treatments, with urea at $400/t.

Farming systems research

The Regional Agronomy team continues to conduct an extensive field-based farming systems research program in collaboration with CSIRO and the New South Wales Department of Primary Industries (DPI NSW). This program is focused on developing farming systems to better use the available rainfall to increase productivity and profitability.

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 team is undertaking research 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.

In 2015 research began with local growers and agronomists 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 the Commonwealth Scientific and Industrial Research Organisation (CSIRO) at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres by Department of Agriculture and Fisheries (DAF) and the DPI NSW. 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 location in Queensland, how they are implemented locally and the results after the first three crops at each site. Data and system performance indicators have been developed to compare performance across sites. For example, the Relative Water Use Efficiency in terms of 'Return ($) per millimetre of rainfall' can be compared to that of a typical (Baseline) system at each site (Figure 1). It should be noted that the initial data provide an insight into the comparisons that can be made but are based on just three crops and are heavily influenced by recent seasonal effects. More data will be presented in next year's publication.

2. Can cover crops increase the net water accumulation in grain and cotton systems with low ground cover (<30%) in the northern region?

This new research by the same collaborating agencies has investment from both the Grains Research and Development Corporation (GRDC) and the Cotton Research and Development Corporation (CRDC). It will assess opportunities to make greater use of the available rainfall and maintain more sustainable systems. This early report contains initial results from one site only (with no statistics), but the work will continue for the next three years.

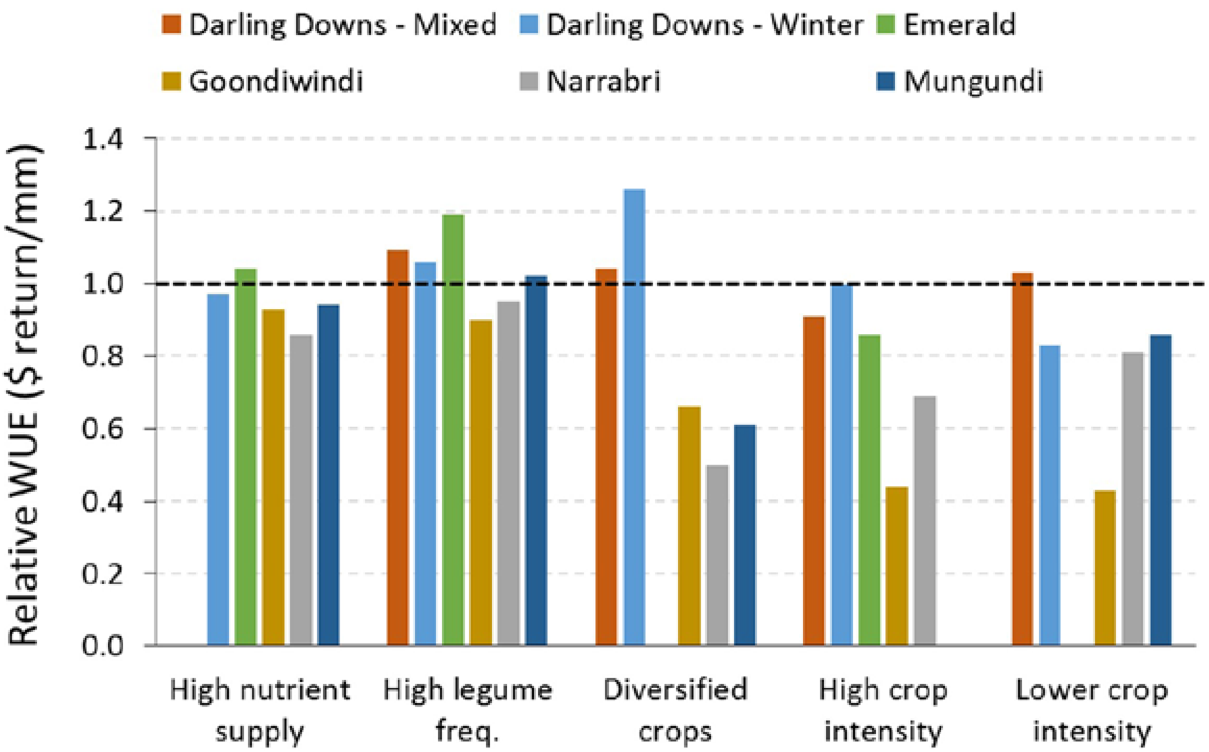

Figure 1. A comparison of systems performance at selected farming systems trial sites; the relative water use efficiency (WUE) in terms of return ($) per millimetres of rainfall is compared to the typical baseline farming systems used at each of the five site (Emerald, Goondiwindi, Mungindi and Narrabri)

Farming systems research assessing the impact of cover crops on fallow soil water storage in grain and cotton systems

Northern Farming Systems—Emerald regional site

Darren Aisthorpe and Ellie McCosker
Department of Agriculture and Fisheries

RESEARCH QUESTION: *What long-term impacts on systems performance (e.g. productivity, profitability and soil health) can be observed when strategically different 'farming systems' are applied to one geographic location over a 5-10 year period?*

Key findings

1. The most profitable and highest yielding treatment in 2017 was the *Higher soil fertility* system planted to wheat.
2. The most profitable rotation thus far is wheat/chickpea/wheat which was planted in the *Higher legume* system.
3. Chickpeas, on average over the past three years, have more efficiently used plant available water compared to wheat.

Background

Early in 2015, the project identified six locally relevant farming systems that were consistent with those being studied by the Northern Farming Systems Initiative. A range of agronomic practices (i.e. row spacing, plant population, crop types and rotations, crop frequency, planting time/windows, tillage practices, fertiliser rates and planting moisture triggers) were adopted and strategically used to develop the following treatments:

1. **Baseline**. A commonly used conservative zero tillage system. It has approximately 1 crop/year, with fertiliser applied to match 50 percentile yield expectation for the Plant Available Water (PAW) at planting. Crops include: wheat, chickpea and sorghum.
2. **Higher legume**. An increased frequency of pulses (i.e. 1 pulse every 2 years) to assess the impact of more legumes on profitability, soil fertility, disease and weeds. Crops include wheat, chickpea (but not chickpea on chickpea), sorghum, mungbean and new legume crops.
3. **Higher crop intensity**. Focused on increasing the cropping intensity to 1.5 crops/year. Questions whether a higher risk strategy that plants into lower plant available water is more sustainable in the long-term from both from an agronomic and economic point of view. Crops include: wheat, chickpea, sorghum, mungbean and forage crops/legumes.
4. **Higher nutrient supply**. Applies fertilisers to support 90% of the potential yield based on soil moisture (PAW) at planting. Examines the economic and agronomic implications of increased nitrogen and phosphorus rates that target higher yields and protein levels in a variable climate. The crops and other practices are the same as the *Baseline* system.
5. **Higher soil fertility**. A repeat of the *Higher nutrient supply* system but with the addition of 20 t/ha of manure in the first year and 40 t/ha in 2016. Designed to see if higher initial soil fertility can be maintained with greater nutrient inputs (targeting 90% of yield potential based on soil moisture (PAW)).
6. **Integrated weed management (IWM)**. A minimum tillage system focused on one crop/year but employing a wide range of practices to reduce the reliance on traditional knockdown herbicides in Central Queensland (CQ) farming systems. Practices include tillage with full disturbance planting, contact and residual herbicides, and other cultural practices such as high plant population, narrow rows, crop choice and other emerging technologies. Crops include wheat, chickpea, sorghum and mungbean.

Table 1. Crop rotations used for all treatments since 2015 to summer 2018

	1. Baseline	2. Higher crop intensity	3. Higher legume	4. Higher nutrient	5. Higher oil fertility	6. Integrated weed management
Winter 2015	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Chickpea Kyabra⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶
Summer 2015-16		Mungbean Jade-AU⦶				
Winter 2016	Chickpea Kyabra⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Chickpea Kyabra⦶	Chickpea Kyabra⦶	Chickpea Kyabra⦶
Summer 2016-17						
Winter 2017	Wheat Sunguard⦶	Wheat Sunguard⦶	Chickpea PBA Seamer⦶	Wheat Sunguard⦶	Wheat Sunguard⦶	Wheat Sunguard⦶
Summer 2017-18	Sorghum MR-Buster	Sorghum MR-Buster	Sorghum MR-Buster	Sorghum MR-Buster	Sorghum MR-Buster	Sorghum MR-Buster

What was done

There were no treatments planted in the 2016/17 summer rotation due to insufficient PAW during the summer planting windows (Table 1). In March, the site received 165 mm in several useful rainfall events, capped off with 45 mm from cyclone Debbie at the end of the month. This rainfall set up the site for a full winter program to be planted across all six treatments.

2017 winter crop

The moisture trigger was achieved by the end of March. However planting moisture was starting to slip away as we waited for the window to open. Not wanting to deep plant like 2016, the longer season Sunguard⦶ wheat was planted relatively early across all systems (except *Higher legume*), on 13 April. The IWM system was planted on a 25 cm spacing, the remaining systems were planted on a 50 cm spacing. PBA Seamer⦶ chickpea was planted on a 50 cm spacing in the *Higher legume* system on 16 May following 15 mm rainfall during the week prior.

Both crops flowered in early-mid July, and reached physiological maturity in late August. Negligible rainfall fell during the growing season, with a total of 61 mm and 40 mm in-crop rainfall on the wheat and chickpea, respectively. Crops were harvested in early September.

2018 summer crop

The site received 363 mm of rainfall between the 2017 winter crop harvest and the planting of sorghum in all treatments on 23 January. Treatments were planted with MR-Buster using a precision planter. The *IWM* system was planted on a 50 cm spacing; all other systems were planted on 1 m spacing.

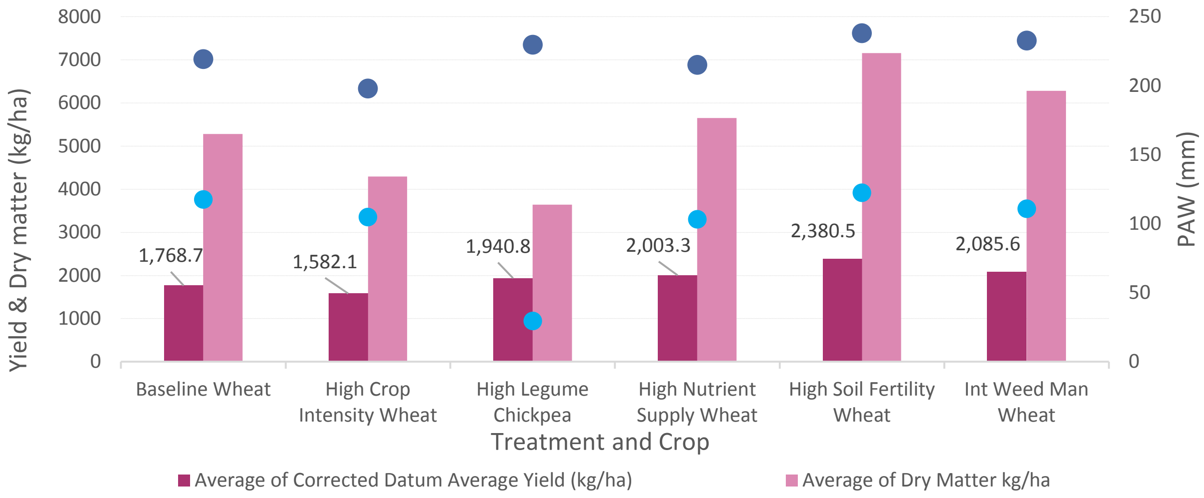

Figure 1. Analysis of grain & biomass production across all six treatments for winter crop 2017; starting and ending PAW figures are also represented by the dots

Results

There were negative implications of the manure application completed on 7 November 2016 to the *Higher soil fertility* system. A weed assessment in January 2017 indicated that the *Higher soil fertility* system plots had a higher occurrence of weeds, specifically feathertop Rhodes grass (FTR). This weed seed was likely deposited with the manure. Following the weed assessment, the trial site was sprayed with Verdict® + Glyphosate + Uptake® on 21 January 2017, and a Sprayseed® double knock on 28 January 2017.

The trial site was later inspected for weed pressure on 24 March 2017 following rainfall and with cyclone Debbie approaching. Light general scattering of weeds across all treatments were observed, generally annual broadleaf weeds such as black pigweed, Boggabri, wild gooseberry and green amaranth. No FTR was observed. However, as the season progressed, mature FTR plants were noticed.

Yield x dry matter x planting/harvest moisture

Despite reasonable planting moisture, 2017 was another very dry winter with only 60 mm of rain received in-crop for the wheat and 40 mm for the chickpea. Yields averaged 1.95 t/ha for both the wheat and chickpea treatments. Biomass and grain yield production did vary between treatments (Figure 1) with the *Higher fertility* system again out-yielding the other treatments. Grain qualities across all treatments this year were very good, despite the hard season, with wheat proteins averaging 13.1%. Screenings were all within receival standards, with the *Higher intensity* treatment achieving the highest screenings with an average of 3.4%.

Post-harvest water cores were taken to measure ending PAW levels. This number was generally consistent across all treatments except the *Higher legume* treatment. While all wheat treatments generally ended the season with approximately 100 mm of PAW down to 150 cm, the *Higher legume* treatment only had 30 mm of water down to 150 cm, which is consistent with previous years where similar observations were made.

Project life analysis

Now into the fourth year of the project, we are able to make some observations as to how each of the systems are travelling. Total biomass and grain produced for each treatment are displayed in Figure 2. The *Higher legume* treatment stands out for having produced the greatest amount of grain of all the treatments on average, despite having produced the least amount of biomass.

As can be seen in Table 1, the *Higher legume* system rotation has been chickpea, wheat and chickpea, over the past three years, where four of the others have been wheat, chickpea, wheat. *Higher intensity* had an additional light crop of mungbean in 2016, however it is still the second lowest in average grain yield.

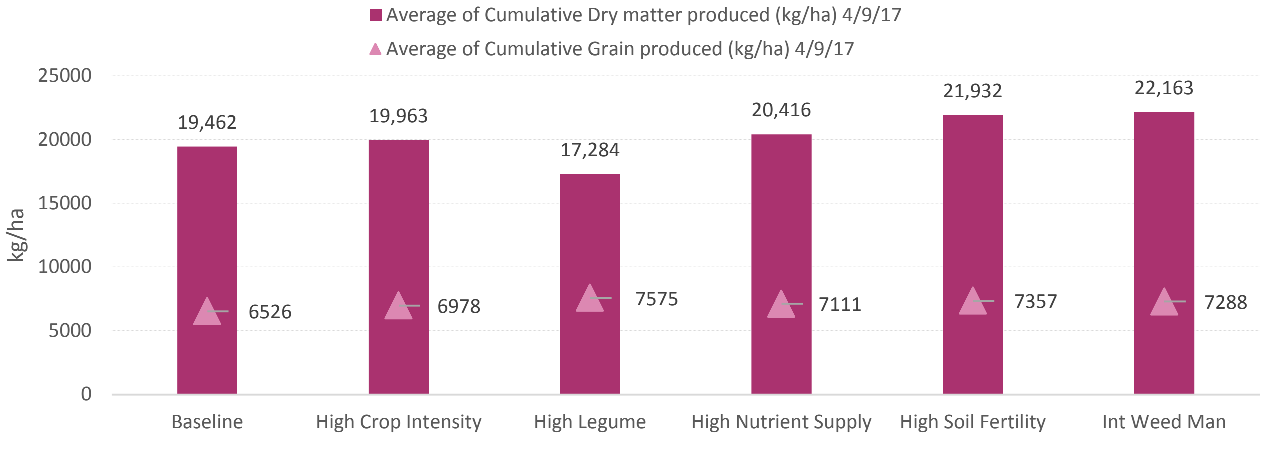

Figure 2. Cumulative biomass and grain yield production since 2015 for all six treatments; bars indicate gross biomass production per hectare, triangles indicate total grain production per hectare

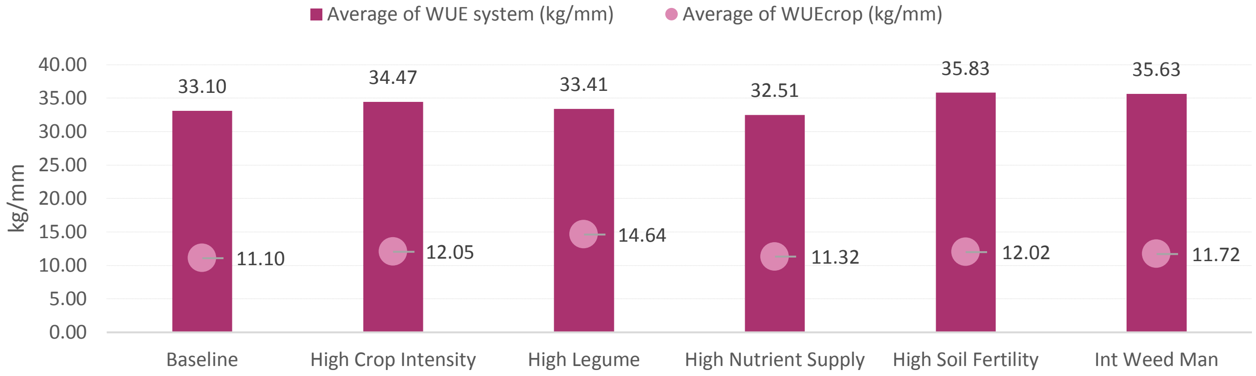

Figure 3. Cumulative water use efficiency (WUE) for biomass and grain production since the start of the trial in 2015; bars indicate gross biomass production per ha WUE, dots indicate gross grain production per ha WUE

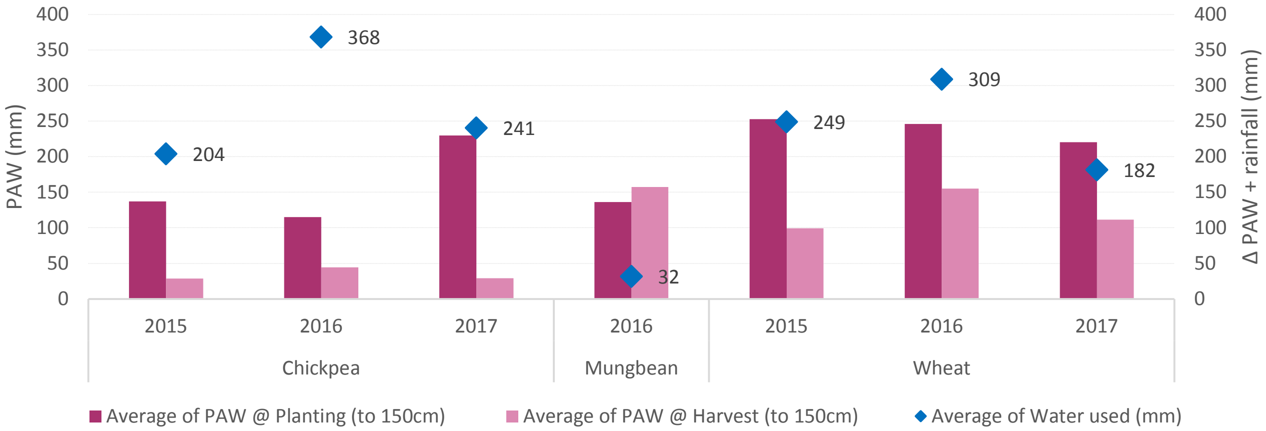

Figure 4. Comparison of Starting PAW, Finishing PAW and water used (△PAW + in crop rainfall) for all crops planted since 2015 within the Emerald Northern Farming Systems trial

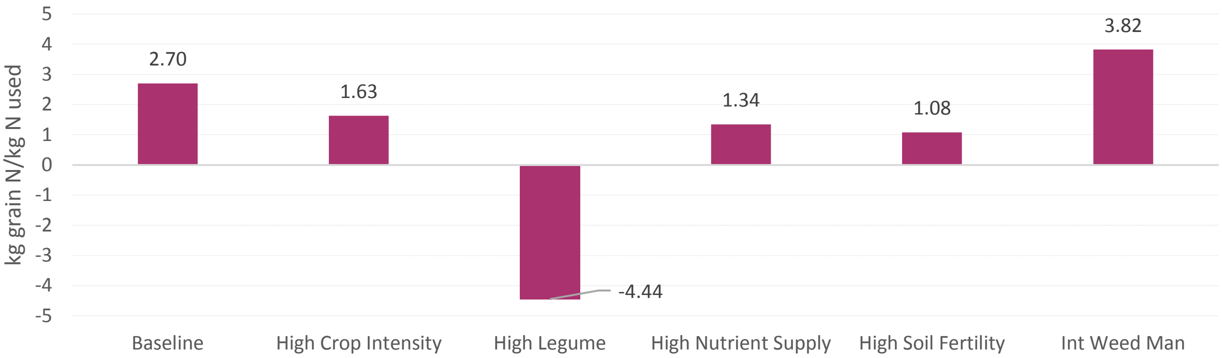

Figure 5. Cumulative nitrogen use efficiency calculated for all treatments with the Northern Farming Systems trial since 2015

Numbers above 1 indicate more N being taken away than is being added, numbers below 1 indicate net N has been added since the trial started

When water use efficiency (WUE) is compared across the treatments, again the *Higher legume* system comes out on top for grain yield at 14.46 mm/kg (Figure 3). For WUE relative to biomass produced, the *Higher soil fertility* system just managed to edge out the *IWM* treatment, despite the difference in row spacing (50 cm versus 25 cm).

Crop water use varies from year to year and crop to crop, depending on the amount of water available and seasonal conditions. In Figure 4, on average chickpea has made better use of available water over the past three years it has been grown, particularly when you consider the amount of PAW post maturity. It must be noted that the mungbean crop grew in very hot dry conditions. Despite having excellent starting water, the mungbeans were not able to successfully use the water available, yielding an average of 0.8 t/ha and more PAW than at planting.

The system nitrogen use efficiency (NUE) assesses how well balanced each of the treatments are with respect to nitrogen use. The equation;

NUE = (Total N removed by grain)/(Difference between trial starting and finishing N + N applied during the life of the trial)

should, if truly in balance, give a result of 1. Higher than 1 and we are removing more N than we are applying; lower than 1 and the treatment is actually increasing the amount of N available since the start of the trial. Unsurprisingly, the *Higher legume* system with two chickpea crops and no N applied since the start of the trial, is increasing its N levels. All other treatments are reducing N levels. It is also interesting to note that the *IWM* treatment is drawing N down faster than all other treatments (Figure 5).

2015-2017 economic—yield and gross margins

While yield is important, marketing options and cost structures also play a pivotal role in growers' bottom line (Figure 6). The *Higher legume* system with its two chickpea crops has the highest gross margin as of the end of 2017. Not only were there two reasonable chickpea yields to its advantage, but also the 3.8 t/ha wheat yield in 2016 that pushed it up above the other treatments. It is also important to observe what occurred in the *Higher crop intensity* system. The one poor mungbean crop, although profitable at 0.8 t/ha, cost the treatment down the track with a very late planted wheat crop. Again, the late wheat was profitable at 2.8 t/ha, but less so than the 3 t plus of chickpea or the 3.8 t/ha wheat planted one month earlier.

Implications for growers

The six systems are now starting to drift apart as the rotation, nutrition and management variance between them take hold. The *Baseline* system has slipped behind all systems on most indices, showing a conservative 'steady as she goes' approach may not be ideal for CQ. The *Higher legume* system has benefited significantly not only from the two chickpea crops, but also the rotational benefits of the wheat crop in between.

