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QUEENSLAND
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GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

GRDC 2020 Grains Research Update Welcome

If you are reading this, then chances are you have taken time out from an extraordinarily tough season in our very sunburnt country to hear the latest grains research, development and extension (RD&E) information.

Welcome.

We at the GRDC understand how very challenging the current situation is for growers, advisers, agronomists, researchers and those associated with the grains industry across New South Wales and Queensland.

Drought takes an enormous toll financially, emotionally and physically on those working and living through it daily. We trust that these GRDC Grains Research Updates will offer you new research information to help guide your on-farm decisions this season and to be best placed to take advantage of future seasons. We also hope the Updates provide a chance to connect with your peers and temporarily escape work pressures.

We would like to take this opportunity to thank our many research partners, who, like growers and advisers, have gone over and above in recent years to keep trials alive in rain-deprived environments.

Challenging seasons reinforce the importance of rigorous, innovative research that delivers genuine gains on-farm. For more than a quarter of a century the GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of the industry.

Sharing the results from this research is a key role of the annual Updates, which are the premier event on the northern grains industry calendar and bring together some of Australia's leading grains research scientists and expert consultants.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers.

For the past four years we have been doing that from regional offices across the country. Through the northern region offices in Wagga Wagga and Toowoomba and a team of staff committed to connecting with industry, we are now more closely linked to industry than ever.

Today, GRDC staff and GRDC Northern Panel members are at this Update to listen and engage with you. This is a vital forum for learning, sharing ideas and networking, all of which are critical to effect successful change and progress on-farm.

Regards,
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Australia's grains industry in 2030 – key challenges and opportunities

Professor Ross Kingwell, Australian Export Grain Innovation Centre

Keywords

Grains industry, grain markets, competition

Take home message

- The grains industry in eastern Australia will experience further structural change towards 2030 as east coast demand for feed grain grows
- Farmers in eastern Australia are likely to increase their commercial dependence on grain storage, feed grain production and domestic marketing
- Improved harvest technology and transport logistics will enhance farmers' capitalising on market opportunities
- Australia's population and income growth, although slower than might have been anticipated in a pre-COVID world, will help underpin feed grain demand in Australia, as will the gradual re-build of cattle and sheep populations
- Towards 2030 the grains industry faces a carbon challenge.

Background

Although the business of grain-farming will largely stay the same towards 2030, some things are changing to challenge grain-farming and deliver further market opportunities. The sources of change and challenge include:

(i) Technological change
The ability in real-time to affordably track grain quality at harvest will improve, enabling farmers to more cost-effectively segregate grain at harvest and better match end-user preferences. Improved logistics and multi-mode hubs will facilitate greater use of containerisation. Lower cost grain storage combined with low interest rate will allow more grain to be stored, and stored for longer.

(ii) New crops and changing crop mixes
The wheat-sheep belt, the mainstay of Australian agriculture, will more flexibly switch its land use to favour greater crop diversity. Canola, chickpeas, lentils and lupins, once little known crops, will remain as important crop options in different regions. The swing into reliance on crop revenues is evidenced by Australia's sheep population now being as small as it was almost 120 years ago and in the early 1900s Australia only produced 1.5mmt of wheat from 2.5mha whereas this year Australia is on track to produce over 27mmt of wheat from 13mha. Moreover, 17.8mmt of other grains is also likely to be produced this year.

(iii) Altered soil management
Traditionally fields were ploughed repeatedly to combat weeds and form a friable seed bed. However, the advent of conservation agriculture now sees crops established in single pass operations, with minimal soil disturbance, increased reliance on herbicides and weed seed management at harvest. Soil amelioration is increasingly commonplace.

(iv) A changing climate
Grain production in Australia is based on rain-fed farming systems. Hence, temporal and spatial changes in rainfall and temperatures are crucially affecting national crop production. Extreme heat during grain filling is an increasing problem in some regions with farmers observing occasional 'heat frosts' that worsen grain yield and quality.

(v) An altered role of government
Traditionally, government played a major role in Australia's grain industry. Rail systems were owned and operated by State governments. Statutory grain marketing was ubiquitous. Research and advisory services were funded and supplied principally by State governments, with the Commonwealth government playing an important collaborative role in research funding. Provision of new plant varieties was almost solely the province of State government agencies, universities and the CSIRO. Governments were important employers in many rural towns. Yet now, the march of privatisation, the lesser relative economic contribution of agriculture and the emergence of other claims on the public purse (natural disaster relief, COVID relief, health and social welfare) have altered the role of government in the farm sector. Increasingly grain farmers pay fully or in large part for advice, grain marketing, research services and grain transport.

Privatisation has not only affected government services. Even farmers' ownership of the key services of grain handling and storage has passed into private ownership (GrainCorp, Viterra).

(vi) Maturing low-cost overseas competitors
Over the last few decades, a seismic shift in grain export prowess and rankings has occurred. In previous decades North America, Europe and Australia were main grain exporters. However, first South America (i.e. Brazil and Argentina) and then the Black Sea region (Russia, Ukraine and Kazakhstan) have greatly increased their grain production and grain exports. Russia has replaced the USA as the world's main exporter of wheat. Argentina and Brazil are main export suppliers of feed grains (soybean and corn).

(vii) Altered populations, incomes and power
As people become richer their indirect per capita consumption of feed grains increases as they consume more meat, aquaculture and livestock products (dairy, eggs). South Asia, sub-Saharan Africa and the MENA (Middle East & North Africa) are increasingly dominant contributors to the world's population. Although China's population growth is slowing, nonetheless its per capita income growth continues almost unabated helping it to flex its political muscle which has affected Australia's barley industry.

(viii) An increasing emphasis on the sustainability credentials of grain production
The costliness of grain and its quality matter to most consumers, especially overseas customers. Yet within agriculture and the urban consumers and voters that influence Australian agriculture, the sustainability credentials of farm production also increasingly matter. For example, major agricultural organisations like the MLA and NFF have signalled the need for Australian agricultural industries to plan to be carbon-neutral.

All these changes, in combination, are affecting the current and future potential of grain production in Australia.

Australia's grain industry towards 2030

- Towards 2030, feed grain demand and supply will increase in prominence in Australia, especially in eastern Australia
- In a COVID-affected Australia, the national population is likely to increase by around 16 per cent by 2030. This means about 4.1 million additional people in Australia
- Little increase in the area sown to winter and summer crops in Australia has occurred since the mid-2000s and further increases are unlikely towards 2030
- Despite plant breeding, agronomic and technology improvements, the average rate of crop yield improvement has been only 0.6 per cent per annum since the late 1980s. There is spatial variation in yield improvement trends and yield volatility has worsened in eastern Australia

- Climate change and seasonal variation are limiting yield growth in many grain-growing regions
- The mix of crops grown across Australia is fairly stable with a slight increase in the relative importance of canola over the last decade. In eastern Australia, coarse grains and pulses feature more in the mix of crops
- The pattern of meat consumption among Australians is changing, with a growing dominance of chicken and pork consumption at the expense of beef and lamb
- Increasingly, the main meats consumed by Australians are from grain-fed animals
- By 2030 in Australia:

  (i) Feed grain demand will increase by around 2.3 mmt

  (ii) An additional 0.6 mmt of grain will be required for flour and malt production

  (iii) An additional 5.6 mmt of grain will likely be produced

  (iv) The additional surplus of grain available for export could be around 2.7 mmt

  (v) Most of the additional grain produced in eastern Australia will need to flow to the east coast domestic market to satisfy its growth in feed and food demand

  (vi) The main sources of additional exportable surpluses of grain will be WA and SA; and bumper years in eastern Australia

  (vii) The grain quality profile of Australia's main export crop, wheat, is likely to alter, as WA's and SA's share of national wheat exports increases

  (viii) Grain farmers' increased use of liming and urea to boost grain production is increasing emissions from grain production and will increase the cost of ensuring the carbon-neutrality of Australian grain production.

A key implication of above projections is that towards 2030, with grain production being climate-constrained, Australia's domestic requirements for grain will become increasingly important in eastern Australia where most of the population increase and greater demand for feed grains, flour, oil for human consumption and malt will occur. By contrast, most of the exportable surpluses of grain will increasingly come from the less populous states of WA and SA.

The task of finding export markets for the additional ~2.7 mmt of export grain available by 2030 may not be overly challenging, given the projected increase in grain imports envisaged for many of Australia's current overseas grain customers. Nonetheless, it needs to be noted that this task of selling more Australian grain will occur against the backdrop of burgeoning exports from low-cost international competitors who may not have the same commitment to carbon-neutrality.

Assuming crop production in Australia towards 2030 remains seasonally volatile (whilst the stable east coast domestic demand for grain increases in relative importance), then grain farmers and grain users in eastern Australia are likely to react by:

(i) Investing in more grain storage; especially whilst interest rates are low, making the cost of carrying grain affordable

(ii) Focusing more on domestic market opportunities

(iii) Focusing more on feed grain production

(iv) Looking more closely at grain supply security when investing in export-focussed grain processing/animal protein industries – with access to export parity grain rather than exposure to import parity

(v) Committing to further enhancement of the sustainability of grain production (e.g. reduced net emissions of greenhouse gases) whenever price premiums, regulation or market access opportunities reward those commitments

(vi) Supporting varietal development, crop research and grain organisation innovation that delivers benefits throughout the grains industry, but especially to grain producers.

Implications for Vic and NSW Grain Producers

Although the increased demand for feed grains in eastern Australia may encourage its grain producers to alter their crop mix towards more feed grain production, it is unlikely that most farmers will additionally allocate more land to cropping rather than sheep production. Despite the sizeable reduction in the national sheep population since the early 1990s, most NSW and Vic farmers have maintained their investment in sheep since the early 2010s (Figure 1), despite the period of serious drought in 2018 and 2019.

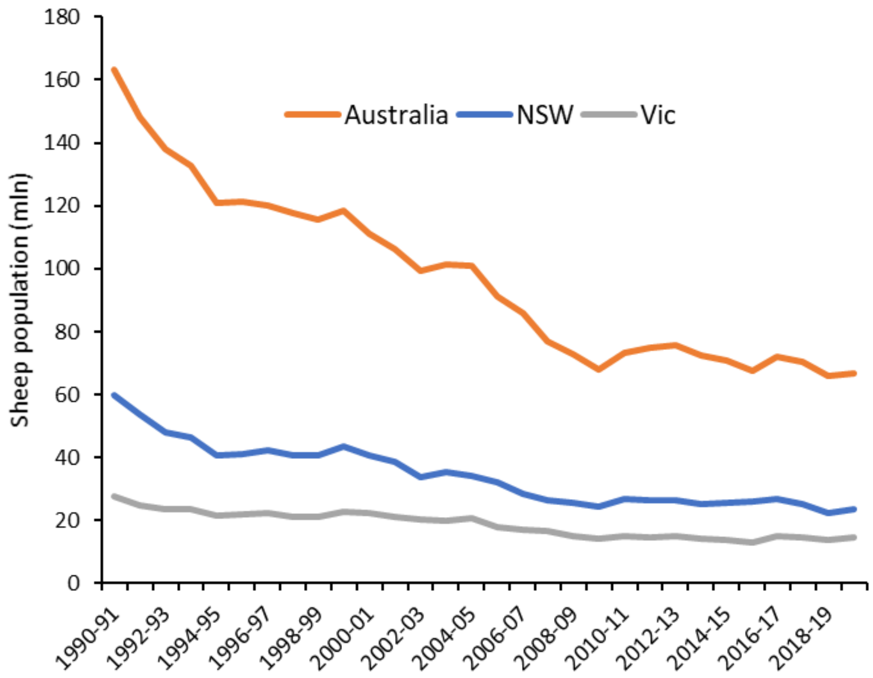

Figure 1. Sheep population in Australia, NSW and Vic since 1990

In order to retain sheep numbers, either pasture areas need to be allocated for sheep production or affordable feed grains always need to be readily available. Given the strong upward movement in sheep meat and wool prices up until the impact of COVID-19, on a gross margins basis, farmers have been less likely to switch land and other resources away from sheep production. Moreover, as the domestic and overseas demand for sheep meat continues to increase, then retention of sheep in farming systems is increasingly likely. In addition, retaining sheep provides a means to add value to feed or downgraded grain produced on a farm. Currently, sheep enterprises form a profitable, risk-diversifying role for many farm businesses. As a result, crop production growth over the next decade is more likely to be based largely on yield increases rather than crop area increases. Accordingly, crop breeding and crop agronomy will play crucial roles in ensuring gains in crop production in NSW and Vic.

In coming decades, the traditional flow of grain from Vic and NSW farms down to ports for overseas export could be a less dominant feature of their crop production, as east coast demand for grain increases in relative importance; and especially in years of low production in eastern Australia.