IWM seems to be the system with the highest nutritional demand as a direct result of the higher target plant populations and improved establishment due to the narrower row spacing.

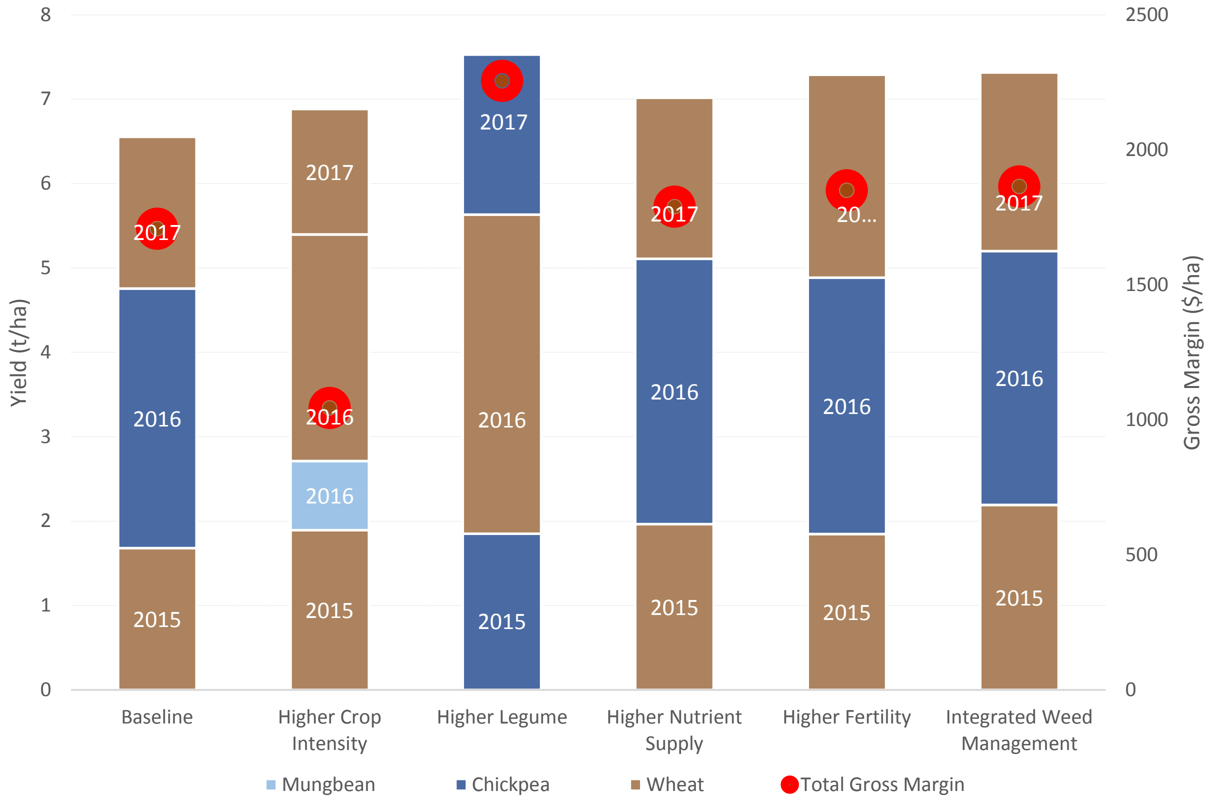

Figure 6. Cumulative grain yields and total gross margins (including fallow costs) of crops and systems at the Emerald site to the end of the 2017 winter system

Yield response has been good to date as a result of the improved populations. Weed densities have been low, however this has been similar for most systems. Summer grass species were always the primary target of this system, so it will be interesting to see how weed populations vary from this system after one or two summer cereal crops are incorporated into the rotation. However, given an opportunity for the trial to run for a longer period, it would be safe to assume that the 50th percentile nutrition program may start to really hurt the system.

Finally, the benefits of the application of 60 t/ha of feedlot manure to the *Higher fertility* system is really starting to show. Despite the weed issues related to the manure source, both biomass and yield increases are evident, and as the trial progresses further it will be interesting to see just how long we can maintain the benefits of a high starting fertility using a 90th percentile nutrition program.

Acknowledgements

We would like to thank the local growers and consultants that have supported and contributed to the project. The Farming Systems Initiative (DAQ00192) is funded by 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.

2017 winter crop, trial close to harvest for both wheat and chickpea

Trial details

Location: Queensland Agricultural Training College - Emerald

Soil type: Cracking, self-mulching, Grey Vertosol, >1.5 m deep, estimated plant water holding capacity of approx. 240 mm

In-crop rainfall: Wheat: 61 mm
Chickpea: 40 mm

Fertiliser: Wheat: 48-76 kg/ha urea and 33-48 kg/ha Granulock Z®
Chickpea: 29 kg/ha Granulock Z®

Treatment summary for 2017 winter rotation:

Treatment	Baseline	Higher crop intensity	Higher legume	Higher nutrient	Higher soil fertility	Integrated weed management
Crop	Wheat Sunguard$^{\phi}$	Wheat Sunguard$^{\phi}$	Chickpea Seamer$^{\phi}$	Wheat Sunguard$^{\phi}$	Wheat Sunguard$^{\phi}$	Wheat Sunguard$^{\phi}$
Row spacing	50 cm	50 cm	50 cm	50 cm	50 cm	25 cm
In-crop rainfall	60.7 mm	60.7 mm	40.2 mm	60.7 mm	60.7 mm	60.7 mm
Irrigation (early post emergent)	15 mm	15 mm	nil	15 mm	15 mm	15 mm
Total nutrition applied (with seed)						
Urea	48 kg/ha	48 kg/ha	nil	76 kg/ha	76 kg/ha	48 kg/ha
Garnulock Z® with seed	33 kg/ha	33 kg/ha	29 kg/ha	48 kg/ha	48 kg/ha	33 kg/ha
Manure	nil	nil	nil	nil	nil	nil

Northern Farming Systems—Billa Billa regional site

Andrew Erbacher
Department of Agriculture and Fisheries

RESEARCH QUESTIONS: *Can systems performance be improved by modifying farming systems in the northern grains region? | In Goondiwindi: (i) What are the trends that are expected in our farming systems? and (ii) How will these changes impact on the performance and status of our farming systems?*

Key findings

1. Both summer and winter crops were low yielding in 2017.
2. Increasing and decreasing crop intensity have returned similar system gross margins.
3. Residual herbicides have influenced crop selection.

Background

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

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

Treatments

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

1. **Baseline**. Typical of local zero tillage farming system with ~1 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 to achieve average seasonal yield potential for the PAW prior to planting.
2. **Lower crop intensity**. Reflects a widely used conservative 'set rotation' with a cropping frequency of 4 crops in 5 years (0.8/year). The system is wheat/barley, chickpea, wheat/barley, long fallow, sorghum, long fallow (repeated back into wheat/barley) with the same minimum PAW triggers for planting and nutrient management as the *Baseline* system.
3. **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 each crop (ranging from 90 to 120 mm) have been identified to manage individual crop risk and target 1.0 crop per year. Crops are fertilised to achieve the average seasonal yield potential[#]. Crops grown in this system include wheat/barley, chickpea, sorghum, mungbean, maize, faba bean, field pea, canola/mustard and millet.
4. **Higher legume**. Aims to minimise the use of nitrogen fertiliser by growing every second crop as a pulse (legume), with a preference for those that produce greater biomass and greater carry-over nitrogen benefits. Crops are similar to the *Baseline* system (wheat/barley, chickpea, sorghum) with additional pulse options (faba bean, field pea and mungbean). Moderate planting triggers of 90 to 120 mm PAW are applied. Crops are fertilised to achieve average yield potential, with nitrogen only applied to cereal crops.
5. **Higher crop intensity**. Minimises the fallow periods to potentially grow three crops every two years. Crops are planted on lower PAW (50 mm for winter and 70 mm for summer) and have greater reliance on

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[#] The unique rules for the *Higher crop diversity* system include: 50% of the selected crops to be resistant to *Pratylenchus thornei*; 1 in 4 crops resistant to *Pratlenchus neglectus;* and two crops of the same herbicide mode-of-action cannot follow each other.

in-crop rainfall. Crop choice is the same as the *Baseline* system, but with mungbean added as a short double-crop option.

6. **Higher nutrient supply**. Fertiliser is applied to allow crops to achieve 90% of the maximum seasonal yield potential (with the risk that crops will be over-fertilised in some years). This system is planted to the same crop as the *Baseline* each year; the only difference is the amount of nutrient applied.
7. **Higher fertility**. Treated the same as the *Higher nutrient supply* system, but with an upfront addition of organic carbon (compost) at the start of the experiment to raise inherent site fertility and see if this fertility level can be sustained with the higher nutrient inputs.
8. **Grass ley pasture**. Uses a perennial Bambatsi grass pasture to increase the soil carbon levels naturally. After 3-5 years, the pasture will be removed and the *Baseline* cropping system applied 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 to boost dry matter production that is nearly always constrained by nitrogen deficiency in grass-based pastures.

Results

After the wet spring in 2016, both the *Lower crop intensity* and *Higher crop intensity* were planted to sorghum on 12 October 2016 (Table 1). An aggressive approach was taken in the *Higher crop intensity* system and it was planted on 1 m solid rows. The *Lower crop intensity* system maintained a more conservative single skip configuration. These systems were desiccated on 16 January and harvested on 1 February 2017 for 0.7 t/ha in the higher and 1.5 t/ha in the lower intensity system. While both systems allowed a push probe to be inserted full depth (1 m), gravimetric soil sampling showed the *Lower crop intensity* system had an extra 100 mm of PAW to 150 cm at planting. With hot conditions through flowering and grain fill and low in-crop rainfall, this difference in starting water accounts for 90% of the yield difference between these systems, with sorghum Water Use Efficiencies (WUE) of 4.7 kg/mm in the lower and 4.2 kg/mm in the higher intensity system.

The *Higher crop diversity* and *Higher legume* systems had field pea and faba beans harvested with 140 mm PAW in mid-October. These systems were kept fallow in spring to control weeds that established in-crop, then planted on 13 December 2016.

The *Higher crop diversity* system was planted to sorghum, but the *Higher legume* system had Spinnaker® applied to the faba beans, so was planted to mungbeans to avoid potential

Table 1. Crops grown at the Billa Billa farming systems site

		1. Baseline	2. Lower crop intensity	3. Higher crop diversity	4. Higher legume	5. Higher crop intensity	6. Higher nutrient supply	7. Higher fertility	8. Grass pasture	9. Grass pasture - fertilised
2015	Winter	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶	Wheat EGA Gregory⦶
	Spring								Bambatsi	Bambatsi
2016	Summer					Mungbean Crystal⦶			Bambatsi	Bambatsi 50 kg N/ha
	Winter	Barley Comapss⦶		Field pea PBA Wharton⦶	Faba bean PBA Nasma⦶		Barley Comapss^{P}	Barley Comapss^{P}	Bambatsi	Bambatsi
	Spring		Sorghum MR-Bazley			Sorghum MR-Bazley			Bambatsi	Bambatsi 50 kg N/ha
2017	Summer			Sorghum MR-Bazley	Mungbean Jade-AU⦶				Bambatsi	Bambatsi 50 kg N/ha
	Winter	Wheat LongReach Lancer⦶				Wheat LongReach Lancer⦶	Wheat LongReach Lancer⦶	Wheat LongReach Lancer⦶	Bambatsi	Bambatsi
	Spring				Sorghum MR-Taurus				Bambatsi	Bambatsi 50 kg N/ha
2018	Summer					Sorghum MR-Taurus			Bambatsi	Bambatsi 50 kg N/ha

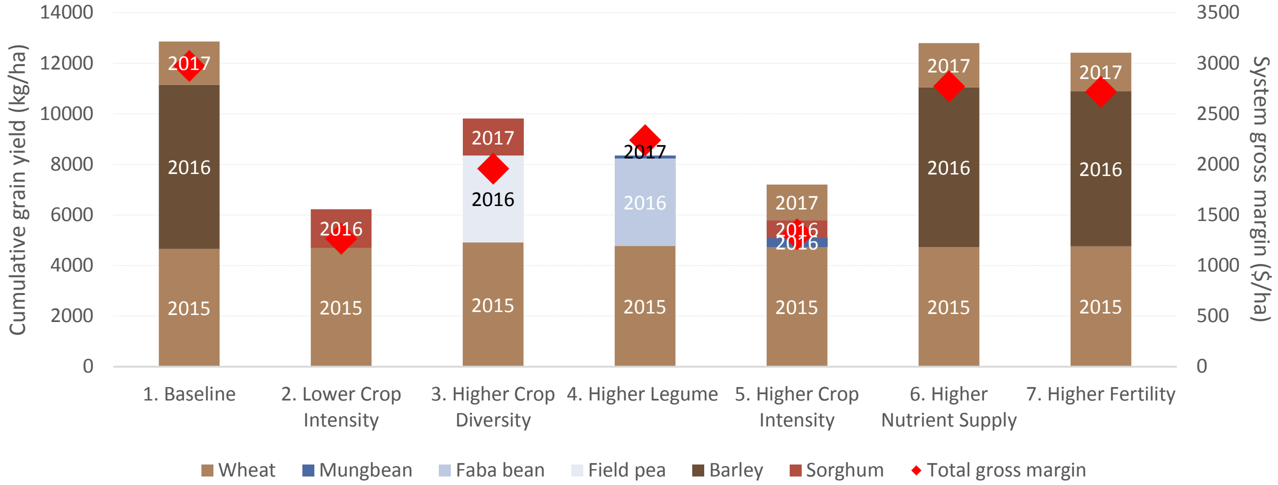

Figure 1. Cumulative grain yields and total system gross margins at the Billa Billa site to the end of 2017

crop damage from carry-over herbicide. The continued hot dry conditions during summer resulted in very poor initial crops. Rain in late February put a second flush of flowers on the mungbeans, increasing the final yield to 0.15 t/ha. The initial outlook for the sorghum was similar to the mungbeans, but good rain in late February and again in late March allowed the crop to put out late tillers which bolstered the yield to 2 t/ha at harvest in July (Figure 1, Figure 2). The downside of allowing the sorghum to take advantage of the late rain was that sowthistle established late in the crop. These thistles were able to set seed before sorghum desiccation and harvest when the weeds could be controlled.

The *Baseline*, *Higher nutrient supply* and *Higher fertility* were planted to LongReach Lancer⦻ wheat on 16 May with 150 mm PAW. With high initial levels of available nitrogen, this was the first time nitrogen fertiliser was required in the *Higher nutrient supply* system. The fertiliser was applied at planting and was offset 10 cm from the 25 cm spaced plant rows. The *Higher crop intensity* system was also planted to wheat on this date with a PAW of 90 mm. The *Baseline* yielded 1.6 t/ha with 17.2% grain protein.

Yield in the *Higher nutrient* and *Higher fertility* systems were similar to the *Baseline* system, and the double cropped wheat in *Higher intensity* yielded slightly lower at 1.3 t/ha. All four systems had similar WUE of 12.5 kg/mm (12.95

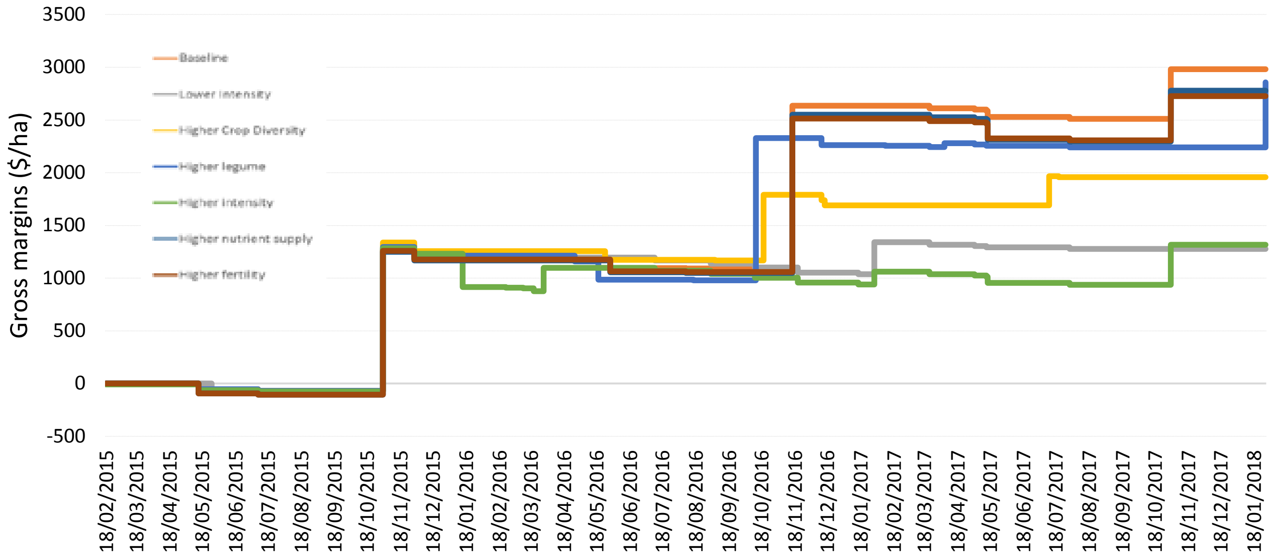

Figure 2. Cumulative cash flow for each of the systems at the Billa Billa site

to 11.3 kg/mm). Predicta B results indicate an increase in pathogens that cause crown rot in the three systems that grew their third consecutive cereal in 2017, however measured levels were still low risk. The use of summer crops in the *Higher intensity* resulted in an absence of visible cereal stubble and kept these pathogens below detection levels.

Similar to 2016, the Bambatsi grass pastures were harvested twice in 2017 to simulate grazing, using a forage harvester to remove the top 70% by height, which is approximately 30% by weight. The first harvest was on 4 May 2017, where the extra nitrogen applied produced an extra 450 kg DM/ha (9050 kg/ha versus 8600 kg/ha), with 300 kg DM/ha difference in the harvested portion (2300 kg/ha vs 2000 kg/ha). There was also an extra 0.5% protein measured in the pasture with added nitrogen (12.5% vs 12.0%). The second harvest was 20 December 2017. Total biomass produced is not available as the hand-cuts were unfortunately lost in an oven fire, as were the subsamples for calculating dry matter content and nutrient analysis of the removed portion of the pasture. Based on the previous pasture harvests at this site, we assumed a dry matter content of 40%, which gave an estimate of 3000 kg DM/ha removed from this site, with no difference measured between the nitrogen fertilised and unfertilised pastures (Figure 3 and Figure 4).

At the start of spring, 75% of the macro-nutrients removed in the previous summer were replaced to compensate for nutrient removal that would normally be recycled by grazing animals. Macro nutrients were applied on 16 November 2017, with a blend of urea, GranAm®, MAP and Muriate of Potash. The grass pasture received 67 kg N/ha, 5 kg P/ha, 88 kg K/ha and 6 kg S/ha, and the grass plus nitrogen pasture received 76 kg N/ha, 5 kg P/ha, 103 kg K/ha and 7 kg S/ha. In addition to this, the grass plus nitrogen pasture received an extra 50 kg N/ha after each harvest event (100 kg N/ha/yr).

Implications for growers

Preliminary gross margin analysis (Figure 2) shows the baseline rotation to be the most profitable system to date. This is largely driven by the exceptionally high-yielding cereal crops in the first two years of the trial (reaching close to maximum yield potential unconstrained by plant available water). The summer crops for the same period experienced below average rainfall and temperatures in the hottest 10% of years, so achieved low grain yield and low crop water use efficiencies.

Predicta B testing is showing increasing levels of the pathogens that cause crown rot and common root rot, so there is a need to rotate to non-host crops to manage these in the near future.

The varied intensity systems have had a major drag on yield and gross margins by the summer crops in 2015-16 and 2016-17. The lower and higher intensity systems are performing quite similarly to each other for both total grain yield and gross margin, despite the *Higher intensity* growing an extra two crops. If this trend continues through the life of the trial, it would suggest there is no financial difference between long fallowing or taking double crop opportunities to change into a summer rotation for disease management. These results to date

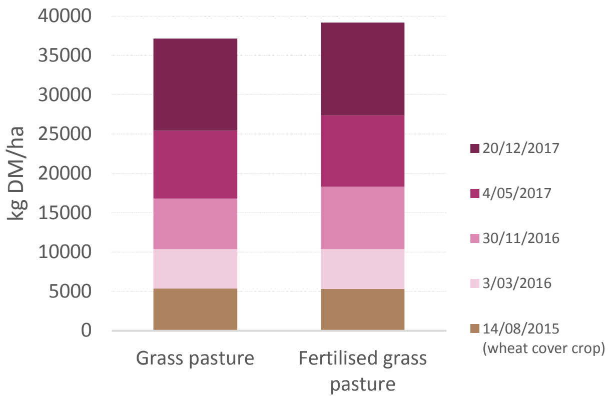

Figure 3. Biomass dry matter present at the time of harvest

*December 2017 yield is estimated based on removal weights

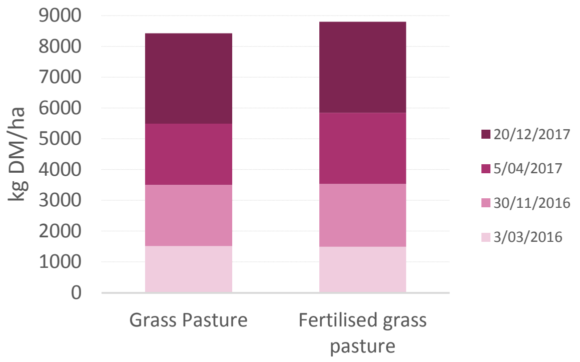

Figure 4. Biomass dry matter harvested

The harvested biomass was cut but not removed in March 2016, but was removed for the subsequent harvests to prevent a mulching effect

*December 2017 dry matter proportion is estimated are supported by APSIM modelling (Whish 2018), which shows a higher intensity cropping system (S,ChxW,Mgx) and a low intensity system (SxxChxWxx) had similar median gross margins. However, the short fallows and double crops performed better in the wet seasons, and the long fallows had less risk of failure in the drier seasons. There are advantages and disadvantages to both approaches. Run-off and soil loss from rainfall is higher on near full profiles in a long fallow, along with increased opportunity to control weeds in fallow with non-selective herbicides. In the more intensive systems there is an increased risk of crop failure from growing crops on lower stored water, but drier soil is less likely to erode and less is conducive to small seeded weeds establishing; and the increased time growing crops allows the use of crop competition to help manage weeds.

Acknowledgements

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

Reference

Whish, J, Bell, L, Zull, A and DeVoil, P, 2018, 'Analysis of risks and returns for different crop sequences. Climate and financial risks associated with rotations of differing types and intensities.' Proceedings of Goondiwindi GRDC grains research update 2018, pp. 206-214.

Trial details

Location:	Billa Billa
Crop:	Bambatsi grass, mungbean, sorghum and wheat
Soil type:	Belah, Grey Vertosol
2017 rainfall:	444 mm

Spring sorghum harvest, with double cropped mungbeans and sorghum in the background

Northern Farming Systems—Mungindi regional site

Grant Cutler
Department of Agriculture and Fisheries

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

Key findings

1. High summer heat combined with low summer rainfall were serious constraints to grain production during 2016-17.
2. Diverse crop options and long fallows continue to reduce nematode populations.

Background

The Mungindi dryland farming area is based mainly on winter cropping systems; primarily cereals such as wheat and barley and pulses such as chickpeas, with limited opportunity summer cropping (dryland cotton and sorghum). Local rainfall is variable and winter cropping relies heavily upon stored moisture, typically from the highest rainfall months in late summer.

Most farms operate on a zero or minimum tillage system with a fairly set rotation of cereal/cereal/chickpea. Local knowledge of nematodes is limited, however soil samples taken in some long-term cropping areas north of the border have shown significant numbers while nematode levels are typically lower to the south.

The site is located 22 km north west of Mungindi towards Thallon on a Grey Vertosol soil with a Plant Available Water Capacity (PAWC) of 180 mm. The site has been cropped for 25 years and is representative of cropping in the region. The site has no major weed pressure but has high nematode populations (*Pratylenchus thorneii*) that range from 6000-26,000/kg of soil. The trial area has been fenced to keep local wildlife away from the plots.

What was done

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

1. **Baseline.** Designed to represent a standard cropping system for the Mungindi region. The area is winter dominant with three main crops (wheat, barley and chickpeas) on a fairly set rotation of wheat/wheat/chickpea with an average of one crop per year.
2. **Lower crop intensity (mixed).** Similar to the 'grain only' option below but may also include summer crop options, including dryland cotton as a high value crop.
3. **Lower crop intensity (grain only).** Designed to plant at a lower frequency when the profile is at least ¾ full. The rotation includes wheat/barley/chickpeas and the option of a cover crop.
4. **Higher crop diversity.** Investigates alternative crop options to help manage and reduce nematode populations, disease and herbicide resistance. The profitability of these alternative systems will be critical. A wider range of 'profitable' crops may

Location of the site near Mungundi and layout of the plots enable growers to maintain soil health and sustainability as the age of their cropping lands increase. Crop options include: wheat/barley, chickpeas, sorghum, maize, sunflowers, canola/mustard, field pea, faba bean and mungbeans.

5. **Higher legume**. Focused on soil fertility and reducing the amount of nitrogen input required through fertiliser. It is required that one in every two crops is a legume and the suite of crops available is: wheat/barley, chickpeas, faba beans and field peas all based on an average moisture trigger.
6. **Higher nutrient supply**. Nutrient supply is currently very conservative in the Mungindi region. Many growers put on very little fertiliser. This system is designed to identify if fertilising for a higher yield (90% of seasonal yield potential for nitrogen, and 100% replacement of phosphorus), is going to be financially beneficial in the long-term. Crop choice is determined by the *Baseline* so that the two treatments can be compared.

Results

System breakdown 2017

The *Lower crop intensity (mixed)* and *Higher crop diversity* systems were planted to cotton and sorghum respectively on 13 October 2016. In winter 2017, sowing triggers were not reached to allow planting of the desired system rotations and the decision was made to plant a wheat cover crop in the *Baseline*, *Higher legume* and *Higher nutrient supply* systems to increase ground cover back above the desired 30%. Due to the nature of the season, germination and establishment were less than hoped for however, sufficient ground cover was achieved. The *Lower crop intensity (grain only)* system was long-fallowed out of single-skip sorghum in January 2015. This system also missed its planting opportunity due to the dry start to winter 2017, and so also required a wheat cover crop.

The *Lower crop intensity (mixed)* system had been fallowed through the 2016 winter and planted to cotton (2 m solid) on 13 October on 145 mm Plant Available Water (PAW) and received approximately 145 mm of rainfall throughout the season. Due to moisture and temperature extremes experienced during the growing season, the crop managed to only produce roughly 1 bale/ha of very low quality lint.

After spring sunflowers in 2015, the *Higher crop diversity* system was then fallowed through the 2016 winter and planted to sorghum on 12 October 2016 on 140 mm soil moisture and received approximately 100 mm of rainfall throughout the season. The crop managed to produce roughly 3 t/ha of biomass, however due to moisture and temperature stress experienced during panicle emergence, the crop did not flower.

Table 1. Crops grown at the Mungindi farming systems site

	1. Baseline	2. Lower crop intensity (mixed)	3. Lower crop intensity (grain only)	4. Higher crop diversity	5. Higher legume	6. Higher nutrient supply
Winter 2015	Wheat EGA Gregory$^{\phi}$	Wheat EGA Gregory$^{\phi}$			Wheat EGA Gregory$^{\phi}$	Wheat EGA Gregory$^{\phi}$
Summer 2015-16			Sorghum MR-Bazely	Sunflower Ausigold 62		
Winter 2016	Chickpea PBA Seamer$^{\phi}$				Chickpea PBA Seamer$^{\phi}$	Chickpea PBA Seamer$^{\phi}$
Summer 2016-17		Cotton Sicot 748 B3F		Sorghum MR-Bazely		
Winter 2017	Cover crop Wheat		Cover crop Wheat		Cover crop Wheat	Cover crop Wheat
Summer 2017-18						
Winter 2018	Wheat LongReach Reliant$^{\phi}$	Wheat LongReach Reliant$^{\phi}$	Chickpea PBA Seamer$^{\phi}$	Wheat EGA Bellaroi$^{\phi}$	Chickpea PBA Seamer$^{\phi}$	Wheat LongReach Reliant$^{\phi}$

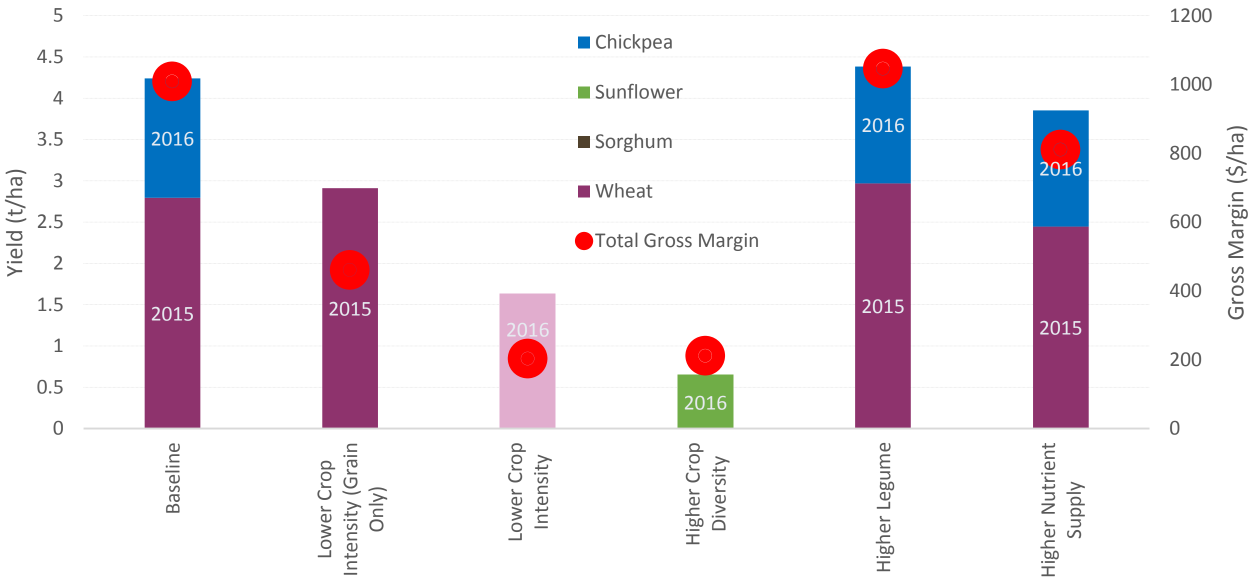

Figure 1. Mungindi cumulative grain yields and total gross margins of these crops (including fallow costs) up to the end of the 2017 winter season

2018 cropping plan

In winter 2018, the *Baseline*, *Lower intensity (mixed)* and *Higher nutrient supply* systems will rotate to wheat. The *Baseline* and *Higher nutrient supply* systems will rotate to wheat to keep in line with the cereal/cereal/chickpea rotation whilst the *Lower crop intensity (mixed)* system will rotate to wheat to provide some much-needed stubble cover coming out of cotton. Both the *Lower crop intensity (grain only)* and *Higher legume* systems will rotate to chickpea with the *Lower crop intensity (grain only)* treatment having approximately 30% higher PAW. The *Higher crop diversity* system will rotate to durum wheat to continue to reduce nematode numbers.

System analysis

Water-use efficiency

Current system water-use efficiency for the six individual systems show significant differences between certain rotations (Figure 2). The *Baseline*, *Higher legume* and *Higher nutrient supply* systems are all similar in both Grain WUE and Biomass WUE (kg/mm) in that all three rotations have until now grown the same crops. Although the *Lower crop intensity (grain only)* has only grown a single sorghum crop and has since been long fallowed, it has still produced more biomass/mm of water than the *Lower crop intensity (mixed)* system. The *Lower crop intensity (mixed)*, having grown wheat and cotton, also shows a decrease in both grain and

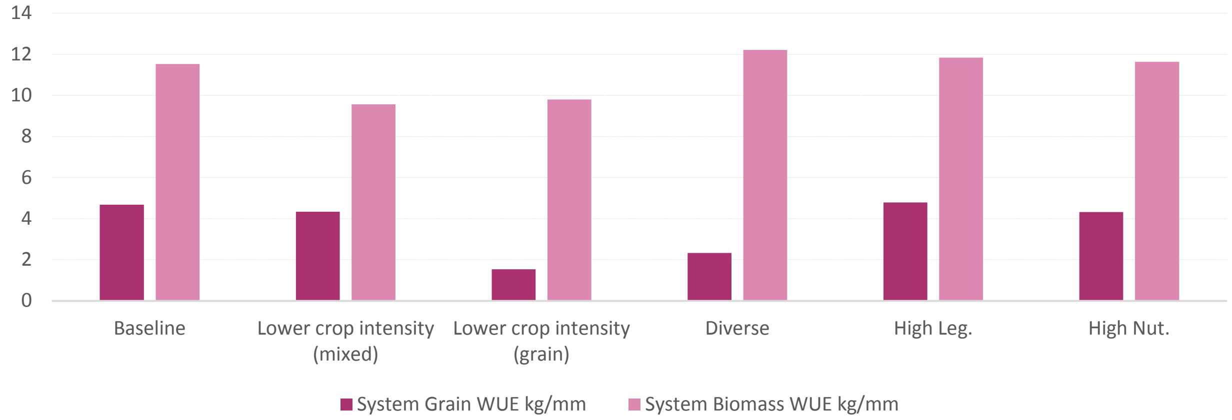

Figure 2. Current relative water-use efficiency for each cropping system

Table 2. ***P. thornei*** **counts (nematodes/g soil)**

		Pre-winter 2015	Pre-summer 2015-16	Pre-winter 2016	Pre-summer 2016-17	Pre-winter 2017
1.	Baseline	13		5	19	11
2.	Lower crop intensity (mixed)	14		5	7	8
3.	Lower crop intensity (grain only)	16	8			3
4.	Higher crop diversity	11	9		4	3
5.	Higher legume	18		7	24	11
6.	High nutrient supply	15		9	25	11

biomass WUE when compared to the *Baseline* system. The *Higher crop diversity* option has so far produced as much biomass as the *Baseline*, *Higher legume* and *Higher nutrient supply* systems. However its grain WUE remains low due to the 2017 sorghum crop failing to produce yield.

Nematode response

Initial samples taken prior to sowing the first crop in winter 2015 showed a high nematode presence at the site. The *Baseline*, *Higher legume* and *Higher nutrient supply* systems were all cropped to wheat (2015) and chickpea (2016) and have shown only a slight decrease in nematode numbers; they still remain very high. Of interest is the *Higher crop diversity* system, which has incorporated only resistant crops and has shown a significant decrease in numbers. The *Lower crop intensity (grain only)* system, which incorporated a resistant crop (grain sorghum) and a long fallow has shown the same decrease in nematode numbers.

Implications for growers

Coming into its fourth cropping year, the systems with more diverse crop options are showing their value by significantly reducing the number of nematodes present. However, it still remains to be seen what will happen to nematode numbers when the *Higher crop diversity* system is rotated back to chickpea in 2019. Winter cropping options do appear to have less risk of failure than summer cropping options and produce higher WUE.

Acknowledgements

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

Trial details

Location:	Mungindi
Soil type:	Grey Vertosol
Rainfall:	246 mm (Sept 2017 to Feb 2018)

Northern Farming Systems—Complex experiment, Pampas

Lindsay Bell[1], Kaara Klepper[2], Jack Mairs[2], John Lawrence[1], Andrew Zull[3], Duncan Weir[3]
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[2]Formerly Department of Agriculture and Fisheries
[3]Department of Agriculture and Fisheries

RESEARCH QUESTION: *How does modifying aspects of the farming system impact on its long-term productivity, profitability and sustainability?*

Key findings

1. Alternative legume and break crops have legacy benefits for soil N and soil-borne pathogens.
2. Crop sequences involving alternative break crops (e.g. canola, faba bean and durum wheat) can achieve similar or higher returns per mm of water used to conventional crop sequences.
3. Double-crop mungbean has legacy impacts on soil moisture and root lesion nematode populations for subsequent crops.
4. Low crop intensity (<0.6 crops per year) are showing lower system water use efficiency, but differences due to crop intensity at higher crop frequencies so far are small.

Background

The Northern Farming Systems projects are investigating how modifications to farming systems will impact on the performance of the cropping system as a whole over several crops in the sequence. Several relevant modifications were identified across the northern grains region that are being tested to examine how these influence long-term water use efficiency, nutrient balance and nutrient use efficiency, changes in pathogen and weed populations and changes in soil health. The key system changes being tested are:

- **Changing crop intensity**. The proportion of time that crops are growing impacts on the proportion of rainfall transpired by crops and unproductive water losses. This is being altered by changing soil water thresholds that trigger planting opportunities. High crop intensity systems have a lower soil water threshold (30% full profile); moderate intensity systems have a moderate soil water threshold of 50% full profile, and low intensity systems require a profile >80% full before a crop is sown and higher value crops are used when possible.
- **Increased legume frequency**. Crop choice aims to have every second crop as a legume across the crop sequence, with the aim of reducing fertiliser nitrogen (N) inputs required.
- **Increased crop diversity**. The aim is to test systems where the mix and sequence of crops are altered to manage soil-borne pathogens and weeds in the cropping system. Crop choice aims to achieve 50% of crops resistant to root lesion nematodes (preferably two in a row), while crops with similar in-crop herbicide mode of action can't follow each other.
- **Nutrient supply strategy**. The aim is to boost background soil fertility by increasing N cycling and maximising yields in favourable years, with increased fertiliser budgets to achieve 90% of yield potential for that crop compared with a 50% of yield potential.
- **Using non-crops to build soil resilience.** Cover crops or ley pastures are being used in the cropping rotation to increase soil carbon inputs, biological activity and maintaining soil cover >50%.

This report focuses on the large 'core' experiment on a Grey Vertosol soil with a plant available water capacity of 250 mm near Pampas on the eastern Darling Downs. The experiment is exploring and testing the interactions amongst modifications to the cropping systems, across a range of crop sequence scenarios that occur within the northern grains region. There are 34 different system treatments being compared.

Crop sequences have begun to diverge, which allows comparisons of the crop sequences on different aspects of the farming system.

This report highlights some of the key differences associated with the different crop choices that have emerged as the above systems modifications have been deployed over the first two and a half years of this experiment (Figure 1). Firstly, information on the legacy of different crops used in crop sequences and, secondly, analysis of system water use and nitrogen use efficiencies across the whole crop sequence.

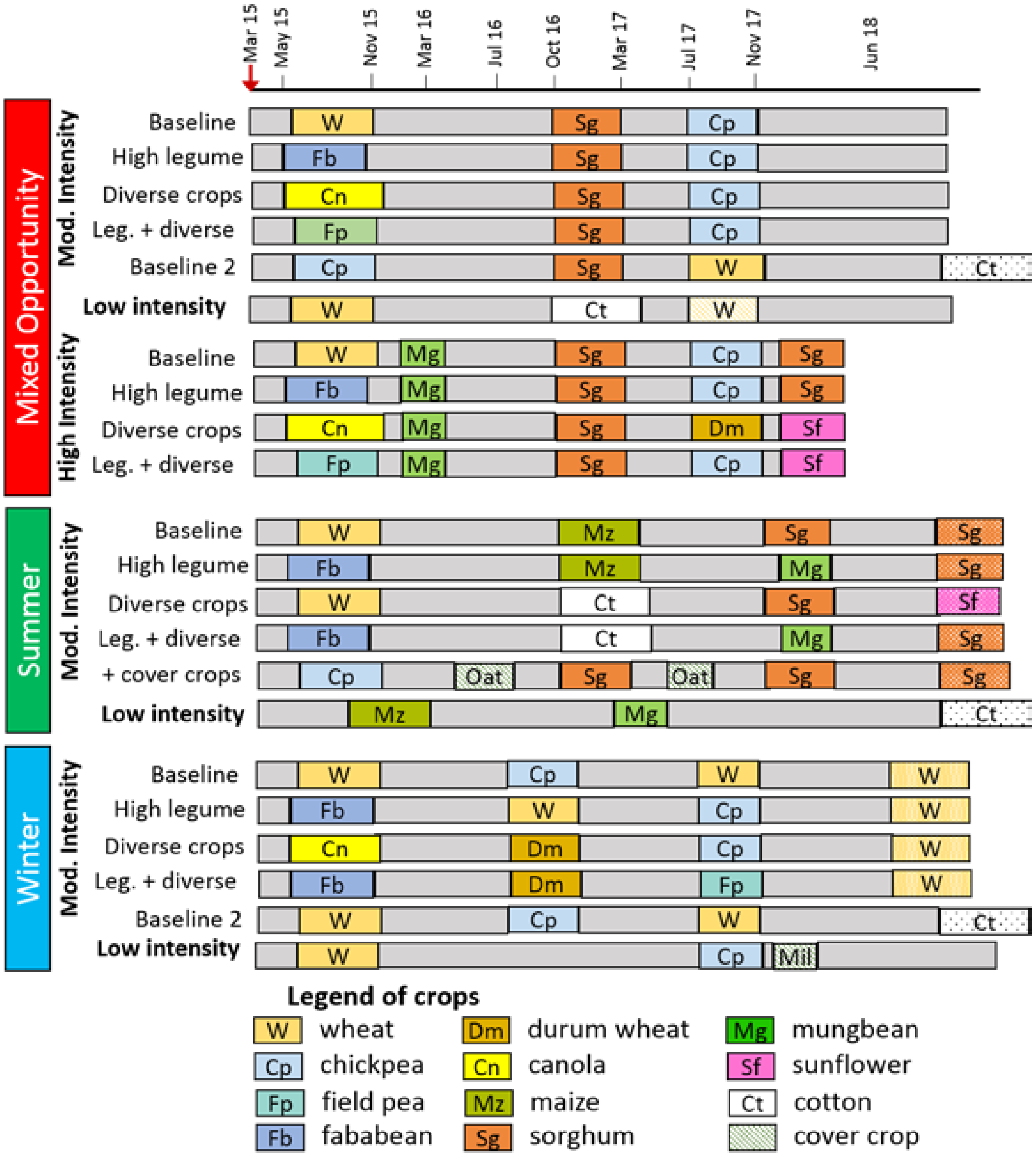


Figure 1. Timeline of different crop sequences deployed over the first two and a half years (from March 2015 to January 2018) at the core farming systems experiment. Different crop sequences emerged based upon soil water availability triggering a sowing opportunity, and rules that dictate crop choice across systems aimed to represent winter dominated, summer dominated or mixed opportunity cropping systems

Results

Yield responses following different crops in crop sequences

Three cases have been observed so far where previous crop choice or sequence has impacted on subsequent crop yields. These key results are:

1. Mungbean yields benefited following canola

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

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

Previous crop	Mungbean grain yield (t/ha)	Pre-sowing plant available water (mm)	*P. thornei* at sowing (#/g soil)
Canola	0.81	78	8.4
Wheat	0.48	78	18.0
Faba bean	0.44	104	13.8
Field pea	0.28	83	12.4

2. Sorghum yield reduced by mungbean double-crop

Sorghum sown in October 2016 was preceded by a range of previous winter crops in 2015 that were followed by either a long-fallow or a double-crop of mungbean. No significant difference was observed in sorghum grain yields where these winter crops followed the long-fallow; all crops yielding around 6.2-6.5 t/ha (Table 2). There was no evidence of long-fallow disorder following the non-mycorrhizal canola, which was also then followed by a long-fallow before the subsequent sorghum crop; probably owing to the high soil P content at our site. Potential benefits of additional N provided after legumes were only small and hence not significant; there was also no response to any additional fertiliser N in this season.

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

3. Crop yield reductions following cotton compared to summer cereals

Significant reductions were observed in both winter crops double-cropped in the next winter, and summer crops sown after a short fallow following cotton, compared to systems where maize or sorghum had been grown previously (Table 3). After cotton, soil water was 30 mm lower in May 2017 compared to following sorghum, and wheat yields were 0.7 t/ha lower as a result. Similarly, soil water after cotton was 20 mm lower in September 2017 compared to following maize; as a result sorghum yields were reduced by 0.4 t/ha and mungbean yields were reduced by 0.3 t/ha.

Table 2. Sorghum crop yields and soil water at sowing following either long-fallow or double-cropped mungbean in summer 2016/17

Previous crop	Pre-sowing plant available water (mm)		Sorghum yield (t/ha)	
	Long-fallow	Mungbean	Long-fallow	Mungbean
Wheat	225	156	6.25	5.56
Canola	215	125	6.28	5.51
Faba bean	196	133	6.22	3.95*
Field pea	188	142	6.49	5.50
Chickpea	199		6.45	

*** potential damage from Spinnaker®**

Table 3. Soil water prior to sowing and sorghum or mungbean crop yields (following either cotton or maize)

Previous crop (summer 16/17)	Wheat yield (t/ha) (Sown June 17)	Pre-sowing plant available water (mm) (1 Sept)	Sorghum yield (t/ha) (sown Oct 17)		Mungbean yield (t/ha) (sown Dec 17)
			Baseline	High N	
Cotton	1.06	127	4.04	3.66	0.73
Maize		145	4.44	4.52	1.04
Sorghum	1.75				

Crop sequence effects on nematode populations

The experimental site initially had moderate levels of RLNs (7-9/g). Since then different crop sequences have brought about some clear differences in the dynamics of nematode populations over the subsequent two years (Figure 2).

1. Winter crop effects on RLN populations

In winter crops in 2015 and 2016, Longreach Gauntletᶲ, the most tolerant and resistant wheat cultivar currently available, increased RLN populations by 2-2.5 times; significantly more than other crops. The grain legumes, PBA Wardaᶲ faba bean, PBA HatTrickᶲ chickpea and PBA Percyᶲ field pea also increased RLN populations, but less than Longreach Gauntletᶲ. Canola and durum wheat did not increase RLN populations, which subsequently declined slowly.