Interstate grain flows from SA or WA (see (Figure 2) could feature when prolonged drought in NSW and Vic leads to depletion of their grain storages such as occurred in 2018/19

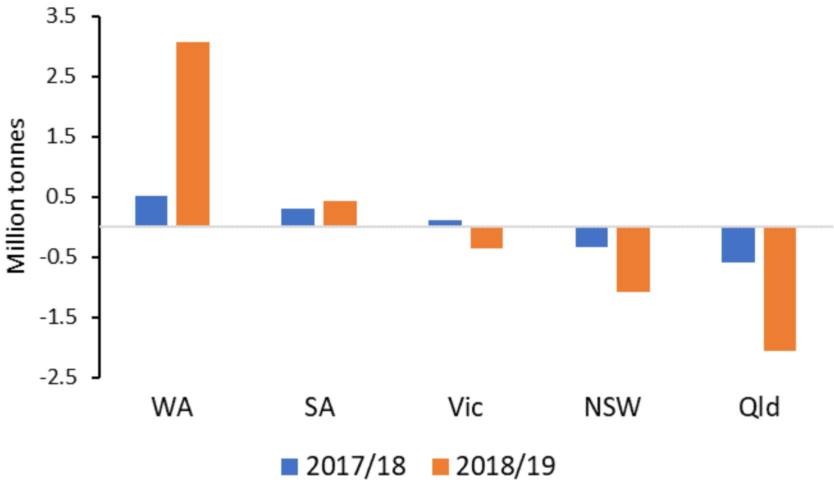

Figure 2. Coastal shipping flows from or into each State in 2017/18 and 2018/19

Source: Based on data in an appendix in ACCC (2019)

In 2018/19 some regions in SA were also affected by drought. The SA grain harvest was only around 5.6 mmt, of which the main grain handler and exporter, Glencore, only exported around 2.6 mmt, indicating that around 3 mmt was either stored, used locally or exported to eastern Australia. Hence, due to SA's small domestic market, even in low production years, SA is able to capitalise on favourable market opportunities in eastern Australia.

In years when SA or WA escape drought, yet eastern states are drought-affected, then sizeable interstate grain flows from these states are likely (see Figure 2). Freight differentials in coming decades could be further affected by construction of the inland rail in eastern Australia, due for completion in 2025. If the inland rail is sufficiently cost-effective, then interstate grain flows from SA could be much enhanced in some years. In addition, construction of additional grain port infrastructure in SA will facilitate coastal trade. In eastern Australia, south to north flows of grain by rail, road and ship are likely to become increasingly important towards 2030 as a product of climate volatility and continuing growth in the demand for grain in eastern Australia.

The constant challenge of a warming, drying climate is likely to limit winter crop yield growth in all winter crop regions of Australia and will increase the dependence of extensive livestock production (sheep, cattle, dairy) on supplementary grain feeding. Simultaneously, further population growth, especially in Qld, NSW and Vic, will increase the national market demand for grains, especially feed grains. The corollary is that growth in grain production in Australia is likely to be modest and the tendency will be for a growing proportion of grain to flow to domestic markets, especially in eastern Australia. Exports of grain from NSW and Vic are likely to be constrained by the growth in the Australian domestic market in eastern Australia and the constraints of climate trends on crop yields. In a low interest rate environment, storage of grain becomes more affordable as a strategy to lessen price volatility and improve the affordability of grains. Hence, grain storage is likely to become part of major grain users' and producers' risk management strategies.

In coming decades, export grain supply chains in Vic and NSW will be affected by the combination of limited growth in crop production and an increased role of grain storage to improve the reliability of supply to domestic markets. Low interest rates make affordable the cost of carrying grain across seasons. In eastern Australia easily stored feed grains like lupins and barley, if high-yielding varieties become available, could feature more in farmers' crop portfolios. Farmers are likely to enlarge their focus on feed grain production and any feed grain value-adding opportunities.

Farmers are likely to have increasing choices over where and when they sell grain, due to the lower cost of storing grain (i.e. a low interest rate environment), and the emergence of a range of domestic market opportunities.

Conclusion

Modest growth in Australian grain production is expected towards 2030. By contrast, Australia's population is projected to increase by around 16 per cent by 2030. This means about 4.1 million additional people, mostly residing in eastern Australia. Despite this projected increase in population and the associated demand for feed and human consumption grains, little increase in the area sown to crops in Australia is envisaged.

The corollary is that, especially during periods of drought in eastern Australia, domestic market opportunities in eastern Australia will drive grain flows, support grain storage and increasingly affect the viability of the ownership and operation of export grain supply chain infrastructure, especially in eastern Australia. Grain storage will increasingly form part of many businesses' risk management strategies. Establishing and maintaining low-cost interstate supply chains will be an increasing complementary strategic need, already being supported by the inland rail project.

How grain is produced (i.e. its sustainability credentials) will be increasingly important, especially to domestic users and consumers.

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CICA1521: a new desi variety for the northern region

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Key words

chickpea variety, desi, yield, disease resistance, Ascochyta blight, Phytophthora root rot, phenology, grain quality

GRDC code

DAN00094, DAN00151, DAN00176, DAN00212, BLG205, BLG209, BLG111, 9177999

Take home message

A new broadly adapted desi chickpea variety for the northern region and other chickpea growing areas of Australia, will be launched in spring 2020. The variety was evaluated as CICA1521 (to be named) and has higher yields in northern NSW and southern QLD than PBA HatTrick⊕. CICA1521 has a medium seed size and is expected to have similar disease ratings to PBA HatTrick⊕.

Significant yield advantage over PBA HatTrick⊕

CICA1521 has been included in National Variety Trials (NVT) since 2015. During this five-year period there has been a very wet season (2016) and a number of dry seasons (2018 and 2019). CICA1521 has shown great consistency despite the highly variable seasons. It has yielded higher than Kyabra⊕, PBA Boundary⊕, PBA HatTrick⊕ and PBA Seamer⊕ in south west QLD (Table 1). In north west NSW it has shown consistent yield gains over PBA HatTrick⊕ (Table 2).

Table 1. Long term yield (2015-2019) of CICA1521 and current chickpea varieties, expressed as a % of the mean yield, in NVT in south west QLD. The mean yield of all varieties in each of the 13 contributing trials was used to assign that trial to a 'yield grouping'. This enables varietal performance to be better evaluated in different yield situations

		Yield group (t/ha)				
		1	**1.5**	**2**	**2.5**	**3.5**
	Mean yield (t/ha)	0.61	1.34	1.74	2.38	3.05
Variety	No trials in total & for each yield group	2	3	3	2	3
CICA1521	**13**	**112**	**109**	**104**	**107**	**109**
Kyabra⊕	13	96	106	97	101	103
PBA Boundary⊕	13	103	102	101	101	101
PBA Drummond⊕	4	121	115		112	
PBA HatTrick⊕	13	95	97	98	97	96
PBA Seamer⊕	13	103	98	102	100	100

Source: https://app.nvtonline.com.au/lty/table/chickpea-desi/qld/swq/?lty-type=yield

Table 2. Long term yield (2015-2019) of CICA1521 and current chickpea varieties, expressed as a % of the mean yield, in NVT in north west NSW. The mean yield of all varieties in each of the 25 contributing trials was used to assign that trial to a 'yield grouping'. This enables varietal performance to be better evaluated in different yield situations

		Yield group (t/ha)					
		0.5	**1**	**1.5**	**2**	**2.5**	**3.5**
	Mean yield (t/ha)	0.41	0.88	1.23	1.84	2.25	2.96
Variety	No trials in total & for each yield group	1	8	4	6	4	2
CICA1521	**25**	**106**	**110**	**110**	**107**	**107**	**105**
Kyabra⦶	25	140	115	107	92	94	80
PBA Boundary⦶	25	114	108	104	99	99	92
PBA Drummond⦶	6	98	113	116	115		
PBA HatTrick⦶	25	105	99	97	96	96	93
PBA Seamer⦶	25	83	95	98	104	103	109

Source: https://app.nvtonline.com.au/lty/table/chickpea-desi/nsw/nw/?lty-type=yield

Ascochyta blight

CICA1521 has undergone Ascochyta blight (AB) testing in the field at Tamworth and Horsham as well as single isolate testing under controlled conditions in Adelaide.

CICA1521 was included in an integrated disease management trial for AB conducted at Tamworth in 2017 (Table 3). In this trial CICA1521 had a similar yield loss to PBA Boundary⦶ and a much lower yield loss than PBA Drummond⦶ and Kyabra⦶. An integrated disease management trial currently being conducted in 2020 will confirm the AB disease management package for CICA1521.

Table 3. Yield (t/ha) of CICA1521 and current varieties with and without fungicide control (1.0 L/ha chlorothalonil) and the % of yield loss at Tamworth in 2017

	Yield (t/ha)		
Name	1L /ha Chlorothalonil (720 g/L formulation)	Nil fungicide	% yield loss
CICA1521	**1.68**	**1.58**	**11**
Kyabra⦶	1.94	0.21	89
PBA Boundary⦶	1.73	1.53	12
PBA Drummond⦶	1.87	0.88	53
PBA HatTrick⦶	1.67	1.58	6
PBA Seamer⦶	1.81	1.68	7
Lsd (P<0.001)	*0.211*		

An increase in the aggressiveness of the AB pathogen has been observed both in the northern and southern regions (Ford et al., 2018). Increased levels of disease have been recorded on CICA1521 and other varieties such as PBA Seamer⦶ from these isolates collected in 2017 compared to isolates collected in 2015 (Table 4). The distribution of the more aggressive isolates in the northern region is currently unknown, due to the reduced chickpea area and dry seasons over the past two years, however a conservative disease rating from the NVT pulse disease rating system for CICA1521 is expected. For northern isolates this is likely to be a Moderately Susceptible rating for Ascochyta blight.

Table 4. Mean disease index of chickpea varieties in single isolate AB screening conducted at Adelaide. The index is calculated as the sum of (% main stems broken + % of stems with lesions + % side branches with disease + % leaves with disease) divided by 4. (0 = healthy plant, 100 = heavily diseased plant)

	Isolate collection location and year							
Name	Yallaroi NNSW 2015	Curyo VIC 2015	Graman NNSW 2016	Curyo VIC 2016	Gurley NNSW 2017	Pt Broughton SA 2017	Gurley NNSW 2017	Curyo VIC 2018
CICA1521	**40**	**50**	**77.1**	**76.3**	**29.2**	**26.7**	**67.9**	**89.6**
Kyabraⓓ			100	100	100	100	100	100
PBA Boundaryⓓ	81.3	67.9	100	100	77.1	55.4	90	100
PBA Drummondⓓ	97.1	100	100	100	66.7	97.5	83.3	100
PBA HatTrickⓓ	87.5	61.7	86.3	94.2	66.7	48.8	67.9	68.3
PBA Seamerⓓ	31.7	37.5	83.8	90.8	29.2	39.2	65.4	84.6
Lsd	*20.6*	*27.2*	*18.1*	*16.2*	*24.7*	*19.2*	*26.6*	*28.6*

Phytophthora root rot

CICA1521 was included in Phytophthora root rot (PRR) yield loss trials conducted at Warwick QLD, over several years (Table 5). Yield losses for CICA1521 from PRR in these trials have ranged from 38.7 to 93.4 %. Similar variability in yield loss has also been observed for PBA HatTrickⓓ; an explanation of the seasonal impacts on yields and varietal PRR disease rankings is provided in Bithell et al., 2018. In 2020, NVT pulse disease rating testing is currently being conducted for PRR for the first time. It is expected that a review of all variety ratings for PRR will be conducted to align with the NVT disease rating definitions.

Table 5. Yield (t/ha) in the absence of PRR and yield loss (%) from PRR across 2016 to 2018 for CICA1521 and other current chickpea varieties. Adapted from Bithell et al., 2018, Bithell et al., 2019

	2016		2017		2018	
Name	Yield (t/ha) in the absence of PRR	% yield loss from PRR	Yield (t/ha) in the absence of PRR	% yield loss from PRR	Yield (t/ha) in the absence of PRR	% yield loss from PRR
CICA1521	**4.06**	**75.1**	**2.74**	**93.4**	**1.94**	**38.7**
PBA Boundaryⓓ	3.98	95.2	2.63	82.5		
PBA Drummondⓓ					2.49	68.1
PBA HatTrickⓓ	4.02	90.0	3.31	78.2	2.28	40.5
PBA Seamerⓓ	4.08	76.7	3.23	90.4	2.81	61.5
Yorker	4.06	68.3	3.50	97.3	2.84	40.1

Phenology and other agronomic traits

CICA1521 is early flowering when sown in the mid-May to mid-June sowing window, approximately six days earlier than PBA HatTrickⓓ (Table 6). Flowering data collected from early May sown chilling tolerance trials (BLG111) indicates that CICA1521 can flower up to 24 days earlier than PBA HatTrickⓓ depending on winter daytime temperatures. An increased understanding of the drivers of chickpea phenology is expected with a number of new GRDC investments in this area. Although there is some data indicating that CICA1521 may produce pods earlier in some environments (e.g. Kingaroy 2019), it is expected that days to first pod is similar to current varieties.

Table 6. Phenology data (2017-2019) collected for CICA1521 and current chickpea varieties from breeding and chilling tolerance trials in northern NSW and southern QLD

		CICA1521		Kyabra		PBA Drummond		PBA HatTrick		PBA Seamer	
Sowing date	Location	DTF	DTP	DTF	DTP	DTF	DTP	DTF	DTP	DTF	DTP
15/6/2017	Spring Ridge	**102**		103				103		102	
23/5/2018	Moree	**91**		96		97		98		97	
7/5/2018	Tamworth	**101**	**134**	112	134	120	134	125	135	126	134
12/6/2018	Tamworth	**96**	**108**	99	108	97	108	102	108	99	
13/5/2019	Narrabri	**77**	**108**	83	106			80	108		
15/5/2019	Breeza	**106**	**122**	105	123			105	122		
17/5/2019	Kingaroy	**79**	**91**	82	95			81	96		

DTF = days to flower from sowing
DTP = days to pod from sowing

CICA1521 has early to mid-maturity, earlier than PBA HatTrick. CICA1521 has an erect plant type with good height to lowest pod and plant height. Under the high biomass producing conditions of 2016, CICA1521 had less lodging than PBA HatTrick at six sites across northern NSW and southern QLD (Table 7).

Table 7. Mean lodging score at northern NSW and southern QLD breeding sites in 2016 for CICA1521 and current chickpea varieties. 1 = erect, 9 = flat.

Location	**CICA1521**	Kyabra	PBA HatTrick	PBA Seamer
Edgeroi	**3.7**	2.3	5.3	5.3
North Star	**4.3**	3.0	7	3.3
Rowena	**5.3**	5.3	6.7	6.3
Warwick	**6.0**	6.3	6.3	5.3
Warra	**3.3**	2.0	6.0	2.7
Roma	**3.7**	3.0	6.0	4.7

In 2019, 30 hectares of CICA1521 at Trangie was harvested by a commercial contract harvester. No negative feedback regarding the harvestability of CICA1521 was reported. Eleven large scale farmer demonstration strips have been sown in 2020 across the northern region. These will provide feedback on the harvestability of CICA1521 with commercial harvesters from a range of growing environments.

Grain quality

CICA1521 has a yellow-brown seed coat and angular seed shape, not unlike PBA HatTrick. The seed size of CICA1521 is larger than PBA HatTrick, similar to PBA Seamer and PBA Drummond but smaller than Kyabra (Table 8). CICA1521 has a higher or similar split yield than PBA HatTrick and PBA Drummond at six sites across southern QLD and northern NSW.

Table 8. Seed size (grams per 100 seeds) and split yield % (SY%) for CICA1521 and other current chickpea varieties at six sites in northern NSW and southern QLD

	CICA1521		Kyabra⌽		PBA Drummond⌽		PBA HatTrick⌽		PBA Seamer⌽	
Site Year	100SW	SY%	100SW	SY%	100SW	SY%	100SW	SY%	100SW	SY%
Roma 2017	**19.8**	**52.9**	21.9	72.5			20.1	40.8	20.8	44.8
Spring Ridge 2017	**22.5**	**53.2**	24.6	45.1			18.9	44.3	21.3	55.7
Warra 2017	**21.7**	**72.3**	24.2	67.5			22.5	70.5	24.1	73.7
Moree 2018	**21.5**	**41.2**	25.1	46.9	22.2	36.7	20.2	42.9	21.5	42.0
North Star 2018	**23.7**	**46.0**	27.2	64.1	24.0	39.7	22.0	39.2	23.5	45.3
Warra 2019	**22.3**	**50.7**	24.2	32.6	22.4	38.0	21.8	37.4	22.2	38.7

100SW = grams per 100 seeds
SY% = split yield % (yield of dhal using a standard SKE milling method without pre-conditioning seeds; Wood et al 2008).

Commercialisation and seed availability

NSW DPI are commercialising CICA1521 through several seed partners in the northern region. In 2020, there are five multiplication crops of CICA1521 throughout northern NSW and southern QLD. Further details regarding the seed partners will be made available in spring when the variety is launched.

Acknowledgements

CICA1521 was developed by the PBA Chickpea program (led by NSW Department of Primary Industries). The partners of the PBA Chickpea program were: GRDC, NSW DPI, Department of Agriculture and Fisheries (QLD), Agriculture Victoria and the South Australian Research and Development Institute.

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The impact of harvest management in chickpeas – desiccation and front of header losses

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Northern Grower Alliance

Key words

chickpea desiccation, harvest losses

GRDC code

NGA00004: GRDC Grower Solutions for northern NSW and southern Qld

Take home messages

- Generally minor impact from desiccant treatments or application timing on yield or grain quality
- Decisions on harvest management choice should be determined by cost, attitude to Ally® plant back restrictions, weed spectrum present at harvest and speed of desiccation required
- Delayed harvest at low % grain moisture caused more damaged and split grain than desiccant treatment or timing
- Ideally target desiccation at ~85-90% pod maturity and schedule harvest 7 days later to reduce grain quality issues
- Large levels of pod and grain losses were measured at the front of the header in four commercial evaluations (~100-200 kg/ha)
- Losses reduced by ~50-90 kg/ha when harvested with air assist or when brushes were attached to the reel
- Impact from the harvest modifications would have improved returns by $34-67/ha
- In the trials conducted in 2018 and 2019, this represented an additional 5-18% yield.

Background

Northern Grower Alliance have been researching two important aspects of chickpea harvest management during the period 2017-2019.

The first has been to evaluate the impact of desiccant choice and timing on yield and grain quality. The second has focussed on the magnitude of header losses and the impact on yield and economics from changes in harvest approach.

Desiccation evaluation 2017-2019

The area of focus has evolved over the three seasons:

2017 – 5 trials evaluating current and new desiccation tools to assist in refining management programs. Treatments included glyphosate alone, glyphosate + Ally (metsulfuron-methyl), glyphosate + Sharpen® (saflufenacil), Reglone® (diquat), Gramoxone® (paraquat) (refer to label and follow use pattern for chickpeas) and Gramoxone + Sharpen.

2018 - 4 trials continuing the original activity. An additional 3 trials focussed on impact of desiccation timing (application ~3, 2 and 1 week prior to ‘planned’ commercial harvest). In all three timing trials, treatments were also harvested after a 14-day delay. Treatments repeated from 2017.

2019 - 3 trials primarily focussed on the impact of desiccation timing (application at ~70%, 80% and 90% pods at physiological maturity). Harvest was conducted for all timings ~7 days after application. Similar treatments to 2017 and 2018 but replaced Reglone with glyphosate + Ally + Sharpen.

Pod maturity was assessed at each application on a minimum of 10 main branches. Pods were considered mature when a 'yellow beak' was starting to extend on the enclosed grains. This stage often corresponded with a purplish tinge appearing on the pod coat.

Key points - desiccation evaluation 2017-2019

Leaf discolouration and leaf drop (visual ratings)

- Treatments increased % leaf discolouration and % leaf drop compared to the untreated but without consistent differences between treatments across sites
- Improvements in % leaf discolouration and % leaf drop compared to the untreated were greatest in 2017 (where high levels of October rainfall encouraged crop regrowth) and generally lowest in 2019 at sites that matured very rapidly under high moisture stress.

Stem dry down (physical rating)

- A 'twist test' was conducted to assess the % of plants where all stems snapped at harvest. This was done to provide an indication of stem ropiness or harvest readiness
- The most consistent treatments in 2017 and 2018 were the mixture of glyphosate + Ally or Gramoxone 250 + Sharpen. In 2019 there was no significant difference, in any trial, between any treatment and the untreated
- There was a positive dose response to glyphosate in 2017 and 2018 with increased stem snapping from the 1.8 L/ha rate (540 g ai/L formulation).

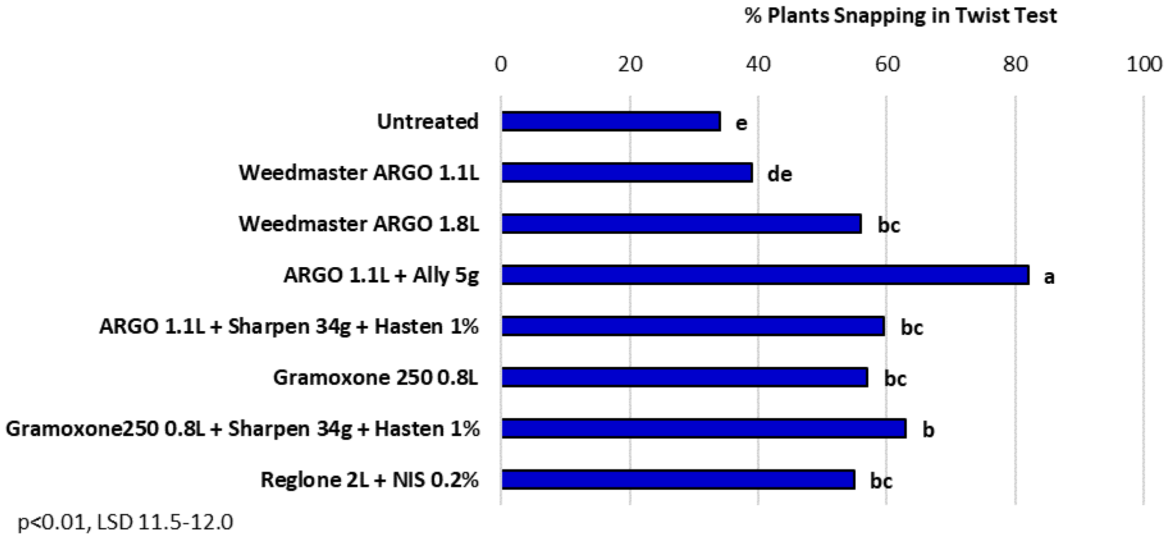

Figure 1. Stem twist test results 10-17 days after application, as an indication of stem dry down.
(Mean of 5 trials 2017)

NIS = non-ionic surfactant

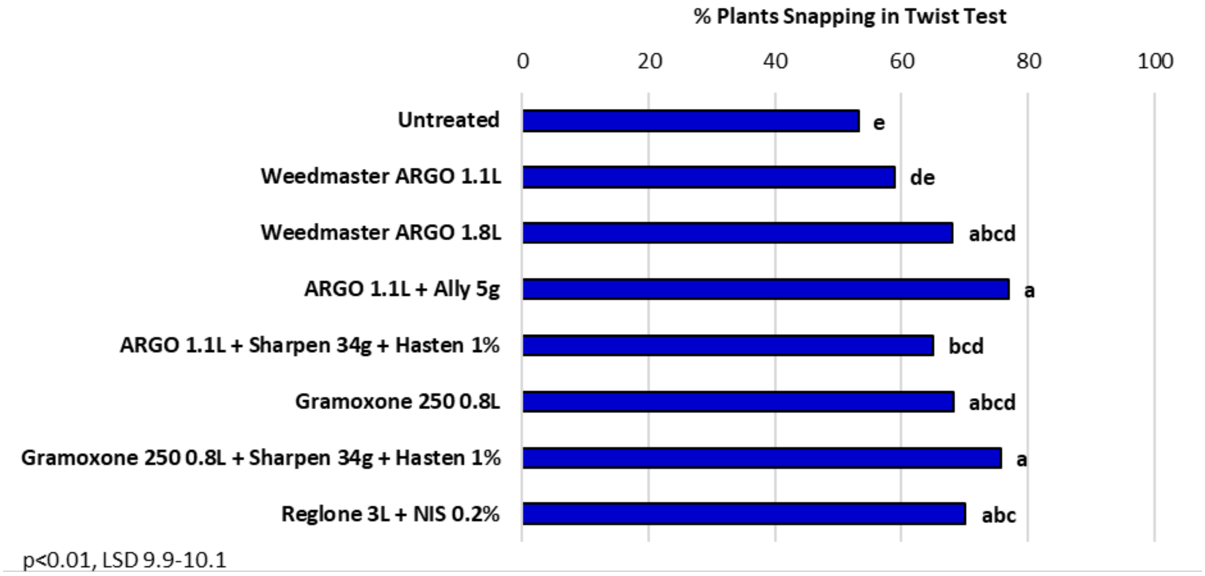

Figure 2. Stem twist test results 7-15 days after application, as indication of stem dry down.
(Mean of 4 trials 2018)