2. RLN populations magnify with susceptible double-crops

RLN populations greatly increased during the double-crop of Jade-AUᶲ mungbean. This increase was far greater when the mungbean double-crop followed susceptible crops of wheat or faba bean (11-14/g), compared to when it followed canola (5/g) (Figure 1). This demonstrates that extending the period of host crops in the system, by double-cropping with two susceptible crops in a row, can dramatically increase RLN numbers. RLN populations then declined during the subsequent fallow and a sorghum crop after the mungbean, but they

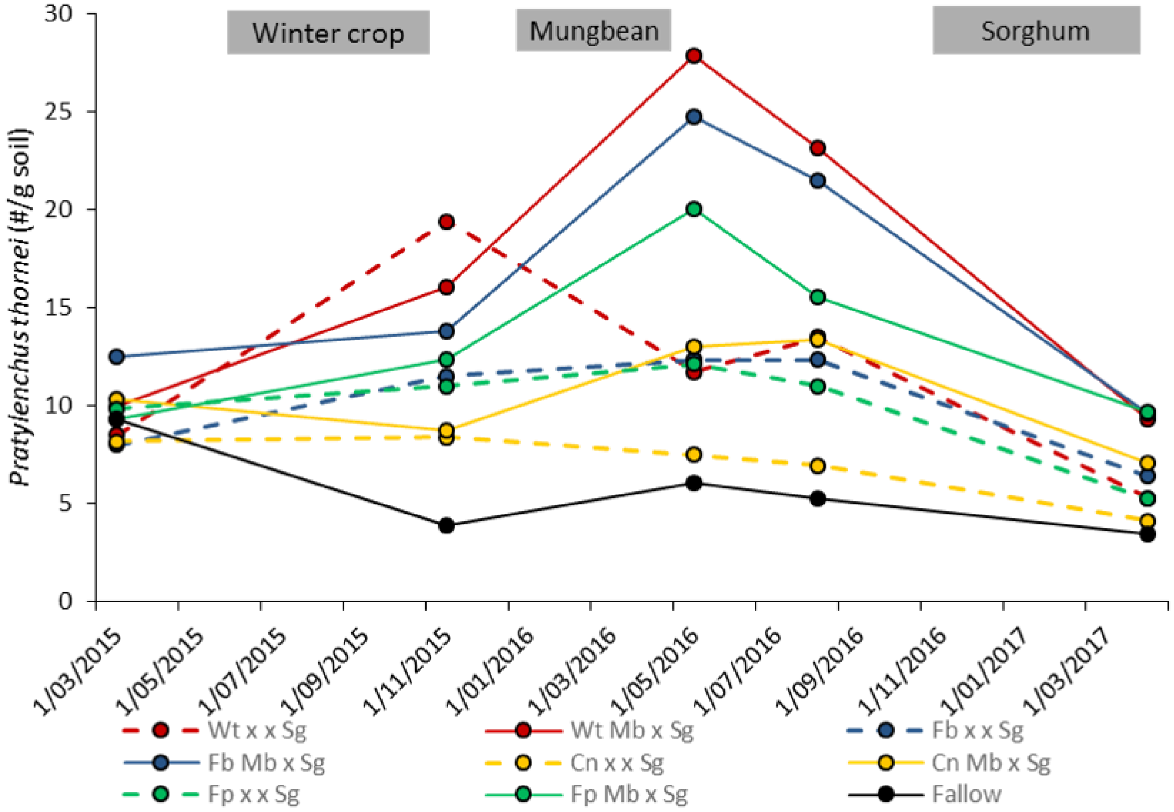


Figure 2. Changes in root lesion nematode population between different opportunity crop sequences where various winter crops in 2015 of wheat (Wt), faba bean (Fb), canola (Cn), or field pea (Fp) were followed by either a long-fallow (x x) or a double-crop of Jade-AUᶲ mungbean (Mb), and a sorghum (Sg)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

remain higher where mungbean double-crops were grown than in the systems that remained fallow after the first winter crop.

3. Resistant crops and fallows reduce RLN populations

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

System water-use-efficiency

System water-use efficiency; that is, gross margin return ($) per mm of water used (i.e. rainfall + change in soil water), was calculated amongst the various cropping systems from March 2015 to December 2017. System gross margin used the grain yields obtained multiplied by the 10-year average price for each crop, minus variable costs (fertiliser, seed, herbicides, and operations) accumulated over the whole crop sequence (Figure 3).

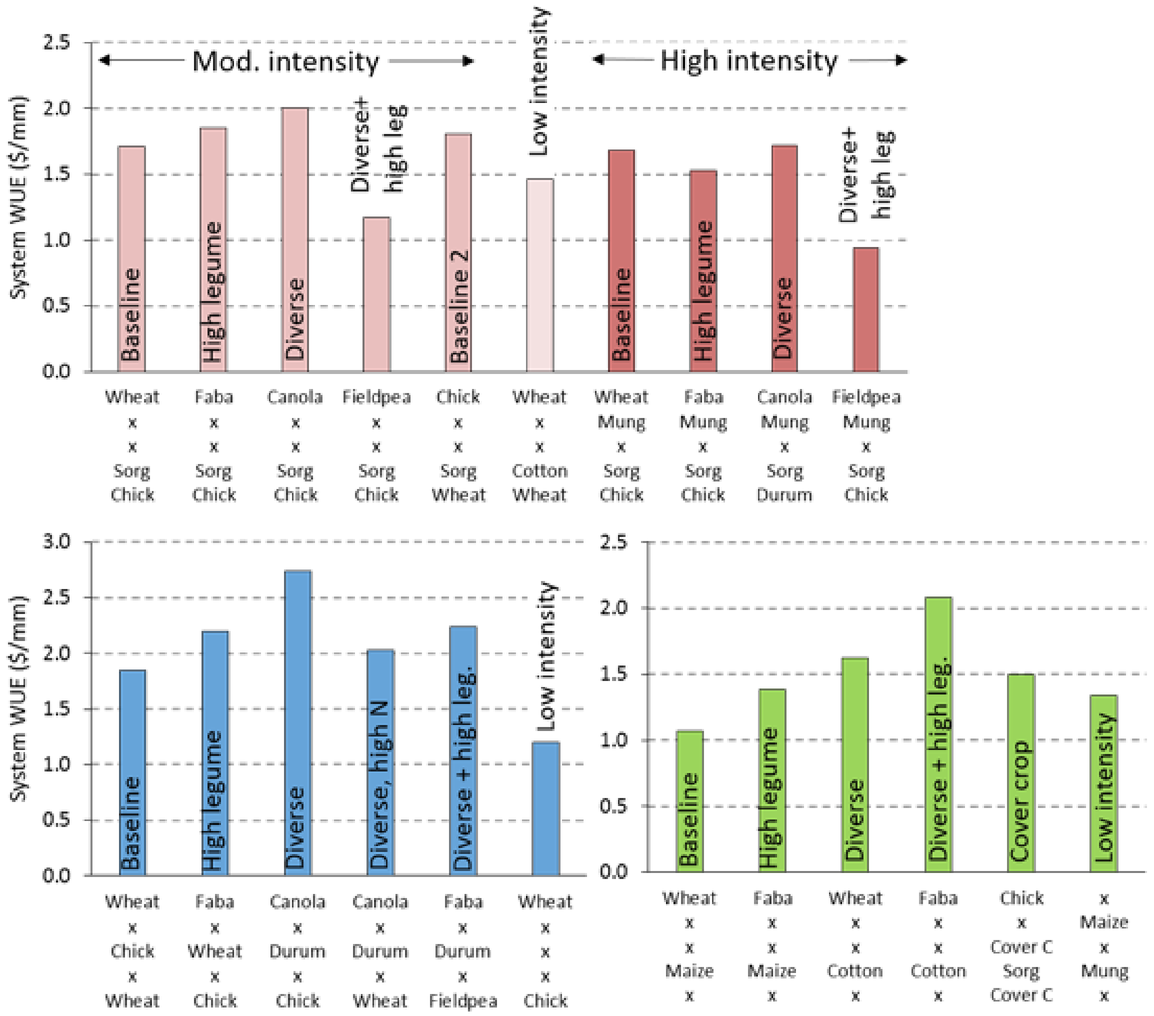


Figure 3. System water use efficiency ($ gross margin/mm water used) for the period from March 2015 to Sept/Dec 2017 for different crop sequences modified to increase or decrease crop intensity, increase legume frequency and/or crop diversity. Opportunity cropping systems (in red) are at the top, b) winter cropping systems (in blue) on bottom left and c) summer cropping systems (in green) on bottom right

Note summer systems are only calculated to September 2017 and have had one less crop so should not be compared with winter or opportunity systems at this time. Crop prices per tonne yield (11% moisture) farm gate after grading and transport costs ($40/t) used were: wheat - $264 (APH), sorghum - $225, mungbean - $710, maize - $285, durum wheat - $284, chickpea - $569, faba bean - $394, field pea $280, canola - $355

In the opportunity cropping systems, only small differences have been observed between several of the key system modifications; six of the ten systems presented here are showing WUE of between $1.7 and $1.95/mm. Most notably, the increased diversity and increased legume systems performed as well, or better than the traditional (baseline) systems. In contrast, the higher intensity systems (i.e. one additional mungbean crop) provided no advantage, and insome cases the WUE was reduced. The sorghum yield penalty was sufficient to negate the gross margin of the extra mungbean crop.

Note that the low intensity systems are currently behind in terms of system WUE, largely owing to the poor performance of the wheat crop following cotton; chickpea crops double-cropped after sorghum performed much better. Systems aiming to achieve both crop diversity and high legume frequency objectives were sown to field pea in the first year. Field pea returns were $700-1100 less than other crops, and subsequent benefits have not been sufficient to make up this initial cost.

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

Implications for growers

Divergent crop sequences are emerging at the core farming systems experimental site, and are showing that crop choice can greatly influence subsequent crop yields, soil pathogen populations and the profitability of the whole crop sequence. Preliminary results are showing that alternative legume and break crops such as canola, faba bean, field pea and durum wheat are providing significant benefits to help manage RLN populations, increase N cycling and availability, and to maintain similar or higher system profitability. Research has also highlighted the system risks for double-crops of mungbean, with reductions in moisture and yields of subsequent crops compared to maintaining fallows, and the risks of increasing RLNs, particularly if they are following susceptible crops.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC (Project CSA00050); the authors would like to thank them for their continued support.

We would also like to thank specifically our co-operators and hosts at he Pampas property who assist us implement this experiment in a variety of ways (too many to mention) that are most appreciated. We must also thank Jon Thelander, Seednet for helping source and supply much of the seed used, Paul McIntosh (Pulse Australia and AHRI) for his advice and help with our pest management program, Wes Judd and Craig Antonio who have helped with cut and conditioning hay from pasture treatments and Department of Agriculture and Fisheries farm staff for their help and patience harvesting and planting the crops.

The impact of cover crops on fallow water recharge in cotton/grain systems—Goondiwindi

Andrew Erbacher and David Lawrence
Department of Agriculture and Fisheries

RESEARCH QUESTIONS: *Can cover crops increase the net water accumulation in grain and cotton systems with low ground cover (<30%) in the northern region? | What is the net water cost to grow the cover crops and the net water gain to the subsequent cotton crops (fallow and early growth periods)?*

Key findings

1. Growing cover crops has improved ground cover, with the later terminated cover crops providing far more resilient stubble.
2. Only two of the eight cover crop treatments had less plant available water than the (bare) Control when the cotton was planted.
3. Yield implications on the subsequent cotton crop are still being evaluated.

Background

Cover crops are typically used to protect the soil from erosion and increase infiltration in low stubble situations, return biomass to maintain soil organic matter and biological activity, and to fix nitrogen if legumes are used. However, recent research suggests that higher stubble loads from cover crops may also reduce evaporation and increase infiltration enough to provide net gains in Plant Available Water (PAW) over the traditional fallows; growing better and more profitable crops.

The capture and storage of rainfall for crop use remains a major challenge for growers across the northern region. Only 20-40% of rainfall is typically transpired by dryland crops, with up to 60% lost to evaporation, and 5-20% lost in runoff and deep drainage. Simulations for Goondiwindi using the CliMate app suggest a six month fallow to March 2018 would have stored 156 mm with 100% ground cover and only 74 mm with 0% cover. This extra 82 mm of stored moisture could lead to yield increases of over 1 t/ha for grain growers, with comparable benefits to cotton growers.

A new project supported by the Grains Research and Development Corporation (GRDC) and the Cotton Research and Development Corporation (CRDC) will quantify the effectiveness of cover crops to increase rainfall infiltration, reduce evaporation, and so increase PAW in fallows for subsequent grain and cotton crops.

The first trial has been conducted in a back-to-back cotton system that traditionally uses wheat as a cover crop; overhead irrigation is used in the cotton with limited supplementary irrigation to establish the cover crops when required. As such, the results will be widely applicable to both cotton and dryland grain production. These early results from the cover crop and fallow will be fully analysed and reported in the next edition of Queensland Grains Research when subsequent yield data are collated.

What was done

The trial was conducted near Yelarbon on a paddock that grew cotton in 2016/17. The crop was picked and root cut in May, before offset discs were used on 12 June 2017 for pupae busting, and to level wheel tracks of the pivot irrigator. Nine cover treatments (Table 1) with five replicates were then planted on that same day; rain that night aided establishment. These cover crops included Compass$^{\text{\textcircled{D}}}$ barley for the cereal, Timok vetch for the winter-active legume and Buster tillage radish. Target populations were 100/m^2 for cereal only treatments, 30/m^2 + 30/m^2 for cereal + legume mixtures and 40/m^2 for tillage radish. The rest of the paddock was planted to wheat for stubble cover two weeks later.

The three termination timings were set to match key growth stages of the main cereal treatments. The early-termination was planned for the development of the first node (Z31), when the crop begins stem development. The mid-termination targeted the beginning of the reproductive phase of the crop, with 'spray-out' at flag leaf emergence (Z41). The late-termination was at peak biomass production of the crop, with the final 'spray-out' at anthesis (Z65).

The early-termination was conducted on 3 August. Mid-termination was five days later than the planned crop stage, and was sprayed-out at awn peep on 28 August. Late-termination took place at anthesis for the barley, on 7 September, when rolling for Treatment 5 was also implemented. The barley was hand-harvested at maturity on 1 November, with header yields taken on 9 November. The surrounding commercial wheat was harvested on 12 November, weeds were sprayed, and then the cotton was planted on 15 November 2017.

Table 1. Cover treatments applied at the Yelarbon site

Treatment	Crop	Termination
1.	Control (bare)	
2.	Cereal	Early sprayout
3.	Cereal	Mid sprayout
4.	Cereal	Late sprayout
5.	Cereal	Mid sprayout + rolled
6.	Cereal	Harvest
7.	Cereal + legume	Mid sprayout
8.	Cereal + legume	Late sprayout
9.	Tillage radish	Mid sprayout

Measurements

Initial soil water was measured in every plot on 20 June. EM38 readings were taken along with soil cores to measure gravimetric soil water. Neutron moisture meter (NMM) tubes were also installed and the initial NMM readings taken at the same time. These NMM and EM38 readings, and percentage ground cover measurements were taken every two weeks while the cover crops were growing. Once all cover crops were terminated, monthly NMM, EM38 and ground cover assessments were taken until canopy closure of the following cotton crop was achieved. A final set of EM38 and NMM readings was taken at cotton defoliation.

Above ground biomass was cut from every plot each time a cover crop was terminated to measure dry matter accumulation, or decline, over time. An EM38 reading and gravimetric soil sample was taken from the same area to measure the soil water used to grow that biomass. The final harvest cuts were threshed to estimate grain yield where the crop was left to mature, and the bottom 25 cm (two-beer-can height) of the stubble was cut off and weighed to estimate the standing biomass left post-harvest.

A range of different cover crops have been established and sprayed out at different times to assess their impact on water storage during the traditional fallow period between cotton crops at Yelarbon, Queensland

The trial has included regular monitoring of dry matter production, ground cover and stored soil moisture across all plots

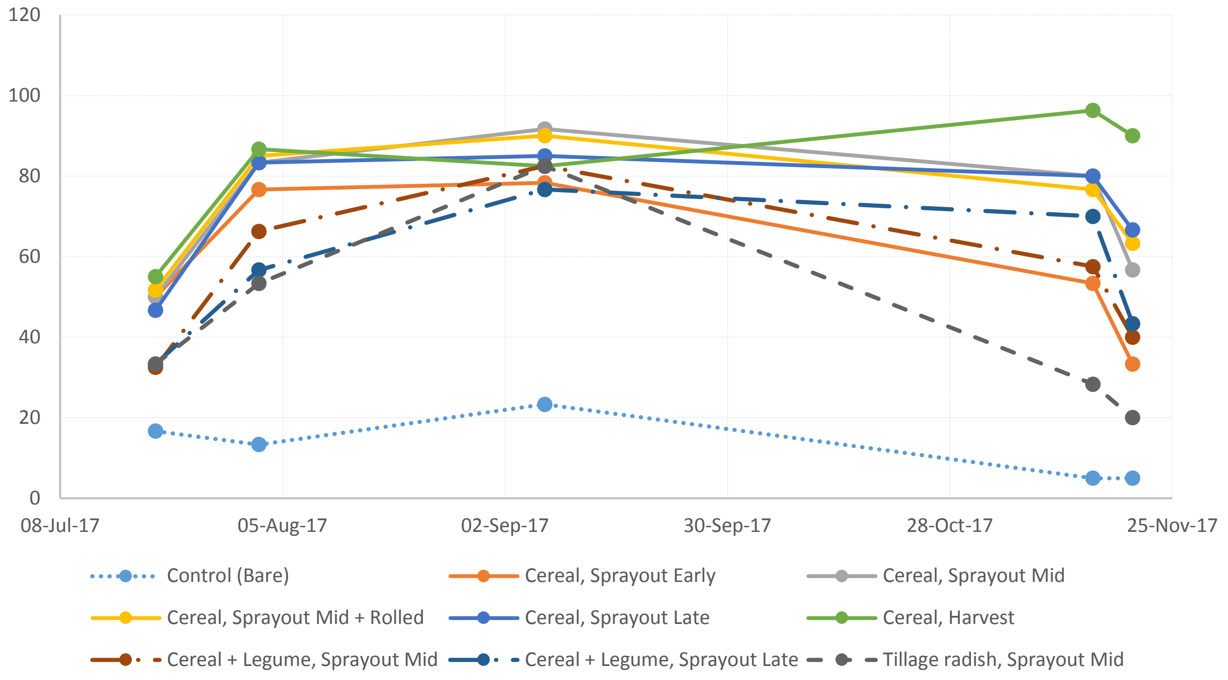


Figure 1. Visual assessments of ground cover over time

Results

Results in this report have not been analysed statistically, so are a preliminary review only. Full results with statistical analysis will be reported in the next edition of Queensland Grains Research.

The paddock was quite rough at the time of planting due to a quick turn-around from cotton, but good populations were established with 13 mm of rain the night after planting.

Plant establishment rates were 70/m^2 for barley only treatments, 30 barley/m^2 and 30 vetch/m^2 for the cereal, legume mixtures and 30/m^2 for the tillage radish.

The early vigour and higher populations of the barley meant that canopy closure was achieved by 2 August (7 weeks after planting) (Figure 1), at which point the early-terminated barley was sprayed out. The lower plant populations of the tillage radish and barley + vetch treatments took

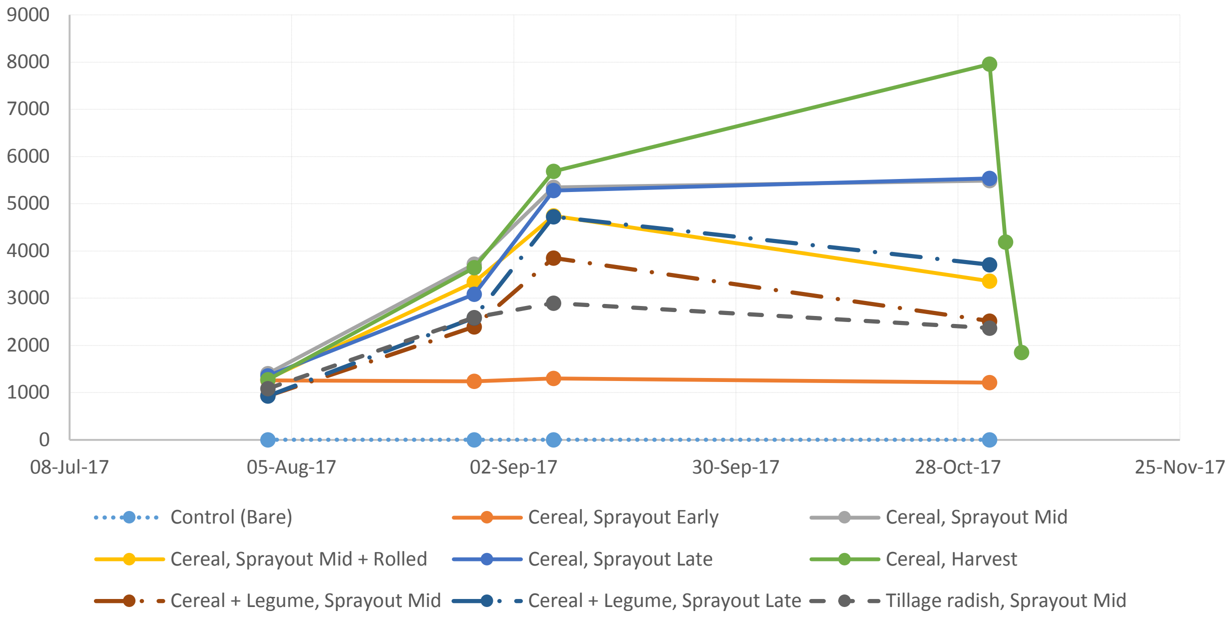


Figure 2. Above ground biomass accumulation for the different cover treatments (note: residual cotton biomass was not included in this assessment)

an extra three to four weeks to achieve the same level of ground cover. At this stage, the barley crops had grown 1300 kg DM/ha of above ground biomass, whereas the barley + vetch and tillage radish had only grown 900 kg DM/ha and 1000 kg DM/ha respectively (Figure 2).

The mid-termination was planned for flag leaf emergence of the barley, but was five days late at awn-peep, on 28 August (11 weeks after planting). At this point, two barley, one barley + vetch and the tillage radish treatments were sprayed out; one of the barley crops was later rolled. At this termination the barley treatments had an extra 1000 kg DM/ha than the barley + vetch and tillage radish treatments (3400 kg DM/ha vs 2400 kg DM/ha) (Figure 2). After a slow start, the vetch rapidly increased its biomass production and the tillage radish was starting to ‘bolt to flower’, at this time.

The late-termination was at barley anthesis on 7 September (13 weeks after planting). At this date, ground cover assessments suggest there was no increase in cover for the barley treatments beyond the early-termination, however the barley + vetch and tillage radish treatments had improved their ground cover to levels similar to the barley treatments (Figure 1). The biomass cut at this time confirms the visual observation that the vetch responded to the warmer temperatures and increased its biomass production more than the barley treatments since the mid-termination (Figure 2).

Grain harvest of the final barley treatment was done a week before the cotton crop was planted. Biomass cuts suggest the soft leafy vetch and tillage radish plants were very fragile and breaking down quickly. The early-terminated barley was also very fragile at this point; however it was still maintaining its biomass. The harvested treatment produced by far the greatest dry matter. However, once the grain was removed, the remaining dry matter was similar to the mid-terminated barley. Dry matter in standing stubble was similar to what remained in the early-terminated barley, however the plant tops were still present as loose mulch (Figure 2).

Visual ground cover assessments after harvest, showed that the re-distribution of barley straw during harvest provided the most ground cover of any treatment. After cotton planting, the fragile leaves of the vetch, tillage radish and early-terminated barley had disintegrated and ground cover was much lower than the later terminated barley treatments.