NIS = non-ionic surfactant

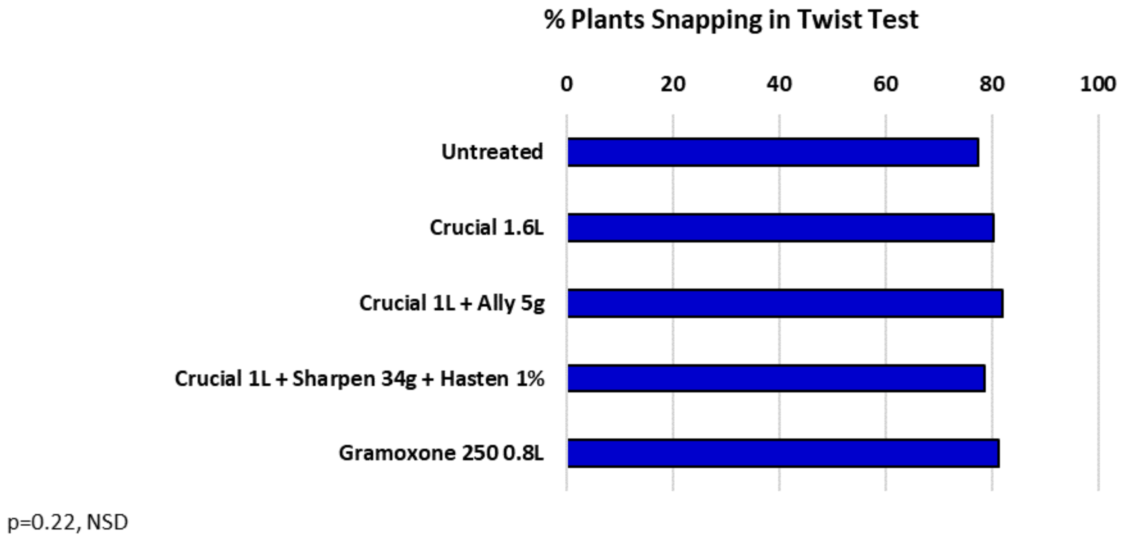

Figure 3. Stem twist test results 6-10 days after application, as indication of stem dry down.
(Mean of 3 trials 2019)

Yield

- In 14 of the 15 trials, there was no significant difference in yield between any treatment and the untreated
- In 2018, there was a significant reduction in yield from Gramoxone 250 at one site where the application was ~4 weeks prior to expected commercial harvest and then harvest was delayed by another 2 weeks. Crop stage at application was only 59% of pods at physiological maturity.

Grain quality (NIR and sievematic)

- Impact on grain quality was generally minor

- Test weight was significantly reduced in 2 trials in 2018 by Gramoxone 250 or Reglone when application occurred ~4 weeks prior to expected harvest. Crop stage at application was ~50-60% of pods at physiological maturity
- There was no significant impact on screenings from any desiccant treatment in 2018 (using a 4mm slotted screen as an indication of defective grain)
- Impact on grain moisture at harvest was minor with no significant difference between desiccant treatments and the Untreated in 12 of 15 trials. All treatments reduced grain moisture by ~1% in a 2017 trial where regrowth was evident and Gramoxone 250 significantly reduced harvest moisture at 2 of the 3 sites in 2019.

Grain grading (visual rating)

- Visual grain assessment on all trials from 2019 showed no significant impact from desiccant treatment or timing on the % green or yellow grain compared to untreated grain harvested at the same time
- In one trial, application of glyphosate alone at 70% of pods at physiological maturity reduced the percentage of mature grain by ~2% and increased the percentage damaged grain by a similar amount. There was no significant impact when glyphosate was applied at 90% pod maturity.

Germination

- Germination tests were conducted on seed samples from application timing trials in 2018 and 2019. Effects were generally minor
- Significant reductions in germination were observed from glyphosate + Ally applied at 58% pod maturity in 1 trial in 2018 and glyphosate + Sharpen + Ally applied at 66% pod maturity in 2019. In both cases, application of the same treatment at later crop stages had no effect
- Reduced germination was observed from all treatments at one site in 2019 when applied at 90% pod maturity where a rain event of ~18mm occurred between application and harvest. There was no consistent impact from treatments on germination from applications at the same site at 70 and 80% pod maturity.

NB The use of desiccants is not recommended when the grain is to be used for seed.

Overall

Differences between desiccant treatments and timing of application were less obvious than originally expected.

- The addition of Ally to glyphosate will generally improve stem dry down compared to other treatments, whilst higher label rates of glyphosate will improve the speed of discolouration and stem dry down.
- Impacts on yield and grain quality were relatively minor, even when application occurred up to 2 or 3 weeks earlier than currently scheduled.

However, in 5 of the 6 trials where harvest timing was also compared, it was clear that the earlier harvest of chickpeas had significantly lower levels of damaged grain. This effect was irrespective of whether the plots had been desiccated or untreated. Although differences in header setup can't be eliminated, it is likely that the lower levels of damaged or split grain is at least partly due to the higher levels of grain moisture at harvest. NB even the early application treatments had grain moisture lower than 10%, when tested within 24 hours of harvest, in 5 of the 6 trials.

Rather than suggesting that the industry desiccate chickpeas at an earlier maturity stage, this data should provide good confidence that desiccation at 85-90% pod maturity is highly unlikely to have any negative impact on yield or grain quality. When combined with harvest scheduled ~7 days after application, this should allow harvest at slightly higher grain moisture and significantly reduce the amount of damaged or split grain in samples.

Commercial harvest losses 2018-2019

Commercial observations have frequently indicated high levels of harvest grain and pod loss in chickpeas, particularly in crops with reduced biomass that ‘feed’ poorly into the header. This grain loss is different to grain that passes through the header (processing loss) or grain left on plants (harvest height loss). Front of header grain loss is made up of pods and grain that are knocked off by the reel, cut off by the knife but fall outside the header front or thrown out from the header by the drum or belt.

In 2018, data was generated at a site near Gurley where PBA Seamer⦶ was harvested with a header fitted with an air front. Replicated strips were established where the only difference was whether the air front was turned on or off during harvest.

Counts were taken of pods or grain on the ground together with the number of grains/pod and grain weight. In 2018, sampling zones were assessed across the harvested width with no pods or grain apparent on the ground prior to harvest. Results in Table 1 are for the pod and grain losses away from the header trail. These are the harvest losses that occurred at the front of the header but exclude any pods that were unharvested but still attached to plants.

Figure 4. Brushes attached to the header reel Bellata 2019

In 2019 three sites were evaluated with sampling away from the header trail to identify the pods or grain losses at the front of the header. Again there was no indication of pod or grain loss prior to harvest. Two of the sites had air assist fitted to the header that could be simply turned on or off. The third site evaluated lengths of brushes attached to the reel (Figure 1).

Table 1. Impact on chickpea yield losses from air assist or reel brushes

Location and year	Variety and yield	Header set-up	Yield losses on ground			Reduced grain losses kg/ha and ($/ha)
			Pods/m^2	Grain/m^2	Total kg/ha	
Gurley 2018	PBA Seamer⫚ ~0.62 t/ha	Air assist OFF	55 a	10	164 a	89 kg/ha ($67/ha)
		Air assist ON	22 b	8	76 b	
Wee Waa 2019	PBA Monarch⫚ ~1.0 t/ha	Air assist OFF	33 a	5	115 a	45 kg/ha ($34/ha)
		Air assist ON	21 b	3	70 b	
Bongeen 2019	PBA HatTrick⫚ ~0.45 t/ha	Air assist OFF	38 a	1	123 a	80 kg/ha ($60/ha)
		Air assist ON	14 b	0	43 b	
Bellata 2019	PBA HatTrick⫚ ~0.40 t/ha	Reel brushes OFF	62 a	11	217 a	63 kg/ha ($47/ha)
		Reel brushes ON	43 b	9	154 b	

Letters of significance show significant differences **within each site** (2 sample T test, p=0.05)
Economic impact calculated on a $750/t grain price
All results in Table 1 are for sampling away from the header trail. This shows the yield losses occurring at the header front.
Assessment of grains/pod and grain weight was conducted to calculate total grain loss.

Key points – commercial harvest losses 2018-2019

- The majority of grain losses were as whole pods rather than individual grains
- At all four sites between ~100 and 200 kg/ha of grain was lost at the front of the header using a conventional setup
- Use of air assist or brushes attached to the reel significantly reduced the losses of whole pods and the total grain loss, at all sites
- There was no significant difference in losses of individual grains
- The mean reduction in grain loss was 70 kg/ha (range 45 to 89 kg/ha)
- The mean reduction in grain loss was $52/ha (range $34 to $67/ha)
- The reduction in losses would have been equivalent to an extra 5-18% crop yield.

Overall

All four trials highlighted the amount of chickpea grain and income that can be lost at the front of the header at harvest. The impact of air assist or even the simple approach of attaching brushes to the reel provided benefits of ~$50/ha. However some caution is needed as both 2018 and 2019 were low yielding seasons with yields varying between 0.4 and 1.0 t/ha. The benefits of simple header adaptations may be more substantial in lower yielding years or where crop biomass or planting configuration is likely to result in poor levels of 'feeding in' of harvested material.

Further evaluation is warranted under more normal conditions to provide growers with realistic indications of the benefits of changes in chickpea harvest management.

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Commercial harvest loss assessments in chickpeas

Ed Offner, Jess Mickelborough, Edward Britten, Agronomist, MCA Agronomy Pty Ltd

Key words

chickpea, harvest, losses

Take home message

- Australian chickpea growers are potentially leaving hundreds of dollars per hectare behind at harvest due to header setup
- Header set up and modifications may have a dramatic impact on harvest losses
- As farm scale has increased over time, harvest efficiency has become more crucial. However, have harvest losses increased to achieve this efficiency? Is there potential to achieve both an efficient harvest and reduce grain losses at harvest?
- Can we produce guidelines to educate growers on what can be achieved by improving harvest setups or using header adaptions in chickpeas?

Introduction

Producing a chickpea crop is a large investment so there is nothing more frustrating than watching a fair percentage of that crop being left on the ground through harvest losses.

Harvest losses are not a new issue to pulse production. Harvest evaluations in mungbeans in CQ in 1985-1987 seasons, found harvest losses to be on average 30% of harvestable yield. This equated to approximately 230kg/ha (Cumming 2010).

Since that time, industry has been extremely fortunate to have had plant breeders working hard to achieve huge advancements in the harvestability of modern pulse varieties including chickpeas. There have also been significant engineering improvements to header fronts: drapers, self-levelling, flex platforms and others.

Air reels were commonly used in the past for harvesting pulses to improve harvestability. Improvements to modern fronts has meant the majority of growers are no longer using air reels as a preferred option. Even with all of these engineering improvements, are we still incurring unacceptable harvest losses?

In recent years growers have been reporting particularly high levels of harvest losses in chickpeas, predominantly at the header front near the knife. Growers were reporting that pod losses were occurring when the knife hit the plant and when pods were rolling off the front over the knife. After observing this happening on many of our clients' farms, MCA undertook some basic pod counts to better understand how much was being left behind. Assessments were undertaken on three farms in the Meandarra district with varying header front set ups. Our data collection and analysis would not stand up to any scrutiny by a biometrician, however the extent of the losses and the potential impact on profitability was extreme in some cases. Refer to Figure 1. (Please note these were multiple fields and in some cases had multiple machines working).

Method 1

Twelve random samples were assessed per field to look at the yield and dollars per hectare lost at harvest. Each sample was 1/10th of a square metre. Whole unsplit pods were counted, and we assumed an average of 1 seed per pod with a seed size of 5000 seeds/kg and an on-farm price \$800/t. Refer to Table 1 and Figure 1.