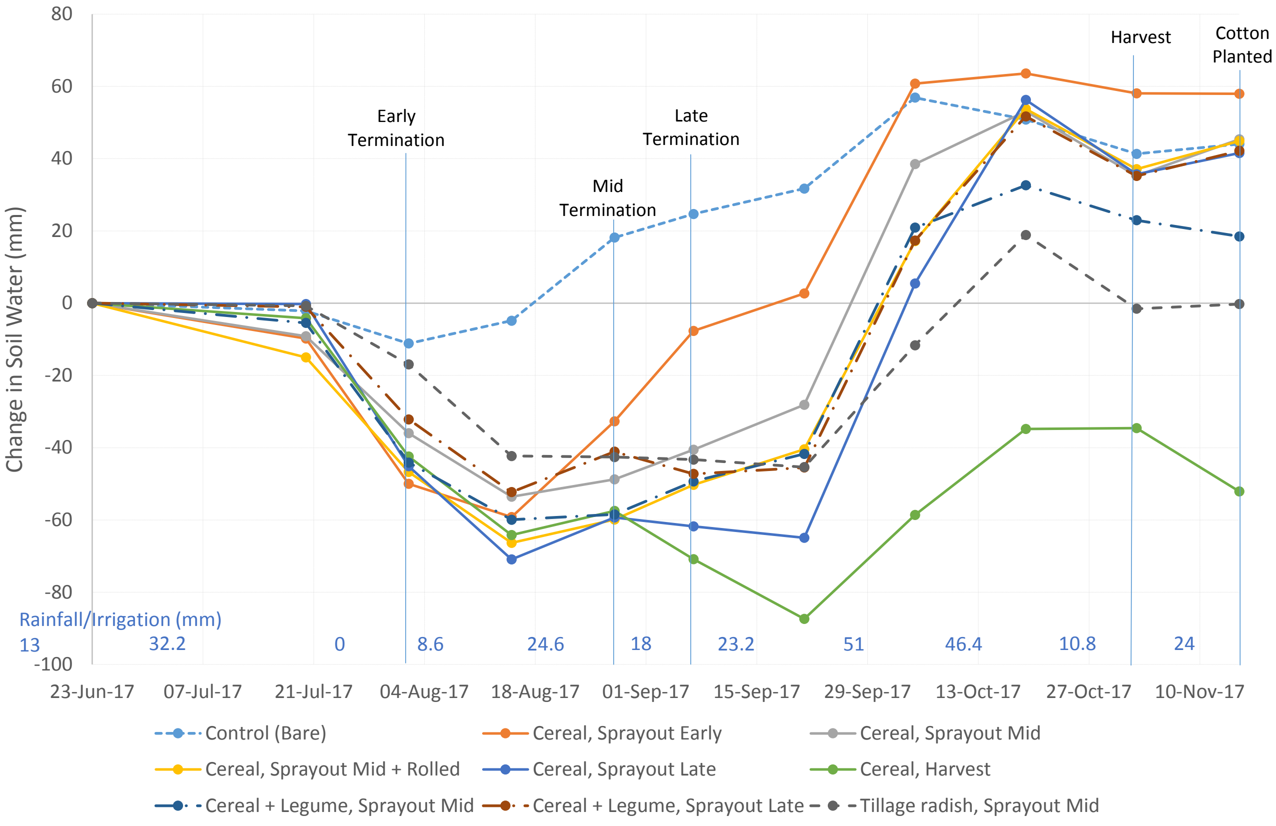


Figure 3. Change in soil water from planting of the cover crop, measured with a neutron moisture meter; average starting plant available water was 90 mm

Gravimetric soil samples taken throughout the course of the trial were matched to NMM readings taken at the same time across the trial. These were used to generate NMM calibration curves and so relate NMM readings to plant available water. Periodic NMM readings in every plot allowed soil water use by the growing cover crops, profile recharge in following fallow and subsequent water use in the early crop period to be monitored (Figure 3).

With the dry seasonal conditions experienced in winter 2017, the paddock received regular irrigations from 15 August to assist the commercial wheat crop in the wider paddock to achieve its target yield of 2.5 t/ha. This allowed the terminated cover crops to begin their fallow recharge. With the assistance of 125 mm irrigation, the stored water in the early-terminated barley was equal to the bare fallowed plots (Control) by 5 October.

The short interval between the mid-termination and the late-termination of the barley and barley + vetch crops, meant these five treatments performed quite similarly over their fallow recharge period. These plots received 138 mm of irrigation and rainfall from the mid-termination to 19 October, when soil moisture was similar to the (bare) Control. Interestingly, the 46 mm of rain from 5 October to 19 October made no difference to the soil water content of the Control and early-terminated barley plots, which had much wetter soil profiles at the beginning of this period. By the time the cotton was planted on 15 November, only the tillage radish and harvested barley plots had less stored soil water than the Control.

The direction of the GPS AB lines from the trial plots were slightly different to the grower planted cotton rows. This resulted in variable populations of cotton being established, with gaps where the cotton rows crossed the cover rows; consequently, more analysis of the data is required before yield impacts can be properly assessed.

Implications for growers

Further analysis of data is required to make recommendations; however, there are a few initial observations from this trial.

The early vigour of barley and the high populations established, meant that these crops grew ground cover quickly. However, the biomass in the early-terminated crops was very fragile, and was no longer visible in the mature cotton crop. These early-terminated crops provided sufficient ground cover for the intensive cropping system and short fallow periods being used by the farmer, and their low biomass provided no problems to plant into.

The later terminated barley cover crops provided much more resilient stubble, which was still visible at defoliation of the cotton. This more resilient stubble will be needed for the longer fallow periods sought by most dryland grain farmers; but of course, it takes more water to grow this stronger stubble. The benefits of carrying stubble through the subsequent crop, in this case cotton, is still being evaluated.

The tillage radish had very fragile above ground biomass that broke down very quickly after termination; however the tubers of this crop were visible late into the cotton crop. The benefits of this below ground biomass and its impact on water recharge are still being evaluated.

Acknowledgements

The team would like to thank the trial co-operator and consultants for their support and contributions to the project. 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:	Yelarbon
Crop:	Cover crops, cotton
Soil type:	Brigalow, Grey Vertosol
In-crop rainfall and irrigation:	895 mm (253 mm cover/fallow and 642 mm in cotton)

Weeds research

With the increase in glyphosate resistance and difficult to control weeds in the northern grains region (Queensland and New South Wales), a wider range of weed management tactics are required. One option is utilising a wider range of modes-of-action by including residual herbicides into an integrated weed management strategy.

Residual herbicides are applied to the soil and are absorbed by the germinating seedlings providing medium to long-term management of weeds by controlling several flushes of emergence. Physical properties of residual herbicides such as solubility, ultraviolet stability and soil or stubble binding characteristics vary by product. Efficacy can also be affected by environmental factors, such as soil type, rainfall, temperature and ground cover. In order to better understand how different herbicides perform under varying conditions it is necessary to gather local efficacy and persistence data across a range of environments and seasons.

To gather this data, the Department of Agriculture and Fisheries research agronomy and weed science teams worked together to conduct residual herbicide trials on a range of soil types and climates across Queensland. In the summer of 2015-16, a range of herbicides were tested, both alone and as a mixture, at nine sites spread throughout Queensland cropping regions.

These sites targeted five major weeds:

- common sowthistle (*Sonchus oleraceus*)
- feathertop Rhodes grass (*Chloris virgata*)
- awnless barnyard grass (*Echinochloa colona*)
- sweet summer grass (*Brachiaria eruciformis*)
- stink grass (*Eragrostis cilianensis*).


Sowthistle seedling

All of these weeds, except stink grass, have had confirmed glyphosate resistant populations in the northern grains region. Stink grass, however, has had confirmed glyphosate resistant reported outside of Australia, so it is also considered a high risk weed. These datasets are intended to compliment the label for the individual herbicides. The herbicide label is a legal document, so should always be read prior to use and herbicides should only be applied as stated on the label.

The trials reported here are a continuation of those reported in 'Queensland Grains Research 2016'. A review of the 2016 trials, as well as trials conducted by other groups within the northern grains region, revealed two things. There has been a large number of trials conducted on the major summer grass weeds (and fleabane) within the northern grains region, but very few on sowthistle, and in most trials the best control achieved by residual herbicides was when two or more modes-of-action were applied together. In light of these observations, the treatments applied in 2016-17 were focused on mixtures of two modes-of-action, and sites were selected to target sowthistle (*Sonchus oleraceus*).

The trials reported here showed many of the residual herbicides commonly used for grass weed control were less effective on the broadleaf weed sowthistle. However, when used in combination with another herbicide of a different mode-of-action, good control of broadleaf weeds was often achieved.

To compliment this herbicide efficacy work, soil from each site was collected to assess the impact of residual herbicides on soil biota, and their effect on subsequent plant growth in wheat and chickpeas. Assessment of soil biology is still ongoing, so will be reported in the next edition of this publication.


Feathertop Rhodes grass

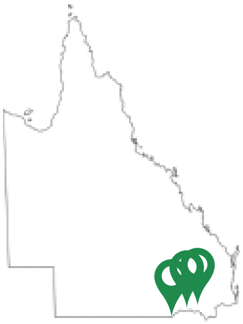

Awnless barnyard grass


Sweet summer grass


Stink grass

Efficacy of residual herbicide—Western Downs

Andrew Erbacher
Department of Agriculture and Fisheries



RESEARCH QUESTIONS: *How effective are different residual herbicides in controlling sowthistle, and how does this change over time? | Is the efficacy of residual herbicides improved by mixing multiple modes-of-action?*

Key findings

1. Valor® and Terbyne® Xtreme® have provided the best control of sowthistle.
2. Some combinations of common 'grass active' residual herbicides have provided good control of sowthistle.
3. Mixing 'grass active' residual herbicides with 'broadleaf active' residual herbicides increases the efficacy of the products as well as increasing the suite of weeds controlled.

NOTE: Products/combinations in this field experiment were tested FOR RESEARCH PURPOSES ONLY. Not all products used are registered for the purposes we have tested. Always read the label prior to use and only apply herbicides as approved in the label.

Background

Common sowthistle or milk thistle (*Sonchus oleraceus*) is widespread in cropping areas of Queensland and New South Wales. Sowthistle was once considered a winter-dominant weed, but is capable of germinating in temperatures between 5° and 35°C, so can potentially germinate at any time of the year.

Similar to the small-seeded cropping weeds feathertop Rhodes grass and fleabane, sowthistle prefers to germinate from the soil surface, with very few seedlings emerging from below 1 cm. Sowthistle also requires several days of moist soil to germinate, so often only germinates after extended rain periods or in conditions with low evaporation (i.e. cool conditions or high stubble).

Glyphosate and 2,4-D are antagonistic for control of sowthistle, so glyphosate alone is often relied on for control in fallows. Several populations of sowthistle have previously been confirmed resistant to Group B (chlorsulfuron). More recently, glyphosate resistance has also been confirmed.

In response to the discovery of evolved glyphosate-resistant populations of common sowthistle in the Liverpool Plains of NSW, two GRDC-funded field surveys have been conducted since 2014 to determine the extent of this issue across the northern grains region. An additional 29 common sowthistle populations were identified as having evolved resistance to glyphosate. Four of these were from Queensland, with the remainder located in New South Wales. While glyphosate remains a viable control option for common sowthistle, it is clear that it should not be the only option used. More diverse chemical and non-chemical practices should be used in combination for controlling common sowthistle and to preserve glyphosate as one of the effective tools in the toolbox for common sowthistle control[1].

One strategy to increase the diversity of chemicals used is to increase the number of modes-of-action applied by using residual herbicides.

What was done

Three south-west Queensland sites were selected in the summer of 2016-17 at Callandoon (20 km west of Goondiwindi), Yagaburne (60 km north of Goondiwindi), and 30 km north of Mungindi. The sites were in areas of a known sowthistle problem during the 2016 winter.

Eighteen herbicide treatments were applied to small plots along with two unsprayed controls (Table 1), and were replicated four times. The herbicides were applied using a boom on a quad-bike at 100 L/ha of water with an air-inducted course (C) droplet size. All weeds within the treated area were counted approximately two weeks after each rainfall event, then sprayed out to prevent double counting and competition effects on later germination events.

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[1] Van Der Meulen A and Jalaludin A 2018, pers comm.

Approximately 90 days after application (DAA), soil was collected from each site and placed into cold storage for later use in pot trials to assess biological symbiotic associations with rhizobia and mycorrhiza (reported separately).

Callandoon

This site was on an alluvial box flat. The paddock had previously been spayed by air, but a combination of lighter soil type, powerlines and the highway resulted in poor control of the sowthistle in the area selected for the trial. The trial was positioned in an area with a high density of mature sowthistles that had recently dropped seed.

The treatments were applied to 3 m x 10 m plots on 27 October 2016. Assessments were made on:

- 13 January 2017 (78 DAA)
- 21 April 2017 (176 DAA)

Soil was collected for biological assessment on 30 January 2017 (95 DAA)

Yagaburne

This trial was on a brigalow soil that came out of spring sorghum. The site was selected on an early flush of sowthistle that was sprayed out prior to the trial commencing. The previous sorghum crop was planted in a double skip configuration, so the treatments were applied across the direction of the sorghum rows, to ensure each of the 3 m x 12 m plots were influenced equally by the row and skip areas.

Treatments were applied on 20 April 2017, and assessed on:

- 30 May (40 DAA)
- 17 July (88 DAA)
- 24 October (187 DAA)

Soil was collected for biological assessment on 17 July (88 DAA)

Mungindi

This site was on a coolibah soil with a history of sowthistle. No plants were visible at the time of application, so a larger plot size of 6 m x 20 m was used to allow for more sparse germinations. The site had standing wheat stubble on 50 cm rows, so the treatments were applied in the same direction of travel as the stubble rows to minimise any shadowing.

Treatments were applied on 3 March 2017 and assessed on:

- 9 May (67 DAA)
- 1 June (90 DAA)
- 18 October (229 DAA)

Soils were collected for biological assessment on 1 June (90 DAA).

Table 1. Treatments applied at all three sites

Trt No.	MOA	Product/s	Rate (/ha)
1	-	Untreated control	
2	-	Untreated control	
3	B	Flame®	200 mL
4	C	Terbyne® Xtreme®	1.2 kg
5	C	Group $C_{triazine}$	3.3 kg
6	D	Group D	3.3 L
7	H	Balance	100 g
8	K	Group K	2 L
9	G	Valor® 500 WG	280 g
10	B + H	Group B + Group H	200 mL + 100 g
11	B + C	Group C1 + Group B	1.2 kg + 200 mL
12	C + D	Group C1 + Group D	1.2 kg + 3.3 L
13	C + K	Group $C_{triazine}$ + Group K	2 kg + 2 L
14	G + B	Group G + Group B	280 g + 200 mL
15	D + H	Group D + Group H	3.3 L + 100 g
16	B + D	Group B + Group D	200 mL + 3.3 L
17	H + K	Group H + Group K	100 g + 2 L
18	C + H	Group C1 + Group H	1.2 kg + 100 g
19	B + K	Group B + Group K	200 mL + 2L
20	G + K	Group G + Group K	280 g + 2 L

Results

Callandoon

November and December were quite dry, with only small showers of rain. The first germination event was triggered by 20 mm over three days from 22 December 2016 (56-59 DAA). This germination was counted 13 January (78 DAA).

At this assessment only awnless barnyard grass (*Echinochloa colona*) (ABYG) had established consistently across the trial. The two Group C products performed poorly, with the rest of the herbicides and combinations providing effective control of ABYG (Figure 1).

Eight treatments had no weeds present (T8, T11, T14, T15, T16, T17, T19 and T20) at this assessment and a further eight had low populations that were not significantly different to zero (T3, T6, T7, T9, T10, T12, T13, T18).

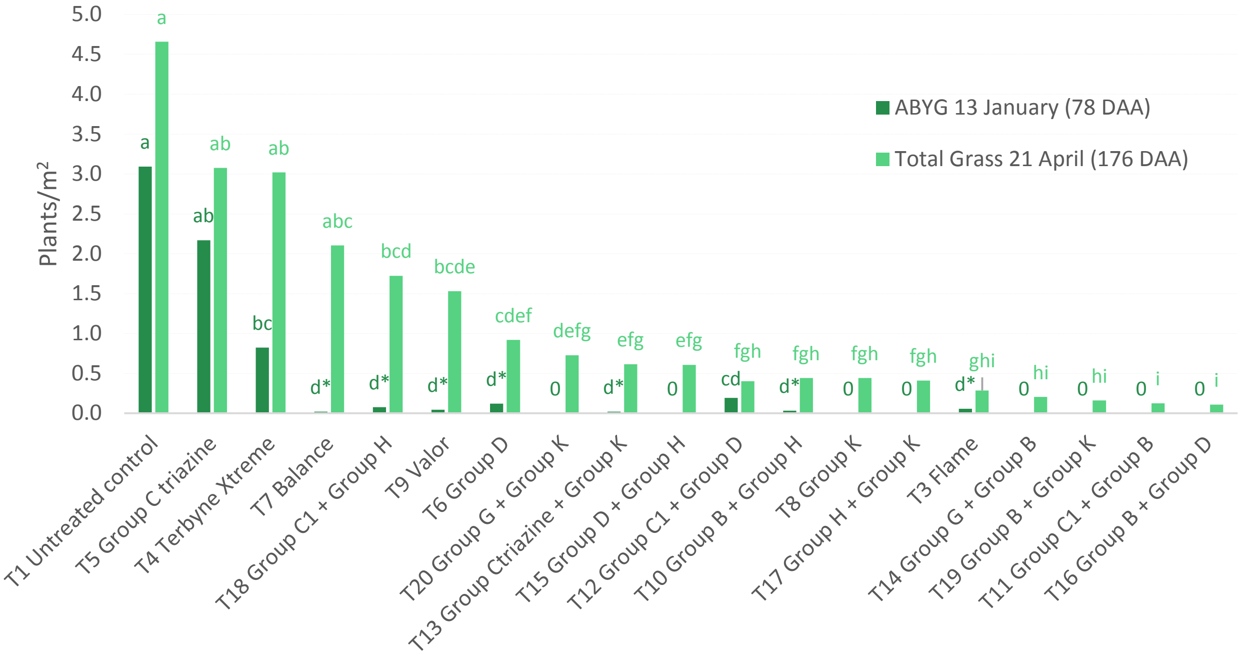

Figure 1. Awnless barnyard grass counted 13 January 2017 (78 DAA) and total grasses counted 21 April 2017 (176 DAA) at the Callandoon trial site
Columns within the same series with similar letters are not significantly different; * = not significantly different to 0; P(0.05)

The final assessment at this site was made on 21 April (176 DAA). This assessment consisted mostly of weeds germinated as a result of 100 mm rain on 30/31 March (154 and155 DAA). There were both ABYG and button grass (*Dactyloctenium radulans*) established across most plots with scattered windmill grass (*Chloris truncata*). There was sufficient awnless barnyard grass and button grass at this site to show significant differences between the herbicide combinations applied. The products performed similarly for each of the grasses, so the three species have been presented as 'total grass'.

At almost six months after application, all treatments had some grass established. Group K and Flame® were still providing acceptable control, but Group C$_{\text{triazine}}$, Terbyne® Xtreme®, Balance®, Valor® and Group D were no longer providing effective grass control without a mixing partner (Figure 1). The best treatments at this stage were four of the five combinations that contain Group B (T11, T14, T16, T19),

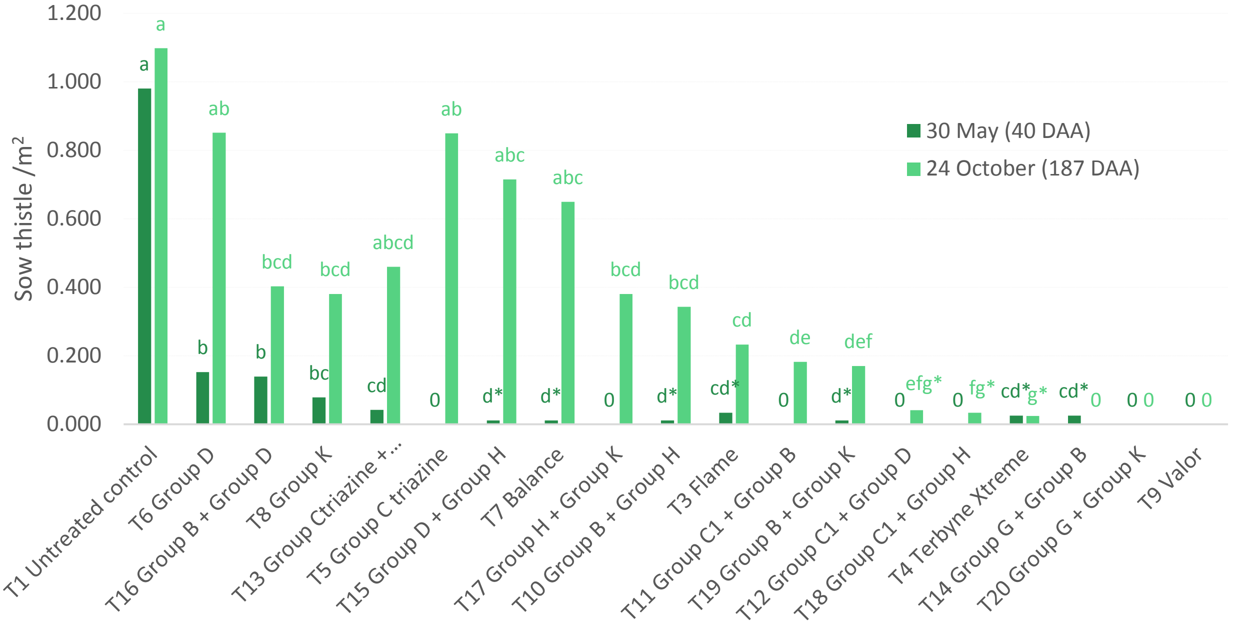

Figure 2. Sowthistle counted 30 May 2017 (40 DAA) and 24 October 2017 (187 DAA) at the Yagaburne site
Columns within the same series with similar letters are not significantly different; * = not significantly different to 0; P(0.05)

however all five of the Group B combinations were statistically similar to Flame® alone (T3). The only difference in herbicide efficacy between the ABYG and button grass was two of the three combination treatments that included Group D (not including Group B + Group D). For button grass these combinations performed the same as Group D alone, however for ABYG these were amongst the best performing treatments, similar to the Group B combination treatments.

The cooler autumn conditions resulted in sowthistle establishment, but no treatments provided effective control of sowthistle at this time (176 DAA).

Yagaburne

The first assessment at the Yagaburne site was 30 May (40 DAA) after 10 mm on 20 May (30 DAA). At this assessment all herbicide treatments reduced the sowthistle germinated relative to the untreated control (Figure 2). There were seven treatments that had no weeds present (T5, T9, T11, T12, T17, T18 and T20) and a further seven that had populations not significantly different to zero (T3, T4, T7, T10, T14, T15 and T19). The worst performing treatments on sowthistle were Group D or Group K alone.

Another germination was assessed 17 July (88 DAA). Sowthistle established was significantly higher in the untreated control than all of the herbicide treatments, but the populations in this event were quite low so it was not possible to measure differences between the herbicide treatments.