Table 1. 2018 Pod loss at the header front

	Conventional header set up	Conventional header set up	Conventional header set up	Conventional header set up	Flex front	Flex front	Flex front
Seed counts/0.1m^2	17	10	0	5	12	3	21
	12	81	16	34	2	6	14
	9	47	19	0	6	12	5
	8	12	8	8	15	7	9
	5	4	6	28	17	27	5
	47	2	8	6	52	6	1
	56	14	12	44	2	16	7
	20	8	7	17	1	45	14
	41	27	46	12	1	8	6
	22	2	13	8	3	31	16
	14	17	7	7	24	15	5
	7	31	22	3	2	9	8
Total	258	255	164	172	137	185	111
Average	21.5	21.2	13.7	14.3	11.4	15.4	9.2
Seeds/m^2	217	214	138	145	115	155	93
Seeds/ha	2167339	2142137	1378024	1444557	1150877	1554103	932460
	GROWER 1	**GROWER 1**	**GROWER 1**	**GROWER 2**	**GROWER 3**	**GROWER 3**	**GROWER 3**
Variety	**HatTrick**	**HatTrick**	**HatTrick**	**HatTrick**	**Seamer**	**Seamer**	**Kyabra**
Rigid/Flex front	**Rigid Front**	**Rigid Front**	**Rigid Front**	**Rigid Front**	**Flex Front**	**Flex Front**	**Flex Front**
Kg/ha assuming 5,000 seeds	433	428	276	289	230	311	186
$/ha on the ground assuming $800/t	$347	$343	$220	$231	$184	$249	$149

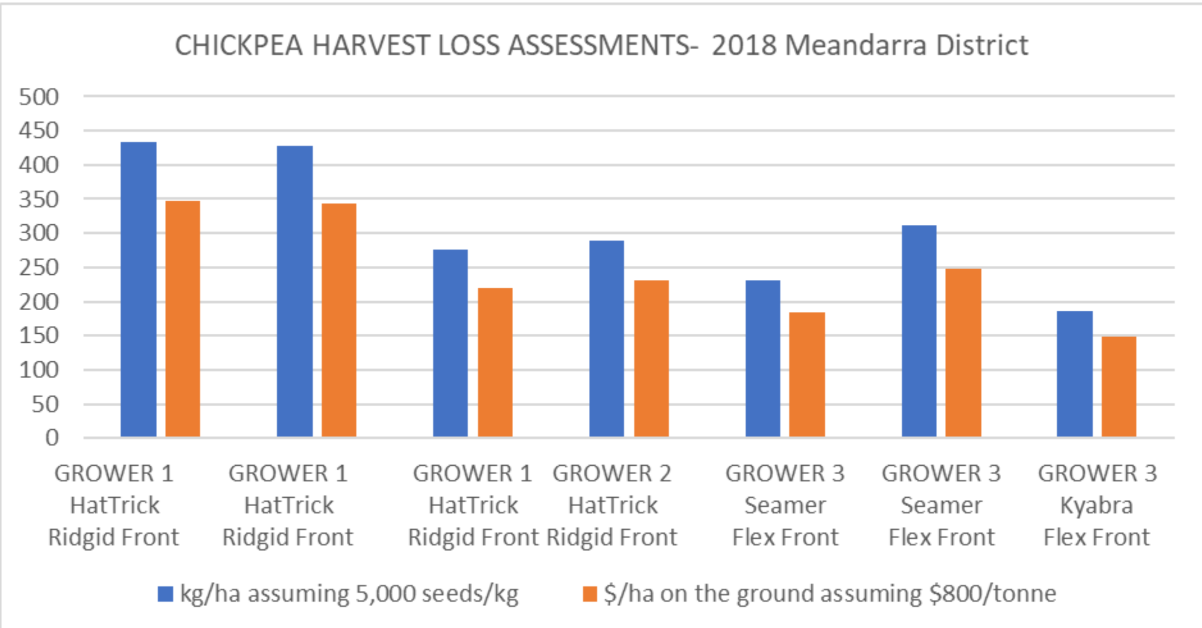

Figure 1. 2018 Pod loss at the header front
(HatTrick, Seamer and Kyabra are varieties protected under the Plant Breeders Rights Act 1994)

Of note: Grower 1 for example, had variations from field to field and there were multiple headers working in these fields. The variation may have been operator, ground conditions and/or set up. It appeared that the flex fronts were an improvement, however in one of grower 3's fields, there was still significant losses.

After being quite shocked by what the pod counts were suggesting, we started asking the question, "Can we reduce losses by modifying the header front?".

Multiple clients tried different modifications, including adding paddles to the reel, fixing different light crop fingers, adding bristles behind the knife sections and a combination of these attachments. They achieved varying results. Some clients also purchased flex fronts, again achieving varying results depending on the design of the front, and crop and field conditions.

After observing a well-regarded pulse grower utilise an AWS Airbar® attachment mounted in front of the reel of a John Deere® flex front harvesting mungbeans, and achieving a large reduction in losses, MCA became interested in the concept and started discussing it with clients.

In 2018 and 2019 four of our clients invested in the Airbar systems. We then decided to do some more basic pod counts to try and measure a reduction in losses. The average improvement in losses was 180 kg/ha with one very short low yielding crop showing an extreme improvement of 297 kg/ha.

Method 2

We asked header operators to do strips with the Airbar operating and then set up without the Airbar operating. In these strips we assessed 20 x 625 cm^2 samples and assumed 1.5 seeds/pod and a seed size of 5000 seeds/kg. Please note our data collection and analysis is not to be seen as statistically valid. Refer to Table 2 and Figure 2.

Table 2. 2019 Airbar pod counts (4 comparison sites)

Site 1: HatTrick(D), yield 0.4t/ha, 50cm rows 2018								
Regular header front								
Counts/$25cm^2$						Average/$625cm^2$ (25x25cm)	Average/m^2	Average/ha
1	5	18	5	5	6	7.8	125	
2	13	14	3	1	9	8	128	
3	13	12	10	22	5	12.4	198	
4	33	4	4	7	10	11.6	186	
					Total Av.	**9.95**	**159**	1,592,000
							Av peas/ha (assuming 1.5 peas/pod)	2,388,000
							Kg/ha (assuming 5000 peas/kg)	478
							t/ha	0.48
Air header front								
Counts/$25cm^2$						Average/$625cm^2$ (25x25cm)	Average/m^2	Average/ha
1	4	0	9	0	0	2.6	42	
2	2	8	12	5	11	7.6	122	
3	1	6	1	6	0	2.8	45	
4	0	0	2	0	8	2	32	
					Total Av.	**3.7**	**60**	600,000
							Av peas/ha (assuming 1.5 peas/pod)	900,000
							Kg/ha (assuming 5000 peas/kg)	180
							t/ha	0.18
							Difference (kg/ha)	298
							t/ha	0.30
							Cost/ha (assuming $800/t)	$238
							Area (ha)	350
							Paddock benefit of airfront	**$83,328**

Site 2: Kyabra(D), yield 0.6 t/ha 50cm rows 2019								
Regular header front								
Counts/$25cm^2$						Average/$625cm^2$ (25x25cm)	Average /m^2	Average/ha
1	3	0	7	3	3	3.2	51	
2	2	6	2	5	3	3.6	58	
3	5	1	0	6	1	2.6	42	
4	0	5	12	6	6	5.8	93	
					Total Av.	**3.8**	**61**	608,000
							Av peas/ha (assuming 1.5 peas/pod)	912,000
							Kg/ha (assuming 5000 peas/kg)	182
							t/ha	0.18
Air header front								
Counts/$25cm^2$						Average/$625cm^2$ (25x25cm)	Average /m^2	Average/ha
1	2	1	5	1	0	1.8	29	
2	1	2	2	4	0	1.8	29	
3	5	2	0	1	1	1.8	29	
4	1	0	2	0	0	0.6	10	
					Total Av.	**1.5**	**24**	240,000

Av peas/ha (assuming 1.5 peas/pod)	360,000
Kg/ha (assuming 5000 peas/kg)	72
t/ha	0.07
Difference (kg/ha)	110
t/ha	0.11
Cost/ha (assuming $800/t)	$88
Area (ha)	292
Paddock benefit of airfront	**$25,789**

Site 3: Seamer, 1.5 t/ha, 75cm rows								
Regular header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average/m^2	Average/ha
1	5	2	10	7	10	6.8	109	
2	2	2	6	2	2	2.8	45	
3	0	12	0	1	3	3.2	51	
4	6	6	0	3	4	3.8	61	
					Total Av.	**4.15**	**66**	664,000
							Av peas/ha (assuming 1.5 peas/pod)	996,000
							Kg/ha (assuming 5000 peas/kg)	199
							t/ha	0.20
Air header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average /m^2	Average/ha
1	1	1	8	3	1	2.8	45	
2	1	1	2	0	1	1	16	
3	2	1	1	1	1	1.2	19	
4	1	2	0	4	2	1.8	29	
					Total Av.	**1.7**	**27**	272,000
							Av peas/ha (assuming 1.5 peas/pod)	480,000
							Kg/ha (assuming 5000 peas/kg)	82
							t/ha	0.08
							Difference (kg/ha)	118
							t/ha	0.12
							Cost/ha (assuming $800/t)	$94
							Area (ha)	150
							Paddock benefit of airfront	**$14,112**

Site 4: SeamerⓅ, 0.5 t/ha, 37cm rows								
Regular header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average/m^2	Average/ha
1	11	3	5	0	10	5.8	93	
2	4	1	4	8	9	5.2	83	
3	11	7	4	1	13	7.2	115	
4	10	2	13	8	2	7	112	
					Total Av.	**6.3**	**101**	1,008,000
							Av peas/ha (assuming 1.5 peas/pod)	1,512,000
							Kg/ha (assuming 5000 peas/kg)	304
							t/ha	0.30
Air header front								
Counts/25cm^2						Average/625cm^2 (25x25cm)	Average /m^2	Average/ha
1	0	4	4	6	1	3	48	
2	2	5	0	0	3	2	32	
3	1	3	2	2	5	2.6	42	
4	0	0	1	1	1	0.6	10	
					Total Av.	**2.05**	**33**	328,000
							Av peas/ha (assuming 1.5 peas/pod)	492,000
							Kg/ha (assuming 5000 peas/kg)	98
							t/ha	0.10
							Difference (kg/ha)	204
							t/ha	0.20
							Cost/ha (assuming $800/t)	$163
							Area (ha)	463
							Paddock benefit of airfront	**$75,562**

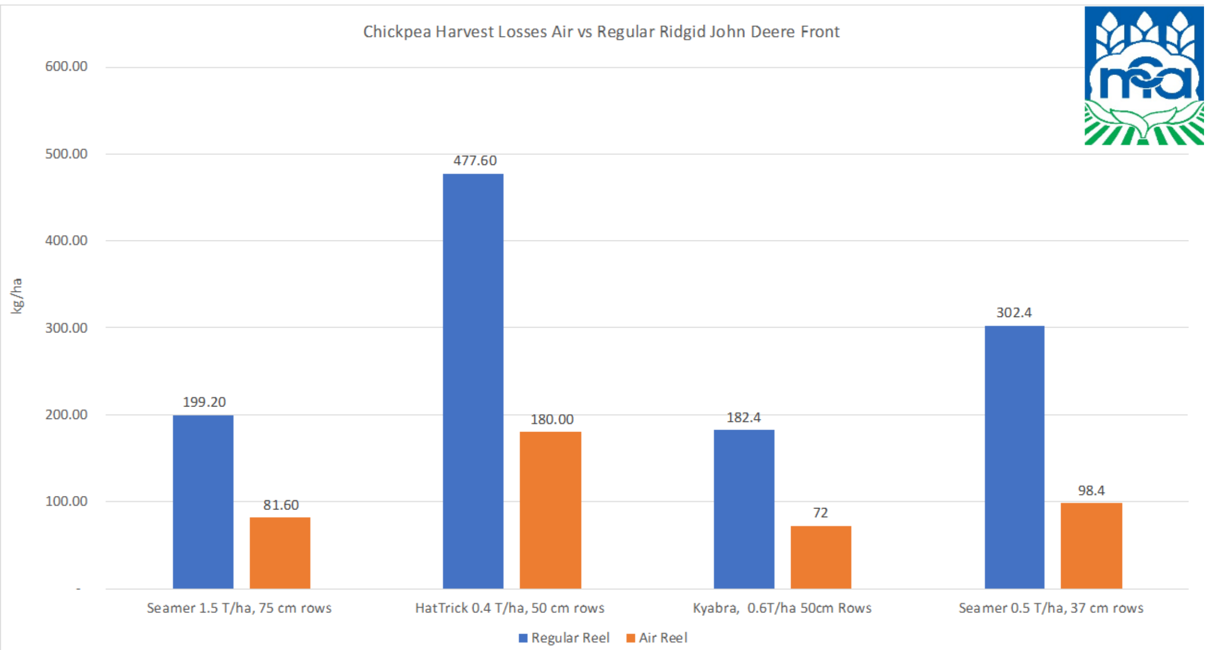

Figure 2. 2019 Harvest losses in chickpeas based on pod counts left on the ground after harvesting with a regular and an air assisted reel
(HatTrickⓅ, SeamerⓅ and KyabraⓅ are varieties protected under the Plant Breeders Rights Act 1994)

Please note: These were all rigid John Deere draper fronts with AWS Airbar attachments. These results may not be replicated with other machines or in different harvesting conditions.

Discussion

From the limited data we collected which was anecdotally supported by machinery operators, header front adjustments and modifications may provide improvements to chickpea harvest losses. Our sampling occurred in varying varieties in a range of crop yields. Of note these years were particularly low yielding. The results may not be replicated in more favourable seasons with taller crop canopies improving feeding over the knife. In fact, in higher yielding years it may be possible that these modifications may have a negative impact on losses. Replicated, statistically significant sampling needs to be collected over multiple years to answer these questions.

Conclusion

Harvest is arguably the most important aspect of chickpea crop management. Very large improvements in profitability may be achieved by adapting harvester set ups in some situations. Growers should invest the time to monitor losses and attempt to reduce these losses as the improvements to profits may be significant.

Acknowledgements

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Herbicide resistance survey results of the Northern cropping region

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Key words

glyphosate resistance, sowthistle, fleabane, feathertop Rhodes grass, awnless barnyard grass

GRDC code

UCS00024, US00084

Take home message

- Glyphosate resistant weeds are present in the northern region. Glyphosate failed to control all of the fleabane populations tested. Glyphosate resistance was also prevalent in feathertop Rhodes grass, windmill grass and awnless barnyard grass, with resistance detected in 68%, 58% and 36% of populations, respectively. Only 14% of sowthistle populations were resistant to glyphosate
- Evolved herbicide resistance to haloxyfop was also detected in feathertop Rhodes grass, albeit at a low frequency
- Other herbicides such as 2,4-D amine, propaquizafop and clethodim provided good control of the broadleaf and grass weeds tested
- Farmers and agronomists should incorporate non-chemical weed management tactics to ensure sustainability of current herbicides
- These survey results provide a first glimpse into the state of herbicide resistance in key crop weeds for Queensland and the Northern region.

Introduction

The area of the Northern grain cropping region from Central Queensland to Dubbo in New South Wales (north to south) has a diverse cropping system, often with both winter and summer cropping, or summer fallow for moisture storage. Effective weed control in crop and fallow is heavily reliant on herbicides such as glyphosate. For the past 30 years, heavy reliance on glyphosate has seen more and more weed species become resistant to this herbicide. This includes annual ryegrass, awnless barnyard grass, liverseed grass, windmill grass, fleabane and sowthistle (Cook 2014, Widderick et al. , 2014, Cook et al. 2004).

Despite the increasing number of herbicide resistance cases, the full extent of herbicide resistance in this part of the Northern region is unknown. The first whole of region survey of key winter and summer weed species started in winter 2016 and was completed in summer 2017/2018. Weed seeds collected from the survey were screened for resistance against various herbicides. This report primarily covers the herbicide resistance screening carried out by the Department of Agriculture and Fisheries, Queensland.

Material and methods

The Department of Agriculture and Fisheries, Queensland (DAF) was responsible for herbicide resistance screening of sowthistle, fleabane, barnyard grass, feathertop Rhodes grass, windmill grass and liverseed grass. Populations of the species listed above that were collected in New South Wales by Dr John Broster of Charles Sturt University were also screened by DAF.

Seed germination

Weed seeds were grown in their growing seasons following the survey. Sowthistle were grown from late March to late November while fleabane and the summer grasses were grown from late November to mid-May.

Sowthistle and summer grass seeds were germinated on 0.6% agar for 4 to 7 days in the glasshouse and transplanted into trays (50 seedlings/population/tray) of potting mix. The trays were then placed onto drip trays filled with enough water to keep the soil moist without causing any water logging for the first few days. After 7 days, the plants were watered from above. A similar approach was used for fleabane, with the exception that fleabane seeds were sown directly into trays of potting mix. After 7 days, fleabane seedlings were thinned to the required density (10 seedlings per column, up to 5 columns).

Herbicide resistance screening

Plants were grown until they reached the three to five leaf growth stage. They were then treated at the recommended label rate for each herbicide (Table 1) with the appropriate adjuvant (if required). For weeds that are not on label for a particular herbicide, the recommended rate for the closest relative weed was used. Assessment of survivors was carried out at 21 days after treatment (DAT). Plants were considered surviving if there were actively growing tillers (grass weeds) or regrowth from the growing point (broadleaf weeds).

Table 1. Herbicides and rates used for screening various weed species for resistance.

Weed species	Herbicide (note rates are of active ingredient)
Sowthistle	Glyphosate (729 g ae/ha) 2,4-D amine (1050 g ai/ha) Velocity (bromoxynil 210 g ai/ha + pyrasulfotole 37.5 g ai/ha) Chlorsulfuron (15 g ai/ha)†
Fleabane	Glyphosate (729 g ae/ha) † 2,4-D amine (1050 g ai/ha)
Feathertop Rhodes grass	Glyphosate (729 g ae/ha)†* Haloxyfop (78 g ai/ha) Clethodim (90 g ai/ha) Paraquat (400 g ai/ha)
Awnless barnyard grass Liverseed grass	Glyphosate (729 g ae/ha) Propaquizafop (60 g ai/ha) Clethodim (90 g ai/ha) Imazapic (96 g ai/ha)**
Windmill grass	Glyphosate (729 g ae/ha) Clethodim (90 g ai/ha)***

†Not registered for control of this weed species

*Glyphosate used as stand-alone and not in tank-mix with 2,4-D amine as per label requirement.

** Used alone as post-emergence . Note that imazapic is only registered for stand-alone use against these weeds as a pre-emergent application.

***As per APVMA permit PER89322 (but without the double knock)

Results

Sowthistle

In total 221 sowthistle populations from Queensland and New South Wales were collected. Only 197 populations were viable for screening with glyphosate and 2,4-D amine. Glyphosate resistance was detected in 14% of the populations tested (Table 2), while 100% of the populations were susceptible to 2,4-D amine. Screening of 136 populations with Velocity® and chlorsulfuron showed that Velocity was able to control all populations while poor control (95% populations survived) was achieved with chlorsulfuron (Table 2).

Table 2. Percentage of populations surviving treatment with different herbicides assessed 21 DAT.

Weed Species	Number of populations tested	Glyphosate (%)	2,4-D amine (%)	Chlorsulfuron (%)	Velocity (%)
Sowthistle	197	14	0		
	136			95	0
Fleabane	61	100	0	n/a	n/a

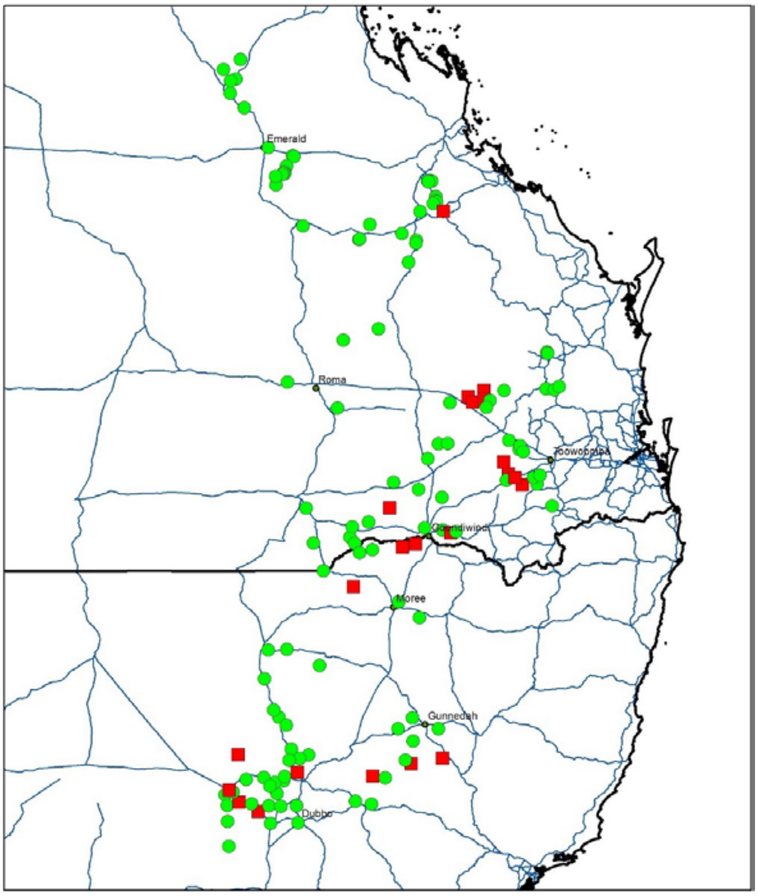

Figure 1. Map of glyphosate resistant and susceptible sowthistle populations across the northern grain cropping region. Red squares represent resistant populations while green circles represent susceptible populations.

Fleabane

There were 100 fleabane populations collected across the Northern region but only 61 viable populations (Figure 2) were screened with glyphosate and 2, 4-D amine. Glyphosate, which is not registered to control fleabane, failed to control all of the fleabane populations tested. However, no population survived treatment of 2, 4-D amine (Table 2).

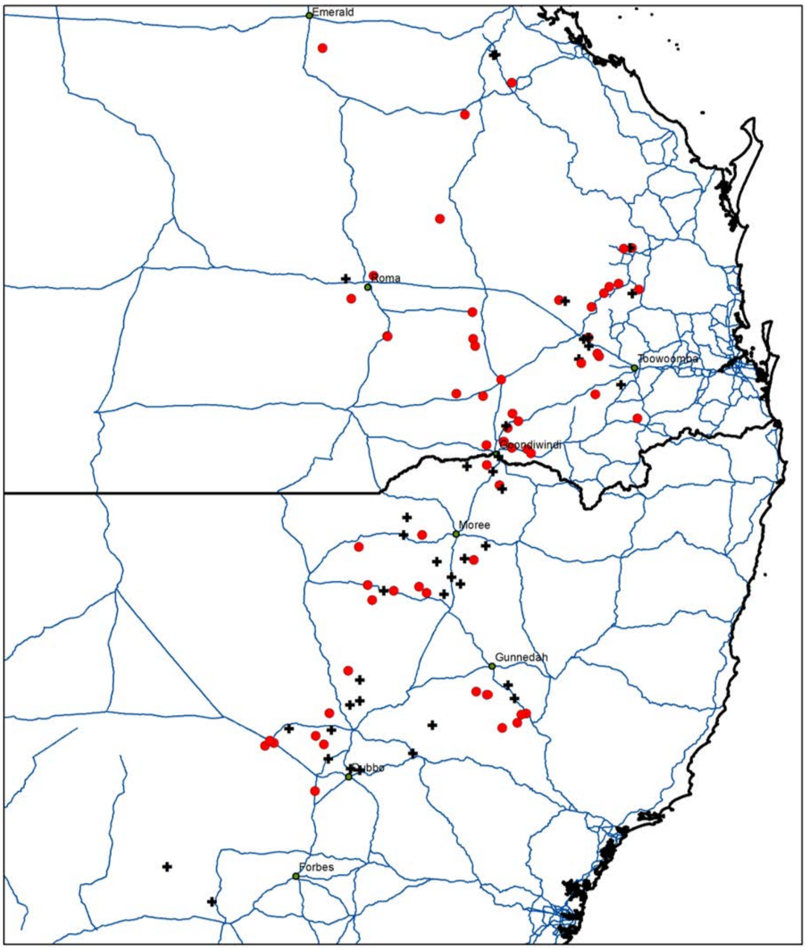

Figure 2. Map of fleabane populations across the northern grain cropping region surviving glyphosate application. Red circles are populations surviving the target glyphosate application rate, while black crosses represent non-viable populations.

Feathertop Rhodes grass

Screening of 62 viable populations revealed 68% survived the glyphosate target rate (noting that glyphosate is not registered for FTR control) (Figure 3, Table 3). One population survived treatment with haloxyfop, while all populations were controlled with clethodim and paraquat.

Table 3. Percentage of feathertop Rhodes grass populations surviving treatment with different herbicides, assessed 21 DAT.