Rain on 3, 12 and 16 October (45 mm, 25 mm and 15 mm) resulted in strong germination events which were assessed on 24 October (187 DAA). By this time Group C$_{triazine}$, Group D and Balance® were no longer effective on sowthistle, with populations established not significantly different to the untreated control (Figure 2).

The most effective treatments had no sowthistle established. These were Valor® and the two mixtures including Group G. Terbyne and mixtures including Group C1 also performed well, with a few escapes. Six other treatments had populations significantly lower than the untreated control, but did not provide satisfactory control of the sowthistle.

Mungindi

The site received 80 mm in the first 30 DAA at this site, including four rainfall events in the first 21 DAA of the herbicides. While these showers did not provide enough rain for weed germinations, it did provide effective incorporation of the herbicides. This is evident by the strong performance of the two Group C products at the first assessment. After 15 mm on 26 and 27 April (54 and 55 DAA) there was a flush of sowthistle, which was counted on 9 May (67 DAA). The most effective treatments at this assessment was Terbyne® Xtreme® and the three mixtures that included Group C1 (Figure 3). Valor® and the two Group G mixtures and Group C$_{triazine}$ and Group C$_{triazine}$ + Group K also performed well at this time, and were not significantly different to the Terbyne® Xtreme® treatments.

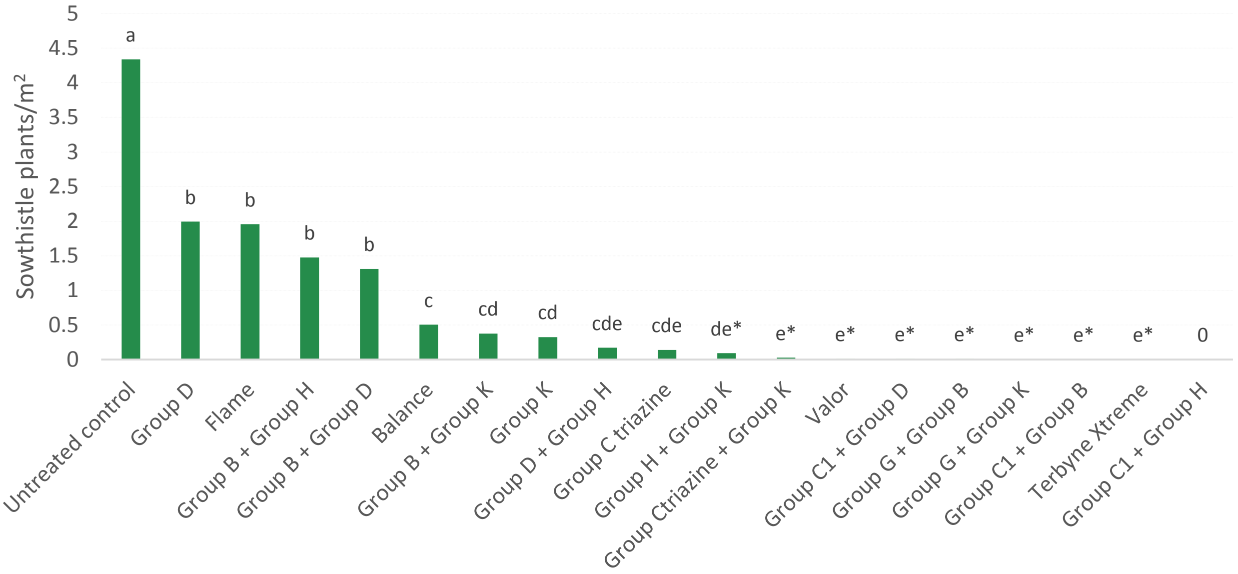

Figure 3. Sowthistle at the Mungindi site, counted 9 May 2017 (67 DAA)

All treatments had significantly less weeds than the untreated control, however Group D, Flame®, Balance® and Group K were not as effective as the best treatments. Mixing Group H with either Group D or Group K did improve the effectiveness of these products, however mixing Group B with Group D, Group H or Group K did not provide the same improvement in efficacy.

The assessment on 9 May also saw a germination of volunteer wheat. While Flame® performed poorly for the broadleaf weed sowthistle, Flame® and mixtures including Group B had the least wheat plants establishing.

The next effective rainfall event at this site occurred in early October. The site had 31 mm on 1–4 October and a further 16 mm on 12 October saw more weeds established, which were assessed 18 October (229 DAA). At this assessment the weeds were mostly Polymeria (*Polymeria pusilla*), Caltrop (*Tribulus terrestris*) and Amaranth (*Amaranthus viridis*), with only scattered sowthistle observed. By this stage the applied treatments were no longer effective, as there was no significant differences for weeds established.

Implications for growers

Sowthistle can germinate over an exceptionally wide temperature range, allowing it to establish at any time of the year. While scattered germinations in spring need to be controlled to prevent further seed set, the greatest impact of residual herbicide will be achieved by delaying application until late summer or autumn,

Flame®, Group D, Balance® and Group K are considered useful residual herbicides for grass weed control; a result observed in many of the trials reported in 'Queensland Grains Research—2016', and again here at the Callandoon site. The trials reported here demonstrated that these products can perform quite poorly on the broadleaf weed sowthistle, when applied alone. The most effective products for sowthistle in these trials were Valor® and the two Group C products, but are limited by their shorter residual active life and, Group C in particular, can be quite weak in controlling grasses (Valor® was not included in the 2016 trials).

In 'Queensland Grains Research—2016', there was a consistent benefit in grass weed control from mixing two products with different modes of action. In the trials reported here the addition of Balance® to either Group D or Group K has provided good control of sowthistle, when these same products applied alone are not providing acceptable control. The addition of Flame®, Group D, Balance® or Group K to the broadleaf active herbicides (Group Cs and Valor®) often improved their efficacy on sowthistle, but more importantly will improve control of the grass weeds common in the northern grains region.

The long term residual control previously observed from Flame® in grasses (greater than 150 days), was not observed for sowthistle in these trials.

Acknowledgements

I would like to thank the growers, whose co-operation and good humour have made these trials a success. This project (UQ00062 'Improving IWM practice in the Northern Region') was co-funded by the Department of Agriculture and Fisheries (DAF) and the Grains Research and Development Corporation (GRDC), and overseen by the DAF weeds research team.

Trial details

Location:	Callandoon, Yagaburne and Mungindi
Crop:	Fallow
Soil type:	Vertosol
In-crop rainfall:	304 mm, 117 mm and 152 mm

Efficacy of residual herbicide—Darling Downs

Duncan Weir
Department of Agriculture and Fisheries

RESEARCH QUESTIONS: *How effective are different residual herbicides in controlling weeds in fallow rotations? | Is the efficacy of residual herbicides improved by mixing multiple modes-of-action?*

Key findings

1. Combining different modes of action can provide better control of broadleaf and grass weeds.
2. Plant back periods need to be considered when using residual herbicides.
3. Cropping systems can influence weed establishment in fallows.

Background

Fallow weed control plays a critical role in the management of cropping land prior to planting. Effective control can result in increased plant available water, higher levels of plant available nitrogen, a wider and more reliable planting window, reduced levels of insect pests, reduced levels of weed vectored diseases and nematodes and reduced physical impacts on planting and crop establishment.

Common sowthistle or milk thistle (*Sonchus oleraceus*), feathertop Rhodes grass (*Chloris virgata*), and fleabane (*Conyza bonariensis*) have become significantly important weeds in our cropping systems. These small seeded weeds germinate from the soil surface, normally requiring several days of moist soil such as extended rain periods or conditions with low evaporation such as high stubble.

Sowthistle emerging from stubble (top) and established sowthistle in fallow cropping rotation, Jondaryan 2017

Herbicides have played a pivotal role in fallow weed management. Unfortunately long term, continual use of knockdown herbicides such as glyphosate has resulted in weeds such sowthistle, awnless barnyard grass (*Echinochloa colona*), liverseed grass (*Urochloa panicoides*) and fleabane developing resistance. Residual herbicides are providing important alternatives to knockdown herbicides through their different modes of action (MOA). The MOA indicates how the chemical affects a plant and is an important method in grouping herbicides.

There is however incomplete data on herbicide efficacy and plant back times on some of the new and existing products. Nine trials were established throughout southern and central Queensland to gather localised data on the efficacy and persistence of residual herbicides and residual herbicide combinations with three established in south-eastern Queensland.

NOTE: Products /combinations in this field experiment were tested FOR RESEARCH PURPOSES ONLY. Not all products used are registered for the purposes we have tested. Always read the label prior to use and only apply herbicides as approved in the Label.

What was done

Three trials were established over the summer of 2016-17 to evaluate, over time, the control of broadleaf and grass weeds by different residual herbicides and herbicide combinations. Two sites were located at Jondaryan and one north of Jandowae.

Eighteen herbicide treatments and two unsprayed controls (Table 1) were applied to small plots using a shrouded 3 m boom spray mounted on a quad bike. Each plot was 3 m x 10 m with four replicates. The boom was fitted with Teejet AIXR 110015 nozzles 0.5 m apart using a spray volume of 100 L/ha. All weeds within the treated area were counted following each emergence and then sprayed out to prevent double counting and competition effects on later germination events.

Ninety days after application (DAA), soil was collected from site and used in pot trials to assess biological symbiotic associations (rhizobia and mycorrhiza), that will be reported seperately.

Table 1. Treatments applied to sites

Trt No.	MOA	Product/s	Rate (/ha)
1	-	Untreated control	
2	-	Untreated control	
3	B	Flame®	200 mL
4	C	Terbyne® Xtreme®	1.2 kg
5	C	Group Ctriazine	3.3 kg
6	D	Group D	3.3 L
7	H	Balance® 750WG	100 g
8	K	Group K	2 L
9	G	Valor® 500WG	280 g
10	B + H	Group B + Group H	200 mL + 100 g
11	B + C	Group C1 + Group B	1.2 kg + 200 mL
12	C + D	Group C1 + Group D	1.2 kg + 3.3 L
13	C + K	Group Ctriazine + Group K	2 kg + 2 L
14	G + B	Group G + Group B	280 g + 200 mL
15	D + H	Group D + Group H	3.3 L + 100 g
16	B + D	Group B + Group D	200 mL + 3.3 L
17	H + K	Group H + Group K	100 g + 2 L
18	C + H	Group C1 + Group H	1.2 kg + 100 g
19	B + K	Group B + Group K	200 mL + 2 L
20	G + K	Group G + Group K	280 g + 2 L

Jondaryan Trial One

The trial site was located on a cracking Black Vertosol soil. It had a high density of mature sowthistle and was well covered with old sorghum and wheat stubble. Stubble was removed from the nil-stubble treatments using harrows prior to the application of treatments. Treatments were applied on 9 November 2016.

Treatment plots with and without stubble

Assessments were made on:

- 20 December 2016 (41 DAA)
- 12 January 2017 (62 DAA)
- 5 April 2017 (147 DAA)
- 6 June 2017 (208 DAA)

Soil was collected for biological assessment on 23 February 2017 (106 DAA).

Jandowae

This trial was located on a Grey Vertosol soil which only had a small amount of forage sorghum stubble cover. A split plot trial design was used with each main plot consisting of two adjacent plots (one treated and a nil treatment). Plots were 10 m long and 4 m wide, split into a 3 m treated area and a 1 m nil area randomly placed on either side of the treated area. Treatments were applied on 23 November 2016.

Assessments were made on:

- 12 January 2017 (51 DAA)
- 27 April 2017 (156 DAA)

Soil was collected for biological assessment on 1 March 2017 (97 DAA).

Wheat, barley and oats were planted 25 May 2017 into moisture and establishment counts recorded on 13 July 2017.

Jondaryan Trial Two

This trial site was located on a cracking Black Vertosol soil block. It had a high density of mature sowthistle and partially covered with old sorghum and wheat stubble. Treatments were applied 27 April 2017. Cotton was planted across the trial area on 6 November 2017.

Assessment was made 4 November 2017 (193 DAA) and cotton establishment counts on 13 December 2017 (232 DAA)

Results

Jondaryan Trial One

The first germination event was triggered by 75 mm rain on 6-7 December 2016 (28 DAA) and was counted on 20 December 2016 (41 DAA). Grass emergence was very low averaging 2.25 plants per 20 m^2 plot area. Plots with stubble had significantly higher weed counts than plots without stubble. Due to the low grass populations established, no significant difference was measured between herbicide treatments.

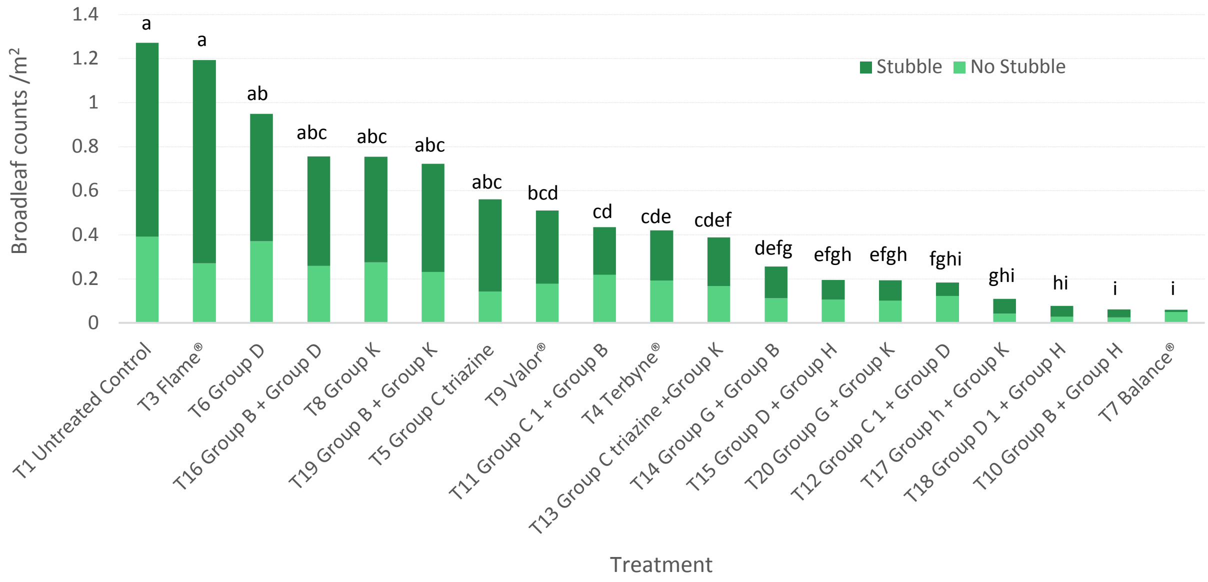

Figure 1. Back transformed data showing average total broadleaf weed count/m^2 in stubble systems and no-stubble systems at Jondaryan Trial One; data counts taken on 20 December 2016 (41 DAA)
Columns with similar letters are not significantly different

Total broadleaf counts in T7, T18, T10, T12 and T17 were significantly lower than all other treatments in the stubble system (Figure 1) but not significantly different from each other.

Sowthistle counts in the T1 untreated control, T6 and T8 were significantly higher than all other treatments.

Rainfall through December 2016 and early January 2017 (62 mm) resulted in another emergence, which was counted on 12 January 2017 (62 DAA), however uneven and low weed populations prevented significant results. Cumulative small rainfall events throughout January, February and March 2017 enabled another assessment to be undertaken on 5 April 2017 (147 DAA). At this assessment T2, T14, T19, T10, T16, T11, T8, T17 and T9 had significantly lower total grass counts than all other treatments. There was no significant difference in total grass counts between the stubble and no-stubble systems.

There were significantly more sowthistle established in the presence of stubble than the no-stubble system, but herbicide performance was not affected by the presence of stubble. (Figure 2). T14 had a significantly lower sowthistle count than all other treatments except T18 (which was statistically similar). T14 also had statistically lower total broadleaf weed count than all other treatments.

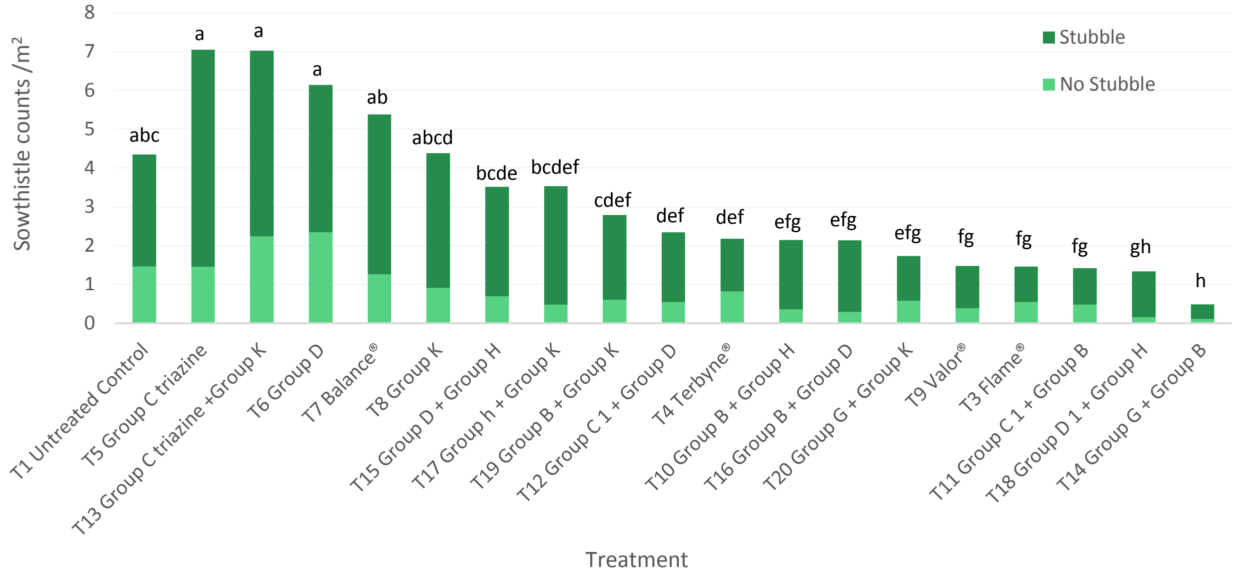

Figure 2. Back transformed data showing sowthistle counts/m^2 for stubble and no-stubble systems at Jondaryan Trial One; counts were taken on 5 April 2017 (147 DAA)
Columns with similar letters are not significantly different

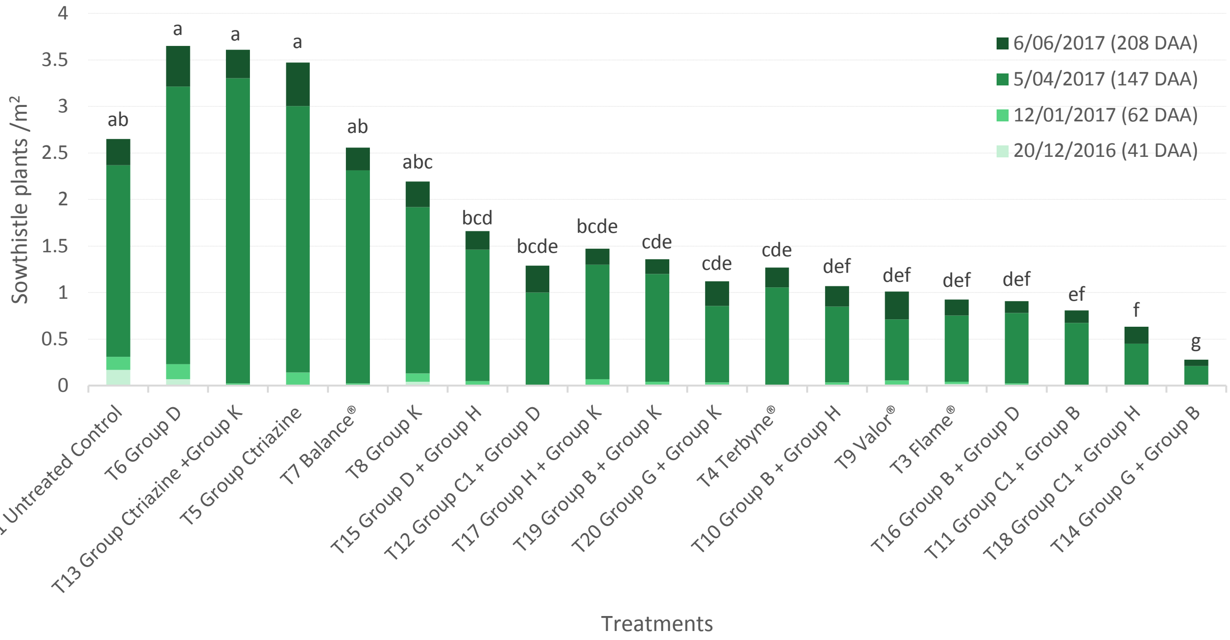

Figure 3. Cumulative sowthistle counts at Jondaryan Trial One combined for both the stubble and no-stubble systems
Columns with similar letters are not significantly different

A final weed count was taken on 6 June 2017, 208 DAA. Very few grass weeds were recorded. There were significant differences between herbicide treatments for both sowthistle and total broadleaf weeds however there wasn't a difference between the stubble and non-stubble systems. T14, T16 and T11 had the best control of sowthistle and total broad leaf weed emergence.

Cumulative sowthistle counts over the length of the trial show significant differences between treatments as well as differences between the stubble and no-stubble system (Figure 3).

Jandowae

A dry period followed the application of the treatments delaying incorporation into the soil. On 21 December 2016, 33 mm of rain was received and a further 15 mm on 3 January 2017. This rain initiated a weed emergence allowing a plant count to be undertaken on the 12 January 2017 (51 DAA).

Large numbers of awnless barnyard grass (*Echinochloa colona*) and feathertop Rhodes grass (*Chloris virgata*) emerged and significant responses to the treatments were recorded for grass weeds. High levels of control were achieved by T18, T6, T8, T13, T9, T19, T12 T3, T11 and T4. Average grass counts in this group ranged from 0 plants/m^2 for T18 to 0.7 plants /m^2 for T4. Five treatments (T4, T1, T6, T5 and T9) provided little control and were significantly worse than all other treatments ranging from 18 grass plant /m^2 (T9) to 60 grass plants /m^2 (T4).

T19, T11, T16, T10, T14, T20, T3, T15 and T18 had significantly less broadleaf weeds than other treatments, while T1, T6, T13, and T8 had significantly higher broadleaf weed counts than other treatments.

Between the start of January and the end of March only 61 mm of rain was received, resulting in very few weeds emerging over this period. Rain over 30 and 31 March 2017 (67 mm) initiated another emergence allowing a second assessment to be made on 27 April 2017. Although weed emergence was very patchy, significant differences were observed between treatments.

Treatments T10, T11, T16, T19 and T20 provided the highest level of control of sowthistle ranging from 0.4 sowthistle/m^2 for T20 to 2.2 sowthistle/m^2 for T11. T11, T16, T19 and T20 had the highest level of control of total broadleaf weeds ranging from 0.56 broadleaf weeds/m^2 for T11 to 4.4 broadleaf weeds/m^2 for T16.