Weed species	Number of populations tested	Glyphosate (%)	Haloxyfop (%)	Clethodim (%)	Paraquat (%)
Feathertop Rhodes grass	62	68	2	0	0

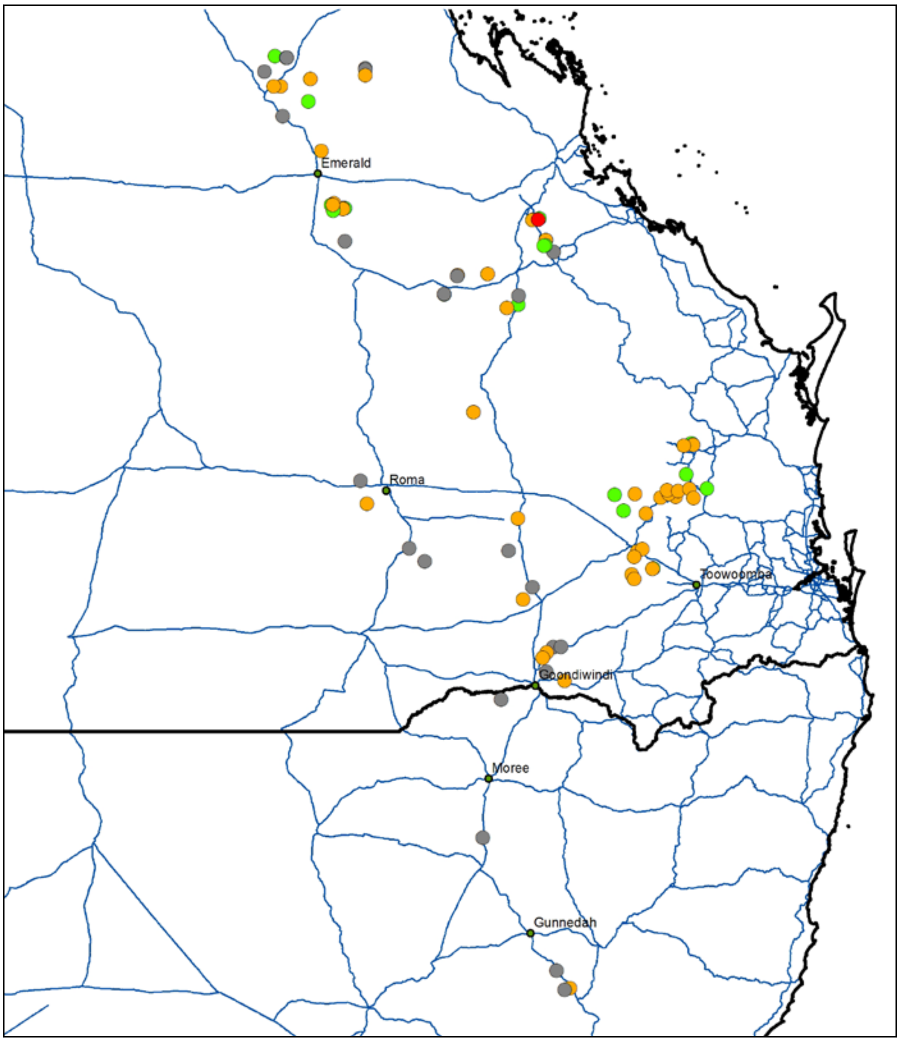

Figure 3. Map of glyphosate resistant and susceptible feathertop Rhodes grass populations across the northern grain cropping region. A red circle represents a glyphosate and haloxyfop resistant population, yellow circles represent glyphosate resistant populations that are susceptible to haloxyfop, green circles represent populations susceptible to all herbicides tested, and grey circles represent populations that were not viable.

Awnless barnyard grass

Screening of 42 viable populations revealed 36% were resistant to glyphosate (Figure 4, Table 4), while all of the populations were susceptible to propaquizafop, clethodim and imazapic (noting imazapic was applied as a foliar application and not a soil residual treatment).

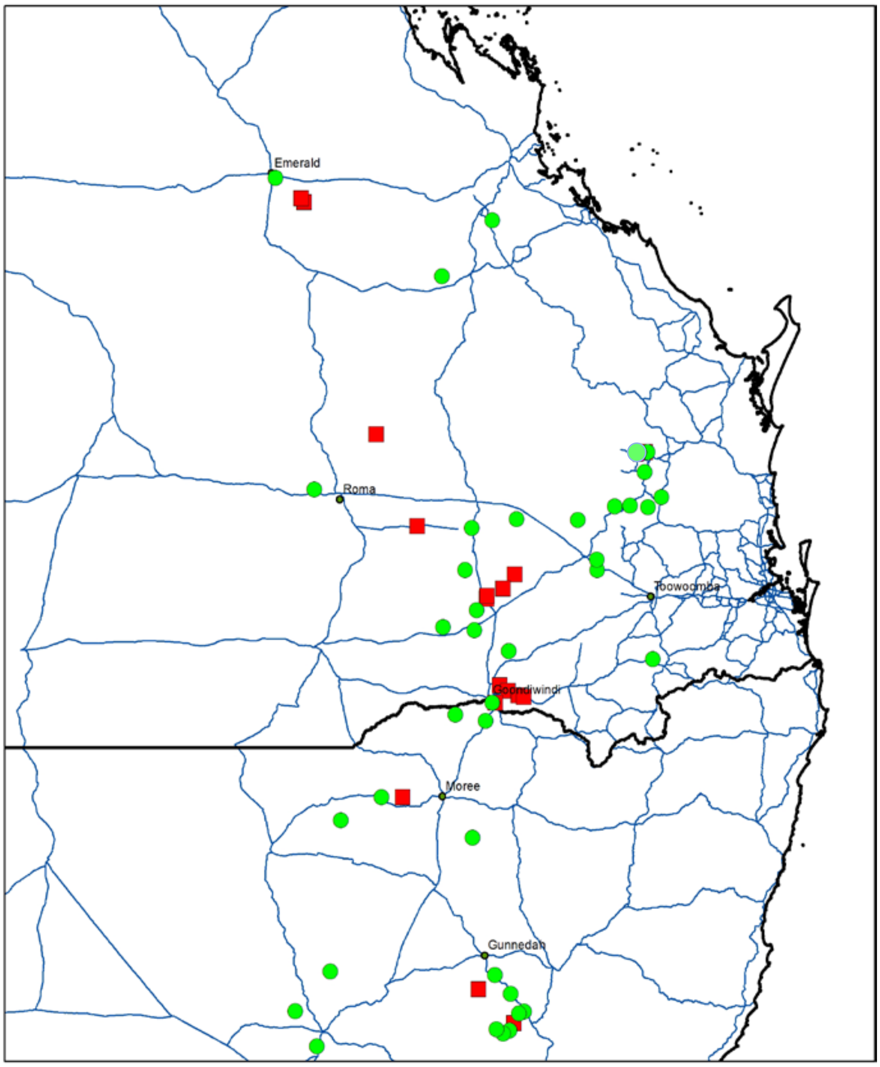

Figure 4. Map of glyphosate resistant and susceptible awnless barnyard grass populations across the northern grain cropping region. Red squares represent resistant populations while green circles represent susceptible populations.

Table 4. Percentage of awnless barnyard grass, windmill grass and liverseed grass populations surviving treatment with different herbicides, assessed 21 DAT.

Weed species	Number of populations tested	Glyphosate (%)	Propaquizafop (%)	Clethodim (%)	Imazapic (%)*
Awnless barnyard grass	42	36	0	0	0
Liverseed grass	3	0	0	0	0
Windmill grass	12	58	n/a	0	n/a

* Imazapic was applied as a foliar application, and not a soil residual treatment

Windmill grass

Screening of 12 viable populations revealed that more than half of them (58%) survived the target glyphosate rate (Table 4). All of the populations were controlled by clethodim.

Liverseed grass

There were only 14 liverseed grass populations collected across the Northern region. Almost none of them were viable. Herbicide resistance screening of the viable populations (3) showed no evolved resistance to any of the herbicides tested (Table 4).

Discussion

For years, there have been anecdotal reports of certain weed species becoming more difficult to control. This project provides, for the first time, proof of widespread occurrence of herbicide resistance in key weed species in the Northern region.

Glyphosate resistance is the most pressing issue, as all of the weed species tested have populations that were able to survive robust glyphosate application rates, except for liverseed grass (noting only three liverseed grass populations were tested). Especially worrying is fleabane, where total glyphosate failure was recorded. Frequency of glyphosate survival for the other weed species ranges from low (14%, sowthistle) to moderate/severe (68%, feathertop Rhodes grass).

Glyphosate is not registered for control of feathertop Rhodes grass, as it has been known to provide unreliable control. The inclusion of glyphosate screening to feathertop Rhodes grass was to confirm the extent of survival.

Despite the number of weed species and populations that have evolved glyphosate resistance, it should be noted that other herbicides tested were still effective. 2,4-D amine controlled all of the fleabane and sowthistle populations tested, including the ones that survived glyphosate.

Group A herbicides such as haloxyfop, propaquizafop and clethodim gave good control of the summer grass weeds, with only one feathertop Rhodes grass sample surviving haloxyfop treatment.

Imazapic, a group B herbicide that was used post-emergence in our screening, provided good control of awnless barnyard grass and liverseed grass populations. It should be noted imazapic is only registered for pre-emergent control of both awnless barnyard grass and liverseed grass. For post-emergent application the label requires it to be tank-mixed with paraquat. As such, these results should be interpreted with caution.

Viability of the weed seeds was one of the issues in our herbicide resistance screening. All of the weed species tested had populations with non-viable seeds, ranging from 10% (sowthistle, glyphosate and 2, 4-D amine) and up to nearly 80% of populations (liverseed grass). Some of these non-viable seeds were immature, and we believe some of the weed seeds were exposed to herbicide treatment shortly before collection, which could contribute to non-viability of seeds.

The presence of evolved herbicide resistant weeds in the Northern region is expected, given the reports of resistant weeds in the past. However, the extent of the some of the resistance, e.g. fleabane to glyphosate, is truly worrying. This survey offers, for the first time, an overview of the widespread nature of herbicide resistant weeds in the Northern region in key weed species. Continued heavy reliance on herbicides for weed control is likely to exacerbate the resistance challenge for growers and agronomists. Other weed management tactics that incorporate non-chemical weed control such as crop competition, targeted tillage, and harvest weed seed control (Widderick, Ruttledge, McKiernan, *personal communication*) should be seriously considered to ensure the herbicides that we have now continue to be effective in the future.

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Nutritional strategies to support productive farming systems

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Key words

fertilisers, placement, blends, recovery efficiency, application strategies

GRDC codes

UQ00063, UQ000666, UQ00078, UQ00082

Take home messages

- A critical success factor for cropping systems that rely heavily on stored soil water is co-location of plant nutrients with moist soil and active roots
- Our current fertiliser management practices need refinement, with low efficiency of fertiliser recovery often associated with nutrients and water being in different parts of the soil profile
- There needs to be greater consideration of placement and timing of fertiliser applications to improve fertiliser nutrient recovery
- Declining native fertility reserves means more complex fertilizer combinations will be needed to meet crop demands

Introduction

This paper is based on a series of observations made in recent years from the projects listed above, as well as others made by Richard Daniel and the NGA team in their work on fertiliser N application strategies for winter crops. Collectively, the findings from this research, backed by the underlying regional trends in soil fertility and the drivers for successful rainfed cropping in our region, provide some useful insights into what are likely to be the critical success factors for future fertiliser management programs.

Do we have successful fertility management systems?

To maximise the chance of achieving effective use of available moisture, an effective fertiliser management strategy needs to consider all of the 4R's (right product, in the right place, at the right time and at the right rate – Johnson and Bruulsema 2014). While everyone pays lip service to these 4R's, our real thinking is often driven by considerations about only one – rate. We spend a lot of time agonising over rate, because rate is clearly an important part of the economics of growing the crop. Rate is also an important consideration in terms of soil fertility maintenance (ie. replacing what we remove in grain). In many cases the rate we can afford is not always the rate we need to apply to optimise productivity, much less balance nutrient removal, but we still spend a lot of time thinking about it.

Because of that, we find that the thinking about the other 3R's tends to be much more superficial. Occasionally we might have a try at something a bit different, but in many cases we tend to keep doing what we have always done, and put the same products in the same place at the same time each year. Meanwhile, our background soil fertility reserves have fallen and our crops are becoming increasingly reliant on off-farm sources of fertility (fertilisers, manures etc.) to sustain productivity. It is this increasing reliance on fertilisers, especially N, P and (increasingly) K, that is allowing us to really see the inefficiency in current use practices. The impact of these inefficiencies in terms of lost productivity can often dwarf any of the considerations of rate, and are highlighting challenges for productivity and profitability in the long term.

We will now cover some examples of inefficiencies that are apparent in what has been considered as best practice for both N and P, and how the emergence of K infertility is adding further complexity to fertiliser best practice.

Management of fertiliser N

In the case of N in winter cereals, the recent comprehensive analysis of a series of N experiments from 2014-2017 by Daniel et al. (2018) highlighted the poor winter crop recovery of fertiliser N applied in the traditional application window (the months leading up to sowing, or at sowing itself). Fertiliser N recovered in grain averaged only 15% for applications of 50kg N/ha and 9% for 100kg N/ha. On average, 65% of the applied N was still in the soil as mineral N at the end of the crop season, while an only 15% was in the crop (grain and stubble). The fate of the other 20% of applied N could not be determined. Some of the soil and stubble N will carry over until the next season, but it means that you need last year's residual fertiliser to get you through this year. If you had a big year last year (little residual N) or lost a lot of the N carryover during a wet season, the current crop will suffer.