Significant differences between treatments were identified for awnless barnyard grass (ABYG) , feathertop Rhodes grass and total grass counts. T16 had significantly better control of total grasses compared to all other treatments averaging only 0.05 grass plants/m^2. T14,

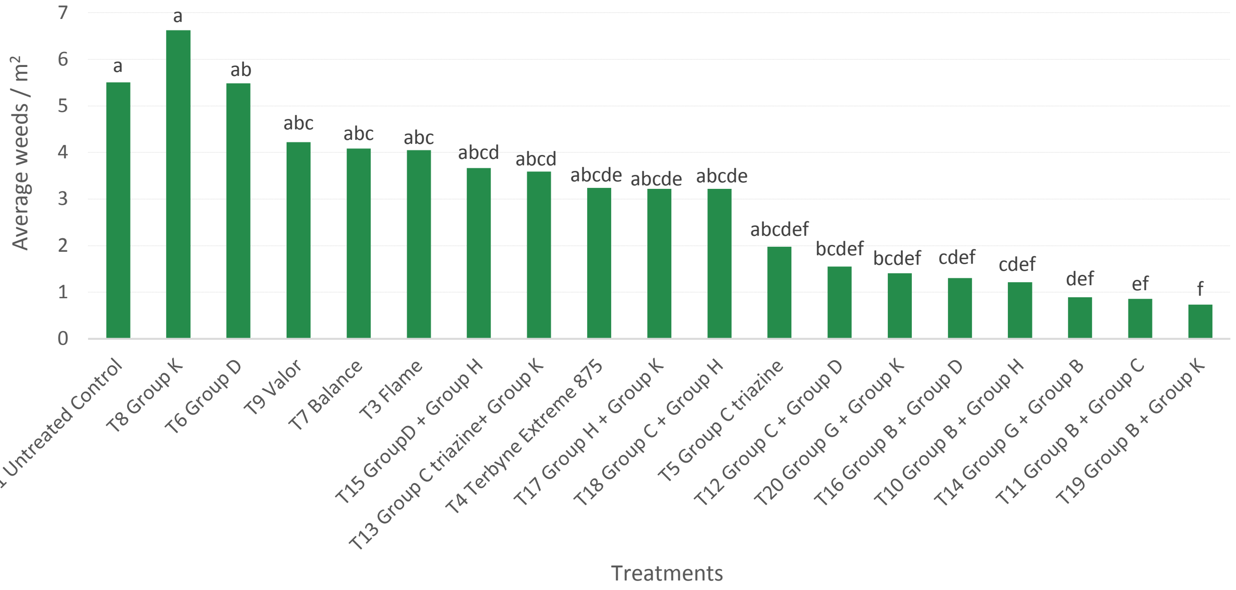

Figure 4. Cumulative average weed counts for grass and broadleaf weeds for two assessment dates at Jandowae
Columns with similar letters are not significantly different

T12 T19 and T11 also provided good control averaging under 0.5 grass plants/m^2. T16, T20, T14, T10 T19, T11 and T12 had better control of ABYG than other treatments averaging less than 1.6 grass plants/m^2.

Cumulative weed counts for both assessment times showed good control over time (Figure 4).

Jondaryan Trial Two

Very few weeds emerged in the seven months following the application of the treatments, as a result of only receiving 80 mm of rainfall during April to September 2017. October rainfall of 77 mm initiated an emergence and an assessment of the treatments was made on 4 November 2017. Sowthistle was the only established weed and had a wide range of maturities. T15, T12, T7, T18, T16, T11, T10, T13 and T19 were significantly lower than all other treatments. Average sowthistle counts were less than 0.2 sowthistle plants/m^2 in these best treatments. T6 and T5 were significantly higher than all other treatments and not significantly different from the unsprayed control (T1).

Cotton was planted into the treated area following rain. Plant counts taken on 13 December 2017 showed that six treatments, T14, T19, T16, T10, T3 and T11 had impacted cotton establishment, with significantly lower establishment counts than all other treatments (Figure 5). All of these treatments contained Group B, which has a 24 month plant-back period to cotton.

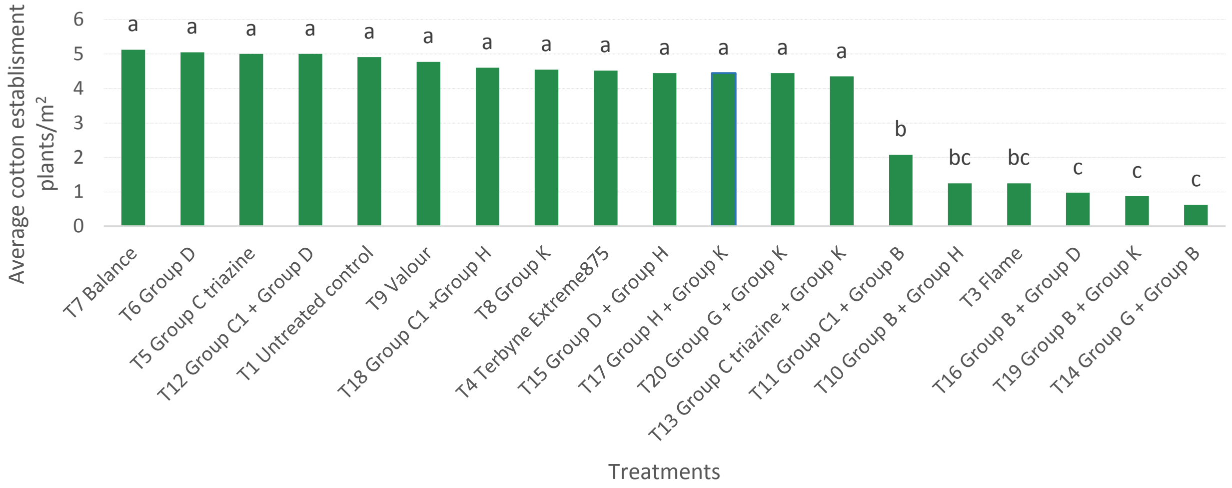

Figure 5. Cotton establishment counts 13 December 2017 at Jondaryan Trial Two
Columns with similar letters are not significantly different P(0.05)

Implications for growers

Weed control during fallow periods of a cropping program can be challenging particularly for weeds such as sowthistle, ABYG and feathertop Rhodes grass. Residual herbicides can provide important alternatives to knockdown herbicides such as glyphosate.

These trials indicate that combining herbicides with different modes of action can provide better and more consistent control of broadleaf and grass weeds than herbicides applied individually. T3 Flame® (Group B), T7 Balance® (Group H) and T9 Valor® (Group G) have provided control of sowthistle and other broadleaf weeds however when combined with herbicides of different modes of action (for example T14, T10, T11, T20, T19, T18), results can be significantly better.

Similarly, when T3 Flame® (Group B), which is registered to control grass weeds, is combined with herbicides of other modes of action, for example T16, T14, T19, T11, better results can be achieved on a wider range of weeds. T6 (Group D), T4 Terbyne® Xtreme®875 (Group C), T9 Valor® (Group G) and T8 Group K have also been shown to provide better control when combined with herbicides with other modes of action.

Results also indicate that control of both broadleaf and grass weeds can be achieved when herbicides with different modes of action are combined. The use of residual fallow herbicides can play an important role in an integrated weed management program.

Growers must consider the plant back period when using residual herbicides. Results clearly show the impact of residual herbicides on following crops that are susceptible, particularly when weather conditions haven't been favourable for the breakdown of the chemical (long dry periods).

The tillage system used should also be taken into account when considering weed control options in fallow situations. Minimal tillage systems where stubble is retained on the surface provides more conducive conditions for the emergence of small seeded weeds such as sowthistle and feathertop Rhodes grass. This was clearly demonstrated in the Jondaryan Trial One where sowthistle numbers were significantly higher when stubble was retained on the surface compared to the system where crop residue had been removed.

Acknowledgements

I would like to thank the growers for their help and support in these trials. The project was co-funded by the Department of Agricultures and Fisheries (DAF) and the Grains Research and Development Corporation (GRDC) and overseen by the DAF weeds research team.

Trial details

Location:	Jondaryan and Jandowae
Crop:	Fallow followed by cotton (Jondaryan), Fallow (Jandowae)
Soil type:	Vertosol
In-crop rainfall:	Jondaryan T1: 237 mm Jandowae: 343 mm Jondaryan T2: 247 mm

T20 (Group D+ Group K) on the right compared to the untreated area on the left; Jandowae 12 January 2017 (51 DAA)

Efficacy of residual herbicides on sowthistle—Central Queensland

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Department of Agriculture and Fisheries

RESEARCH QUESTIONS: *How effective are different residual herbicides in controlling sowthistle, and how does this change over time?* | *Is the efficacy of residual herbicides improved by mixing multiple modes-of-action?*

Key findings

1. Winter fallow or pre-plant application of selected residual herbicides reduced sowthistle and other weed populations.
2. Mixing herbicides together provided higher levels of efficacy than standalone applications.
3. Some treatments provided acceptable control out to six months.
4. Tank mixing residuals has benefits, but also may have ramifications on future rotations if not carefully considered.

Background

Common sowthistle or milk thistle (*Sonchus oleraceus*) is widespread in Queensland's cropping areas. Sowthistle was once considered a winter-dominant weed, but is capable of germinating in temperatures between 5°C and 35°C, so can potentially germinate year-round.

Similar to other small-seeded cropping weeds (e.g. feathertop Rhodes grass (FTR) and fleabane), sowthistle prefers to germinate from the soil surface, with very few seedlings emerging from below 1 cm. Sowthistle also requires several days of moist soil to germinate, so often only germinates after extended rain periods or in conditions with low evaporation (i.e. cool conditions or high stubble).

Glyphosate and 2,4-D are antagonistic for control of sowthistle, so glyphosate alone is often relied on for control in fallows. Several populations have been confirmed resistant to glyphosate and Group B (Chlorsulfuron).

In response to the discovery of evolved glyphosate-resistant populations of common sowthistle in the Liverpool Plains of NSW, two GRDC-funded field surveys have been conducted from 2014 to 2017 to determine the extent of this issue across the northern grains region.

'There have been 29 newly identified common sowthistle populations that have evolved resistance to glyphosate. Four of these populations were from properties in Queensland, with locations ranging from Central Queensland to the Southern and Western Downs. The remainder of the resistant populations were located in New South Wales. While glyphosate remains a viable control option for common sowthistle, it is clear that it should not be the only option used. More diverse chemical and non-chemical practices should be used in combination for controlling common sowthistle and to preserve glyphosate as one of the effective tools in the toolbox for common sowthistle control.' (Van Der Meulen A and Jalaludin A 2018, pers comm.)

One strategy to increase the diversity of chemicals used is to increase the number of modes-of-action applied by using residual herbicides.

NOTE: Products /combinations in this field experiment were tested FOR RESEARCH PURPOSES ONLY. Not all products used are registered for the purposes we have tested. Always read the label prior to use and only apply herbicides as approved in the Label.

What was done

Three central Queensland (CQ) sites were selected in March 2017; two near Gindie and one at Mount McLaren. One Gindie site was brigalow scrub soil and the other on open downs soil, 31 and 52 km south of Emerald respectively. Mount McLaren was on open downs soil 57 km north of Clermont. Trial sites were located in known sowthistle patches, confirmed by emergences after tropical cyclone Debbie.

Nineteen treatments and two unsprayed controls (Table 1) were applied using a three-point-linkage tractor mounted shrouded boom with 100 L/ha water rate and 110 015 Agrotop® airmix nozzles to produce a coarse (C) droplet size. Sprayed plots were 2 m wide by 10 m with weeds counted in an area 1 m wide by 8 m long (10 m for controls) in the middle of each plot. Trials had four replicates at Gindie brigalow and Mount McLaren and three replicates for Gindie open downs.

Assessments were carried out approximately two weeks after rain events. Plots were sprayed out to prevent double counting or weed competition impacting future emergences. Soil collected from the Gindie open downs site was placed in cold storage for later use in pot trials to assess herbicide impacts on soil biological symbiotic associations with rhizobia and mycorrhiza (reported separately).

Gindie brigalow

This site was in 2015/16 mungbean stubble after sowthistle escapes in the 2016 winter fallow. An area with standing sowthistle stems was selected for the trial.

Treatments were applied on 27 April 2017, then the paddock was planted to chickpea in the first week of May 2017.

Weeds were assessed on:

- 27 July (91 Days After Application - DAA)
- 24 October (180 DAA)

Gindie open downs

This site was in 2016 wheat stubble with old sowthistle plants on the adjacent contour bank. The trial was planned to be planted to chickpea, similar to the other sites, but was too dry, so remained fallow for the duration of the trial.

Treatments were applied 5 April 2017. The weeds were assessed on:

- 12 July (98 DAA)
- 24 October (202 DAA)

Soils were collected for biological assessment on 13 July 2017 (99 DAA).

Mount McLaren

This site was in 2016 wheat stubble with flowering and mature sowthistle present throughout the trial. Adult plants were successfully managed by the farmer co-operator a few days after treatments were applied.

Treatments were applied on 3 May 2017 and the site planted to chickpea on 10 May 2017.

Weeds were assessed on:

- 31 July (98 DAA)
- 17 October (202 DAA)

Table 1. Treatments applied at all three sites

Trt No.	MOA	Product/s	Rate (/ha)
1	-	Untreated control	
2	-	Untreated control	
3	B	Group B	200 mL
4	C	Terbyne® Xtreme®	1.2 kg
5	C	Simazine	1.1 kg
6	D	Group D	3.3 L
7	H	Balance®	100 g
8	K	Group K1	2 L
9	G	Group G	280 g
10	B + H	Group B + Group H	200 mL + 100 g
11	B + C	Group C1 + Group B	1.2 kg + 200 mL
12	C + D	Group C1 + Group D	1.2 kg + 3.3 L
13	C + K	Group C2 + Group K1	1.1 kg + 2 L
14	G + B	Group G + Group B	280 g + 200 mL
15	D + H	Group D + Group H	3.3 L + 100 g
16	B + D	Group B + Group D	200 mL + 3.3 L
17	H + K	Group H + Group K1	100 g + 2 L
18	C + H	Terbyne® Xtreme® + Balance	1.2 kg + 100 g
19	B + K	Group B + Group K1	200 mL + 2 L
20	G + K	Group G + Group K1	280 g + 2 L
21	K	Group K2	118 g

Results

Four weeds were assessed; sowthistle, african turnip weed (*Sisymbrium thellungii*), wild sunflower (*Verbesina encelioides*) and sweet summer grass (*Brachiaria eruciformis*). Herbicide treatments responded similarly across trials so data is presented by weed species.

Two trials had chickpea planted into them, while the third site was too dry and was not planted. There was no observable crop herbicide injury from any of the treatments, with no impact on plant stand or crop height. Dry conditions were experienced over the 2017 autumn and winter in CQ, which may have limited crop damage symptoms. However, the lack of crop damage for these two trials with crop is not an indication or a recommendation to use herbicides in unregistered use patterns.

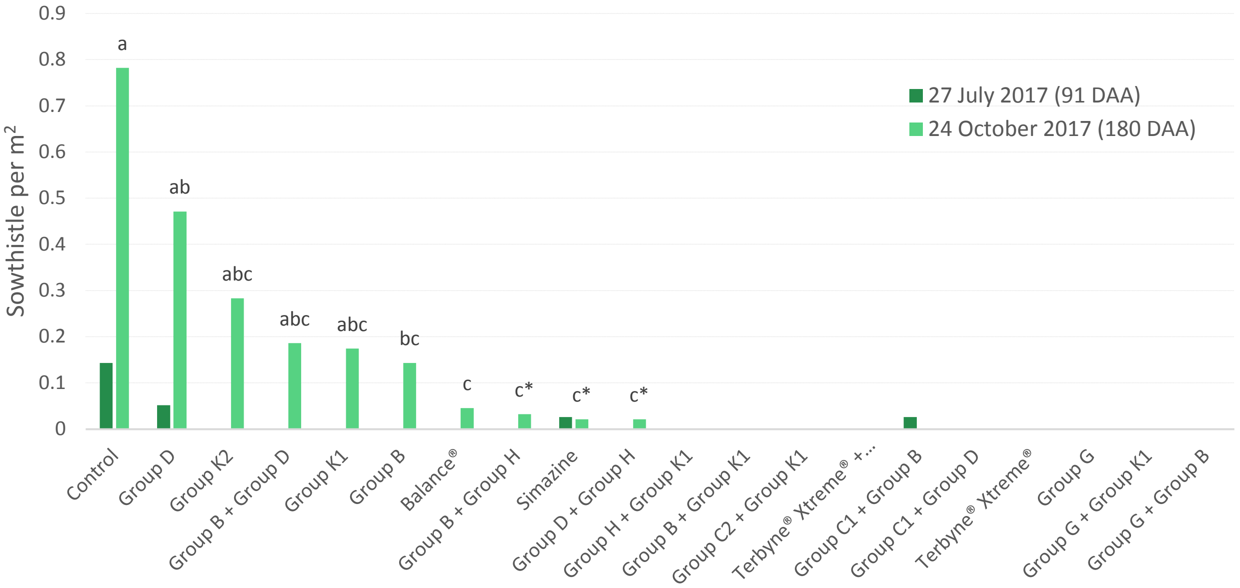

Figure 1. Treatment assessment on sowthistle for the Gindie brigalow site
Letter indicate significant differences between treatments with escapes, P(0.05); * = not significantly different to 0

There were no significant differences measured at the Mt McLaren site, however the trends at this site support the significant responses measured at the other two sites.

Sowthistle

Dry conditions meant that germinations were quite low for all three sites with average population counts no higher than 1.5 plants/m^2. For the first assessments (at around 100 DAA across the three sites), only Group D, Group K and Group C products applied alone were not providing complete control. The Group H product was inconsistent, but all herbicide mixtures provided acceptable levels of control.

For the second assessment, Terbyne® Xtreme® and Group G had no weeds present. Balance® and Simazine were also significantly better than the untreated control with very low numbers of weeds present. Any herbicide mixtures including Group K were significantly effective, regardless of what it was mixed with, despite Group K performing poorly when applied alone.

African turnip weed

African turnip was present at both Gindie sites. For the first assessment, all treatments were providing effective control, excluding Group D, which had limited escapes. For the second assessment all treatments were still performing significantly better than the untreated control, however Group D, Group H and the two group K products had limited escapes, when not tank mixed.

Wild sunflower

For the first assessment, group C products and Group K2 provided reduced efficacy, with all other treatments showing excellent levels of control. By the second assessment (180 DAA), treatments including Group B, Terbyne® Xtreme® or Balance® were still performing well, although Balance® was not as strong by itself as it was when tank mixed. The two Group Ks, Group D and Simazine applied alone were not providing a significant level of improvement over the untreated control.

Sweet summer grass

Sweet summer grass (SSG) was observed at the two Gindie sites. For the first assessment at 100 DAA, Simazine and Terbyne® Xtreme® failed to consistently provide control. All other treatments provided excellent levels of control.

By the second assessment, all combinations of residual products were performing significantly better than the individual Group B, group K, Balance® and Terbyne® Xtreme® products (Figure 2). Only the Group G and Group D were matching the tank mixes for efficacy. Group B performed somewhere in-between but inconsistently. Interestingly, some mixtures with Group K were providing good control despite the apparent weakness of the product when not tank mixed.

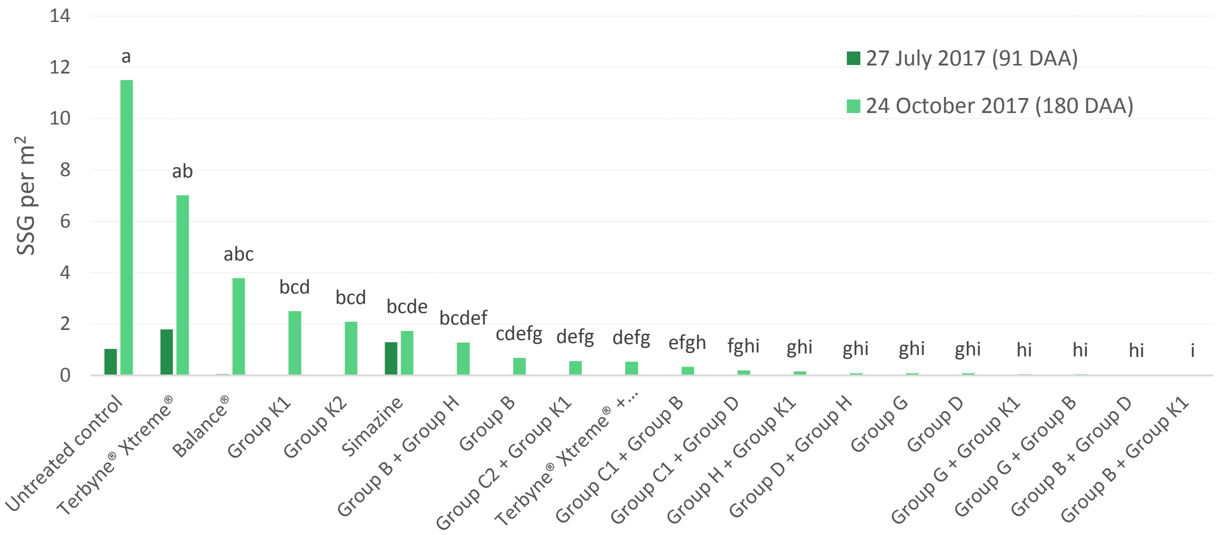

Figure 2. Efficacy of single and mixed residual herbicide treatments in chickpea crop, 91 and 180 days after application (DAA) at the Gindie brigalow site
Treatments with similar letters are not significantly different; P(0.05)

Implications for growers

Residual herbicides are an integral tool for weed management within a farming system. As resistance to knockdown herbicides continues to spread across the region, a reliance on residual herbicides, strategic rotations and management practices will increase. Trials like these highlight some key points to remember when targeting winter in-crop or fallow weeds.

CQ typically has significantly less in-crop rainfall to activate residual products during winter, as was the case in 2017. If rainfall criteria are not met, there is a higher chance that breakdown of some of the products will be prolonged well past label indicated plant back periods. It must be remembered that for UV-stable products, the plant back countdown starts after activation by rainfall (10mm or more) post-application, not the day of application.

Observations for these three sites continued on well into late spring/early summer of 2017 or in excess of 200 DAA and treatment effects could still be observed. That could imply that if susceptible crops were planted into those treatments during summer, crop damage could occur.

As these results indicated, excellent control of all observed species is possible with the right product or products in combination. However the best combination of herbicides did change from species to species. The target species for this trial was sowthistle, and it was Terbyne® Xtreme® and Group G which performed the best, both individually and as a combination. Interestingly any combination with Group K as a mixing partner seemed to perform significantly better than Group K applied alone.

African turnip was managed reasonably well by all treatments, excluding Group D, Group K and Balance® as stand-alone products. Wild sunflowers were the most challenging to control, however once again any of the combinations provided superior control over the untreated control. Group B and Terbyne® Xtreme® were the most effective for wild sunflowers. Finally, for SSG, Group D and Group G really outperformed the other chemicals, along with the combinations including these products.

For further reading on residual herbicides, how they breakdown and how long they can last in the system the following publications (available from the GRDC website) may be useful:

- Nikki Seymour *et. al.* Impacts of residual herbicides on soil biological function. GRDC Update Papers, 27 Febraury 2018
- Mark Congreve and John Cameron. Soil behaviour of pre-emergent herbicides in Australian farming systems: a reference manual for agronomic advisers.

Acknowledgements

We would like to thank the growers whose co-operation and assistance made these trials a success. This project (UQ00062 'Improving IWM practice in the Northern Region') was co-funded by the Queensland Department of Agriculture and Fisheries (DAF) and the Grains Research and Development Corporation (GRDC) and overseen by the DAF weeds research team.

Trial details

Locations:	Gindie and Mount McLaren
Crop:	Pre-applied, incorporated by chickpea planting (Gindie brigalow and Mt. McLaren) Winter fallow (Gindie open downs)
Soil type:	Vertosol
In-crop rainfall:	170 mm for the Gindie sites, most fell during October. 91mm for Mount McLaren, including 39 mm in mid-October.

Above and below: Visual differences between treatments at the Ginde site (about 180 DAA)

Pathology research

In 2017, the regional agronomy team continued research into mungbean pathology. Key areas of focus were powdery mildew control, developing recommended spray programing, and determining the impact of row spacing on spray efficacy.

Managing disease in mungbeans remains one of the major production challenges facing growers, with most varieties being moderately to very susceptible to the main diseases. Powdery mildew (*Podosphaera xanthii*) is found wherever the crop is grown and can cause significant yield loss, particularly in late planted crops when weather conditions are more favourable to disease development. Although newer varieties do have better plant disease resistance characteristics, most are still rated 'susceptible' or 'very susceptible'. Only Green Diamond⁽ᐧ⁾ and Jade-AU⁽ᐧ⁾ have a slightly higher rating of 'moderately susceptible' to powdery mildew.

Plant resistance and the application of foliar fungicides are the only two viable options available for the management of powdery mildew in mungbeans. Recent trials indicate that the best level of control can be achieved when the first fungicide spray is applied between the first sign of the disease (normally found on the lower leaves of a vegetative crop) to when the disease can be found in the lower third of the canopy. The first spray should be followed by a second spray two weeks later.

Research in 2017 confirmed that control of powdery mildew using well-timed fungicide sprays can be very effective, resulting in significantly higher yields when compared to unsprayed controls, as well as having significantly greater economic benefits. Row spacing appears not to have a major impact on spray efficacy, however further research is required.

Treated (back) and untreated (front) mungbeans showing differences in the development and powdery mildew

The impact of different management practices on the control of powdery mildew in mungbeans—Southern Downs

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RESEARCH QUESTIONS: *What is the effectiveness and most efficacious application timing of three different fungicides on the control of powdery mildew? | Do yield differences occur under different fungicide application strategies and row spacing?*

Key findings

1. Controlling powdery mildew in mungbeans using registered fungicides can be a cost effective management practice.
2. Narrow row spacings can significantly increase mungbean yield.
3. Fungicide efficacy is not impacted by different row spacings.
4. There was no difference in efficacy between the three fungicides trialled.

Background

Powdery mildew in mungbeans is caused by the fungus *Podosphaera xanthii* and is found wherever the crop is grown in Australia. The fungus requires a living host and is unable to survive on plant residues. Although there are several confirmed hosts which can carry over the disease from one season to another, infection can also originate from spores traveling long distances in the wind, given the right conditions. In Queensland and New South Wales, the disease is favoured by moderate temperatures (22-26°C) with high relative humidity, and tends to appear in late-planted summer crops maturing into cooler conditions.

Infected plants have a greyish-white powdery growth on the surface of leaves, stems and pods (Figure 1). Infection can appear at any growth stage, depending on weather conditions.

Yield losses due to powdery mildew vary from year to year but can be significant if development occurs before or at flowering. Yield losses most commonly range between 10 and 15%, however they can be as high as 46% depending on the variety, growth stage at infection, and rate of disease development.

Plant resistance and foliar fungicides are the only two viable options available for the management of powdery mildew in mungbeans. Most varieties are rated susceptible, except for Green Diamond(D) and Jade-AU(D), which have a slightly higher rating of 'moderately susceptible' to powdery mildew.

Figure 1. Advanced powdery mildew in mungbeans at Hermitage Research Station

Control of powdery mildew using fungicides has been shown to be both financially viable and highly effective. Past trials indicate that the best results are achieved when the first fungicide spray application is applied at the first sign of powdery mildew on the lower leaves of a vegetative crop, followed by a second spray two weeks later.

Row spacing has also been shown to be very important in optimising crop yield. However, there has been little research into the effect it has on the development of powdery mildew in the crop and the impact it has on control methods.

What was done

Trials were established at Clifton (Missen Flat) and Warwick (Hermitage Research Station – HRS). Both trials used a randomised block design consisting of three factorials (row spacing, fungicide treatment and fungicide application timing) and four replications. Plot size at Missen Flat was 2 m wide x 12 m long while plots at HRS were 2 m x 8 m. Row spacing treatments were 0.25 m, 0.5 m and 1 m. Plots were planted with Jade-AU$^{\phi}$ mungbean, the variety with the highest level of resistance and currently considered the industry standard. Spreader rows were planted with mungbean var. Berken (rated very susceptible to powdery mildew).

Fungicides applied were:

- Folicur SC® (430 g/L tebuconazole) at 145 mL/ha
- Group 3 fungicide (500 g/L propiconazole) at 250 mL/ha
- Veritas® (200 g/l tebuconazole + 102 g/l azoxystrobin) at 300 mL/ha.

The Folicur SC® and Veritas® fungicides were used under the Australian Pesticides and Veterinary Medicines Authority (APVMA) permit numbers PER13979 and PER82104, respectively. Fungicide treatments (Table 1 and 2) were applied using a pressurised hand-held two metre boom sprayer delivering 134 L/ha at 5 km/hr.

NOTE: Products in this field experiment were tested FOR RESEARCH PURPOSES ONLY. Not all products used are registered for the purposes we have tested. Always read the label prior to use and only apply herbicides as approved in the Label.

Table 1. Treatments applied at Missen Flat

Tr.	Description	Total sprays
T1	Control, no fungicide application	0
T2	Spray 1: applied 28 days after emergence	1
T3	Spray 1: applied at the first sign of powdery mildew	1
T4	Spray 1: applied at the first sign of powdery mildew Spray 2: applied 14 ± 2 days after spray 1	2
T5	Spray 1: applied when powdery mildew was 1/3 up the canopy	1
T6	Spray 1: applied when powdery mildew was 1/3 up the canopy Spray 2: applied 14 days ± 2 days after spray 1	2

Table 2. Treatments applied at Hermitage Research Station (HRS)

Tr.	Description	Total sprays
T1	Control, no fungicide application	0
T2	Spray 1: applied 28 days after emergence	1
T3	Spray 1: applied 28 days after emergence Spray 2: applied 14 ± 2 days after spray 1	2
T4	Spray 1: applied at the first sign of powdery mildew	1
T5	Spray 1: applied at the first sign of powdery mildew Spray 2: applied 14 ± 2 days after spray 1	2
T6	Spray 1: applied when powdery mildew was 1/3 up the canopy	1

Table 3. Powdery mildew incidence rating (IR) scale (developed by Sue Thompson USQ)

IR	Infection description
1	No powdery mildew colonies observed on any plants
2	Small colonies in lower 1/3 of canopy, up to 75% of plants affected
3	Colonies in the lower 1/2 canopy, > 75% of plants affected
4	Colonies in the lower 2/3 of canopy, up to 75% of plants affected
5	Colonies in the lower 2/3 of canopy, > 75% of plant affected
6	Colonies in the lower 2/3 of canopy, 100% of plants affected
7	Colonies in the lower 2/3 of canopy, 100% of plants affected, some plants with colonies in the top 1/3 of canopy
8	Colonies to top of plant with > 75% of plants affected
9	Colonies to top of plant with 100% of plants affected and heavy leaf drop

Table 4. Powdery mildew severity rating (SR)

SR	Infection description
1	No powdery mildew colonies observed
2	Small colonies covering up to 10% of leaf area
3	Larger colonies covering up to 25% of leaf area
4	Heavy infection covering up to 75% of the leaf area
5	Severe infection covering more than 75% of leaf area

Treatment plots were regularly monitored and assessed for powdery mildew. Incidence levels (or incidence rating IR) and severity of infection (or severity rating SR) were recorded (Tables 3 and 4). Plots were harvested and grain yield per hectare calculated.

Results

Missen Flats

The trial was planted on 25 January 2017 and harvested on 11 May 2017. Powdery mildew was first observed on 7 March 2017 and developed rapidly in the crop. Plots were rated on a whole plot basis on 7 March 2017 (34 DAE), 19 March 2017 (46 DAE), 24 March 2017 (51 DAE), 2 April 2017 (60 DAE), 10 April 2017 (68 DAE) and 19 April 2017 (77 DAE).

Powdery mildew developed rapidly in the control treatment with no fungicide applied (T1) and reached an average incidence rating (IR) of 8.07 at 65 DAE. Fungicide treatment T2, which received a fungicide application at 28 days after emergence and before powdery mildew was first observed in the crop, had an IR of 8.03 at 65 DAE indicating that the spray had no effect on the disease establishment and development in the crop. When fungicide treatments were applied at first sign (T4 and T5) there was a suppressive effect on the development of the disease early in the crop's development. However, the disease did re-establish itself late in the crop's life resulting in T4 and T5 finishing with IR levels similar to the control treatment (T1). T5 and T6 fungicide treatments were applied when the disease was 1/3 up the plant canopy by which time the disease was well established in the crop. These treatments slowed the progress of the disease, however it eventually continued to develop, finishing at similar IR levels as the control treatment (T1) (Figure 2). No significant difference in incidence rating was found between the three different fungicides used. Treatment differences can be seen in Figures 4 and 5.

No significant difference in yield was found between the three fungicides used in the trial. However, there were significant differences in yields between treatments and there was a significant difference in yield between the different row spacing treatments (Figure 3). T4 and T6 (two spray applications) yielded significantly better than T1, T2 and T3 for all row spacing treatments. T5 yielded significantly better than T1 and T2 for all row spacing treatments.

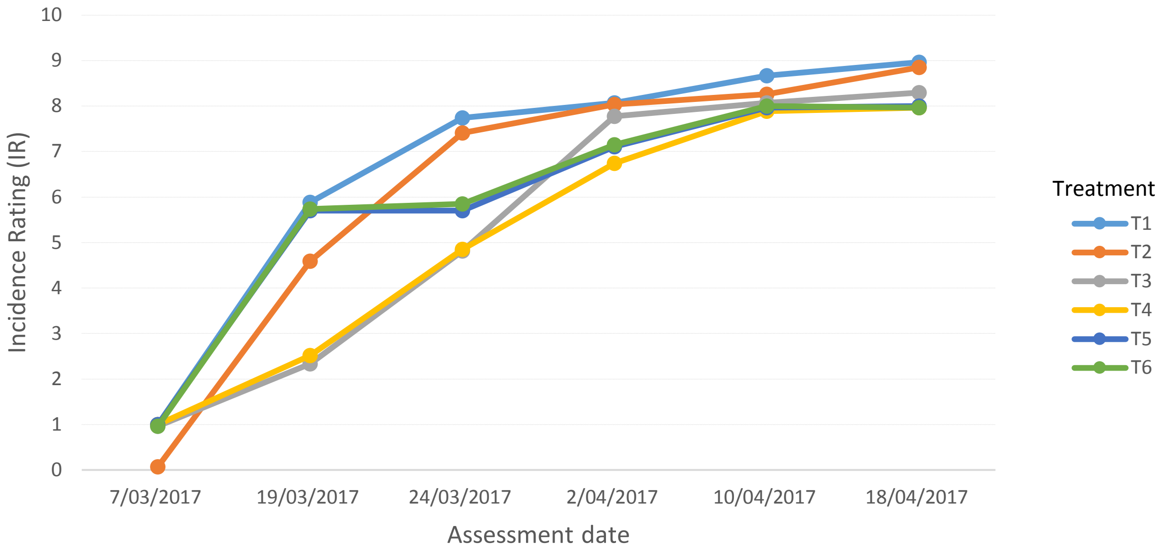

Figure 2. Development of powdery mildew in mungbeans at Missen Flats 2017; points represent the mean of four replications at each respective assessment date

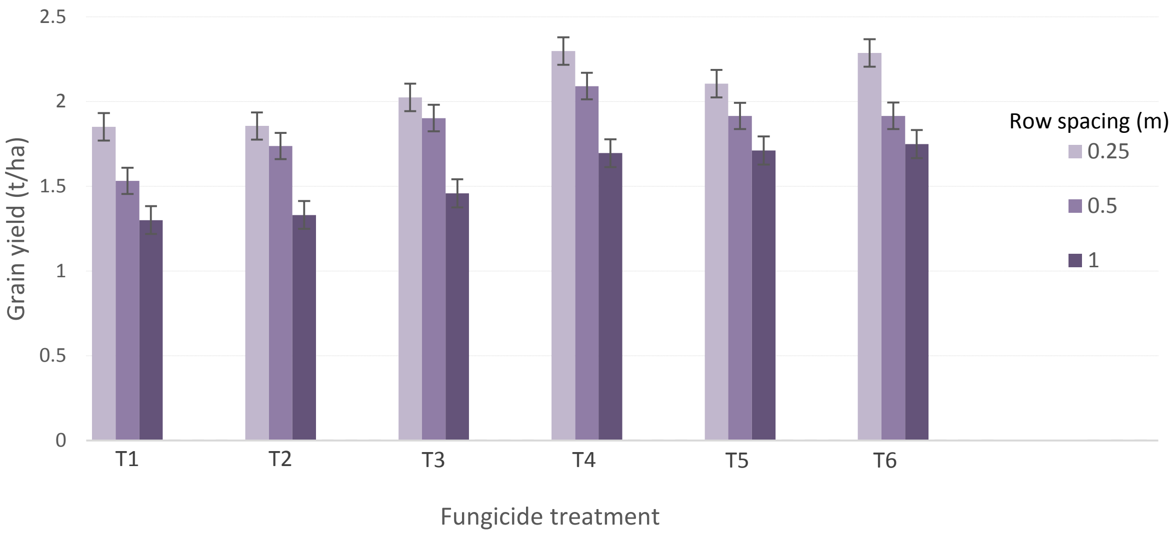

Figure 3. Average grain yields for treatments at Missen Flat 2017 for different row spacings (lsd = 0.164); bars represent the mean of four replications for each fungicide treatment

Figure 4. T5 Mungbeans treated with two fungicides sprays on one m row spacing (IR 6, SR 2); image taken 18 April 2017 (73 DAE)

Figure 5. Untreated control showing mungbeans with severe development of powdery mildew (IR 8, SR 4); image take 18 April 2017 (73 DAE)

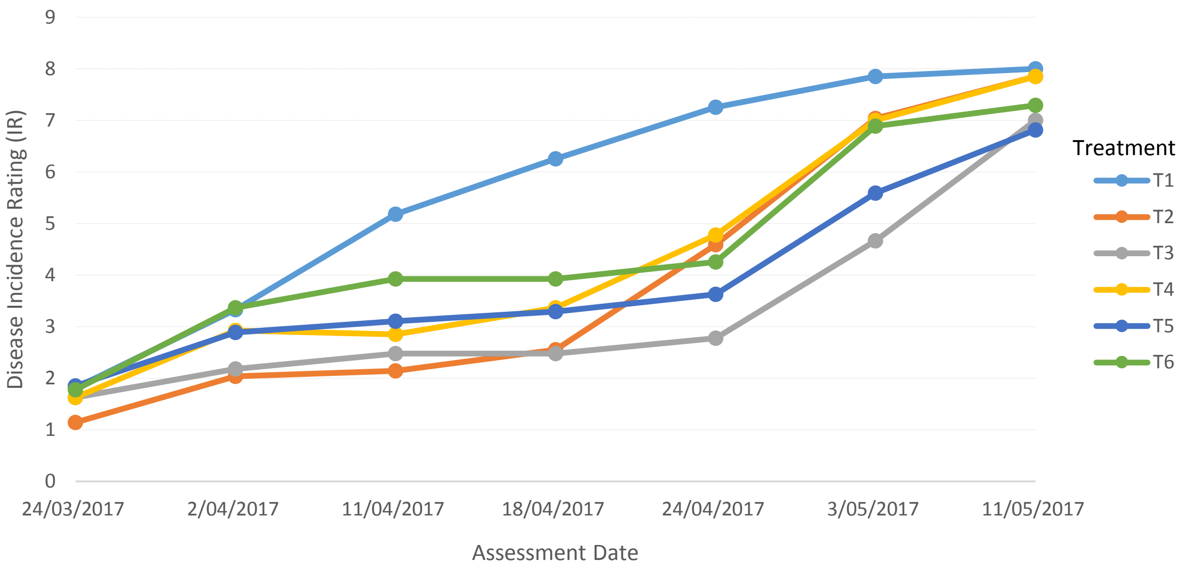

Figure 6. Powdery mildew disease incidence rating (IR) for different fungicide application treatments at Hermitage Research Station 2017; points are the mean of the four replicates

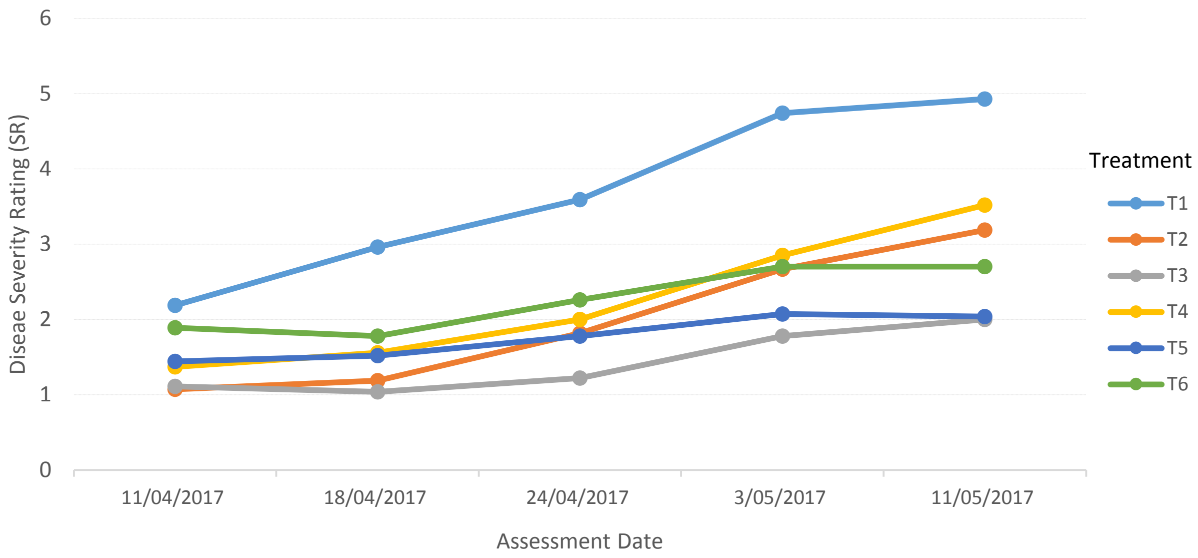

Figure 7. Average severity rating for treatments at Hermitage Research Station 2017 (lsd = 0.24); points are the mean of four replicates

Hermitage Research Station (HRS)

The trial was planted on 13 February 2017 and harvested on 2 June 2017. Powdery mildew was first observed on 24 March 2017, however the disease developed slowly in the crop. Plots were rated on a whole plot basis on 24 March 2017 (35 DAE), 3 April 2017 (44 DAE), 11 April 2017 (52 DAE), 18 April 2017 (59 DAE), 24 April 2017 (65 DAE), 3 May 2017 (74 DAE) and 11 May (82 DAE).

Differences between disease incidence ratings (IR) and disease severity ratings (SR) were observed over the trial period. All treatments expressed significant differences in incidence ratings from the untreated control after the first fungicide applications were applied. These differences were maintained until late in the trial when the incidence ratings for sprayed treatments increased and eventually merged with the untreated control (Figure 6).

Disease severity ratings (SR) in all treatments were significantly different from the untreated control following first applications of fungicide (Figure 7). Significant differences in severity ratings between T3 and T5 (2 sprays) and all other treatments was identified following the last assessment. A significant difference in severity rating was also identified between fungicides in the last recording. Group 3 fungicide had a significantly lower disease severity level than the other two fungicides.

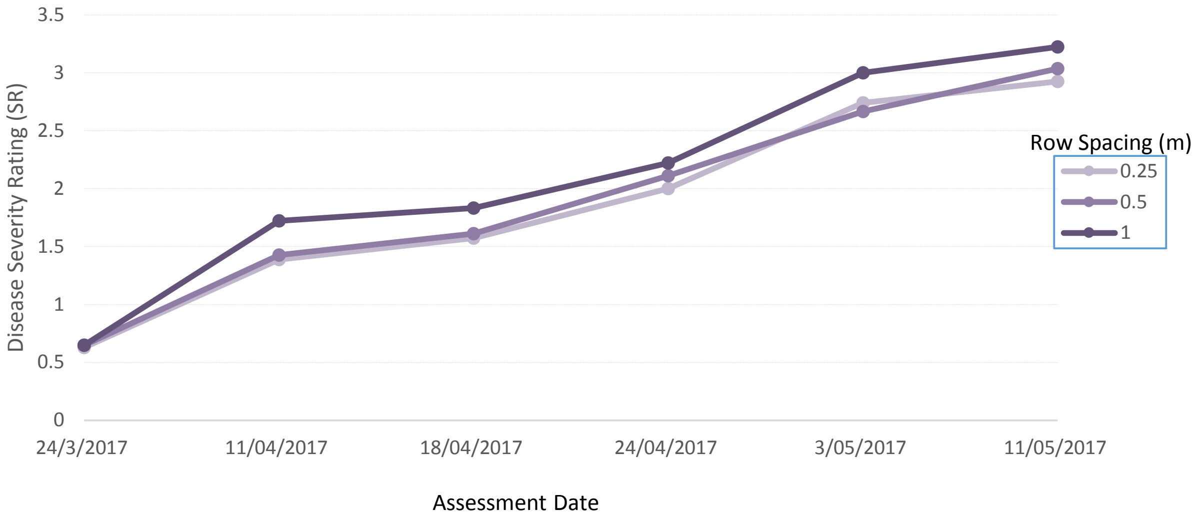

Figure 8. Disease severity levels between different row configurations at Hermitage Research Station 2017; points are the mean of four replicates

No significant difference between the different row configurations was determined however trend lines indicate that further research is required to explore this further (Figure 8).

The trial was severely affected by halo blight and fusarium wilt through the mid to late growth stages, greatly impacting the yield potential. There weren't any significant differences between treatment yields nor was the any significant response of powdery mildew to row spacing.

Implications for growers

Powdery mildew has been shown to cause significant yield reduction and economic impact when environmental conditions are suitable for the development of the disease in the crop. Well timed fungicide application is an effective, economic management practice in the control of this disease. Trial results indicate that best fungicide application efficacy is achieved when the first spray is applied at first sign of the disease followed by a second spray 14 days later. However, the first spray can be effectively applied up to 1/3 plant disease infection as long as it is followed by a second spray 14 days later. Timing of the first fungicide application appears to be more critical than the fungicide used. Results indicate that there is no difference in efficacy between the three fungicides trialled.

Row spacing configuration does not appear to impact on recommended powdery mildew management practices, however row spacing has had a significant impact on yield confirming narrow row configurations can yield significantly more than wider rows, supporting the research from the Pulse Agronomy project (UQ000067).

Acknowledgements

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Trial details

Location:	Missen Flat (Clifton), Hermitage Research Station (HRS) Warwick
Crop:	mungbean
Soil type:	Black vertosol
Fertiliser:	Granulock Z® 40 kg/ha

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