The poor winter crop recovery of applied N in the year of application mirrored that reported for summer sorghum in the NANORP research program reported by Bell, Schwenke and Lester (2016), with the use of ^{15}N tracers enabling a more precise quantification of the fate of N applied prior to planting. Data from the Queensland sites in commercial fields are shown in Figure 1 for the 40 and 80 kg N rates across three growing seasons. Fertiliser N in grain averaged 27% and 23% of the applied N for the 40 and 80N rates, respectively, while total crop uptake averaged only 37% and 32% for the same N rates. What is noticeable in this figure is the variable N losses (presumably via denitrification) and the residual N in the soil, which may or may not be available for a subsequent crop in the rotation, depending on the fallow conditions. Schwenke and Haig (2019) reported good carryover of fertiliser applied for the 2013/14 sorghum crop for recovery by the 2014/15 season under favourable fallow conditions, while extensive loss of residual soil N after summer crops was experienced over large areas during the wet 2016 winter fallow.

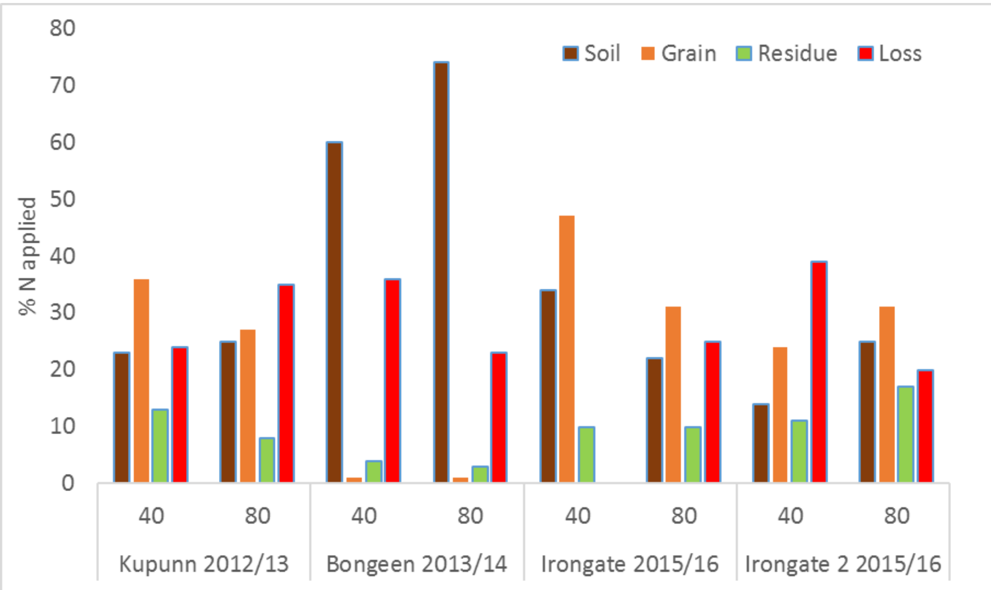


Figure 1. Partitioning of fertiliser N between soil, plant and environmental loss pools for summer sorghum crops grown on the Darling Downs in UQ00066 from 2012-2016

All studies have shown there can be significant amounts of residual N in the soil at the end of the growing season. Large amounts of that N are often found in quite shallow parts of the soil profile (ie. the 0-10cm and possibly 10-20cm layers) and still strongly centred on the fertiliser bands, despite what were often significant falls of rain in-crop (ie. 200-300mm). Even after a subsequent fallow, the Daniel et al. (2018) paper reported that 50-60% of the mineral N residual from fertiliser applied in the previous season was still in the top 45cm, with as much as half of this still in the 0-15cm layer. This largely surface-stratified residual N would have contributed to the quite muted (although still significant) grain yield response to the residual N in those studies.

Interestingly, findings from both the summer sorghum and winter cereal research suggest that crops recover mineral N that is distributed through the soil profile with much greater efficiency than fertiliser applied at or near sowing. In both seasons, 70-80% of the mineral N in the soil profile was recovered in the crop biomass, compared to recoveries of applied fertiliser that were commonly less than half that. The distribution of that N relative to soil water is likely to have played a major role in this greater recovery efficiency.

Management of fertiliser P

The substantial responses to deep P bands across the northern region where subsoil P is low have been detailed in a number of recent publications (Lester et al. 2019b, Sands et al. 2018), with these responses typically additive to any responses to starter P fertiliser (the traditional P fertiliser application method – eg. Figure 2a,b). There has unfortunately been no direct measurement of P unequivocally taken from either deep or starter P bands due to the lack of suitable tracer technology, especially when we consider residual benefits over 4-5 years. However, simple differences in biomass P uptake in a single season suggest that the quantum of P accumulated from deep bands (3-5kg P/ha) is substantially greater than that from starter P alone (1-1.5kg P/ha) in all bar exceptionally dry seasons.

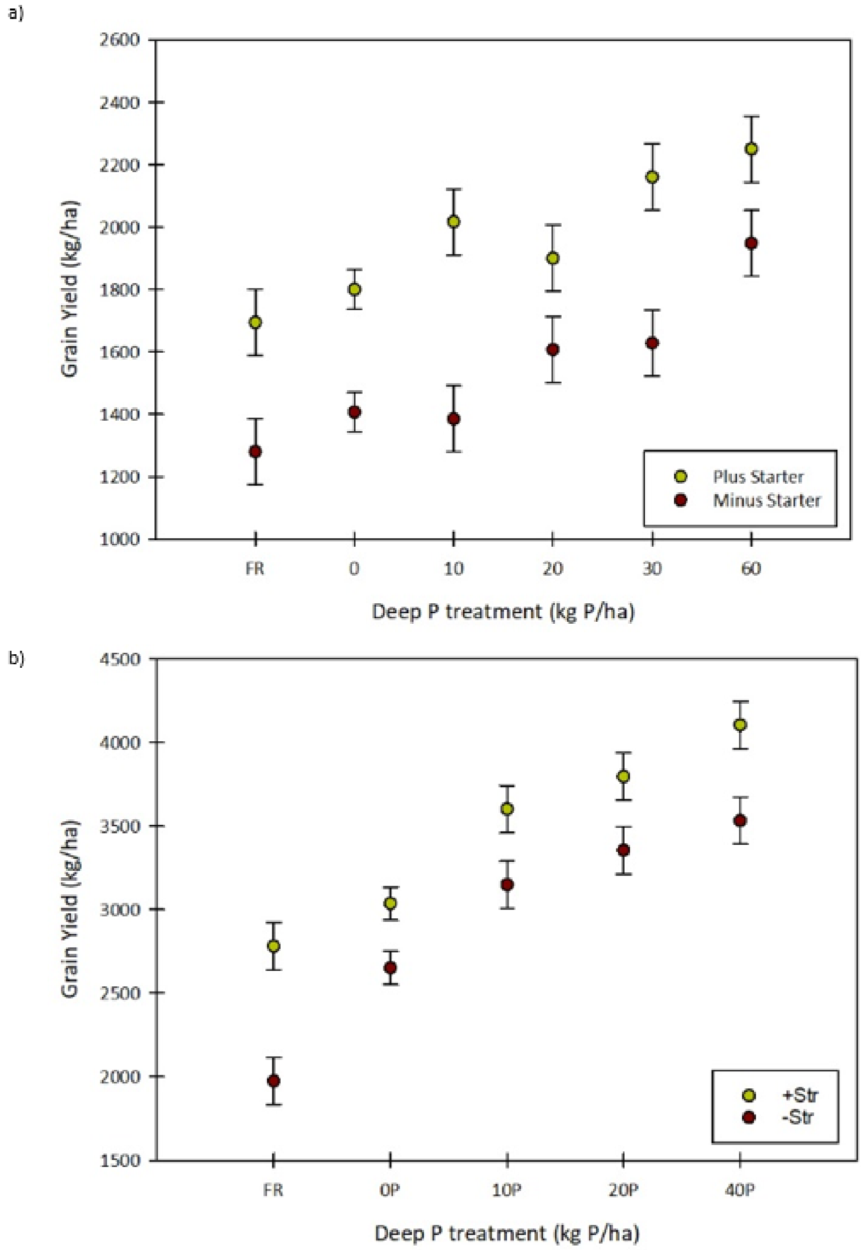


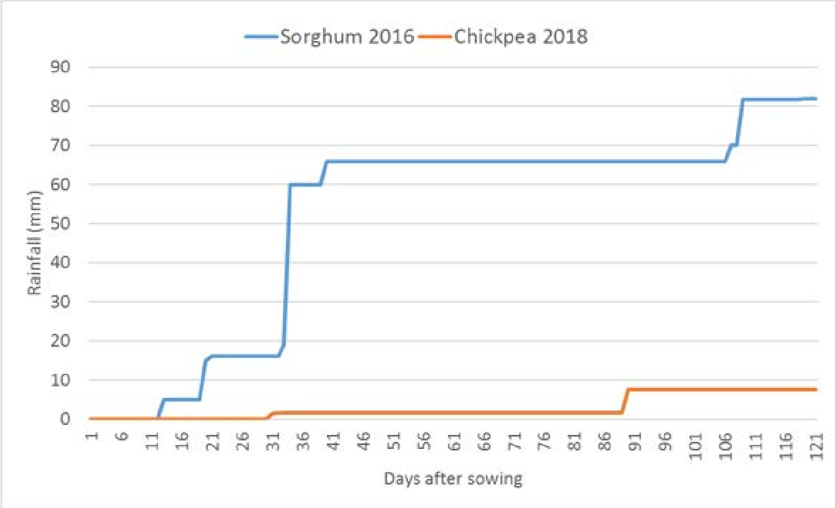
Figure 2. Response to different rates of deep P with and without applications of starter P fertiliser in (a) a wheat crop at Condamine in 2018 wheat, and (b) a sorghum crop at Dysart in 2018/19 grain yield for deep-placed P treatments (kg P/ha) with or without starter application. The vertical bars represent the standard error for each mean. (Lester et al. 2019a)

Perhaps one of the most significant findings from the deep P research has been the relative consistency of P acquisition from deep bands, despite significant variability in seasonal conditions. Research results from sites in Central Qld (CQ) often provide the best examples of this, due to the extremely low subsoil P reserves in some of those situations – if the crop cannot access the deep P bands, there is not much to find anywhere else in the subsoil! Interestingly, this type of profile P distribution is consistent with the lack of grain yield responses to starter P that were recorded over a number of years of trials in CQ and that contributed to reluctance to use starter P in some situations. Early growth responses that were consistent with the crop obtaining an extra 1-1.5kg P/ha from the starter application were observed, but a lack of available profile P to grow biomass and fill grains limited any resulting yield responses.

The inability to acquire P from a depleted subsoil places greater importance on access to P in the topsoil, which means that seasonal rainfall distribution can have a huge impact on crop P status. This is illustrated for a site near Clermont in Figure 3 (a, b), in which the growing season conditions and crop P acquisition by successive crops of sorghum and chickpea are compared. From a yield perspective, deep P increased crop yield by 1100kg and 960kg for the sorghum and chickpea crops, relative to the untreated Farmer Reference treatment, and by 720kg and 970kg/ha for the same crops relative to the 0P treatment that received ripping and other background nutrients. The similar size of yield responses in the two crops represented quite different relative yield increases (40-60% in the sorghum, versus about 300% in the chickpeas), and obviously had hugely different impacts economically, given the price differential between sorghum and chickpea grain. However, from a nutrient use efficiency perspective it is interesting to note that the apparent P acquisition from the deep P bands was similar (3.3kg P/ha in the sorghum and 2.7kg P/ha in the chickpeas - Figure 3b)) despite the vastly different in-season rainfall (Figure 3a).

What is dramatically different, and what is driving the much larger relative yield response in the chickpea crop, was the inability to access P without deep P bands in that growing season. Crop P contents in the Farmer Reference and 0P treatments averaged 2.9kg P/ha in the sorghum crop but only 0.6kg P/ha in the chickpeas. This difference was driven by the combination of deep sowing and extremely dry topsoils encountered in the 2018 winter season. The chickpea crop was planted below the 0-10cm layer, and there was never enough in-season rainfall to encourage later root growth and P recovery from that layer. Despite available moisture in the subsoil, there was not much P available to support growth and yield. In contrast, the sorghum crop was planted into the relatively P-rich top 10cm layer, which was then rewet regularly over a significant proportion of the vegetative phase. This allowed better P acquisition from the background soil, but the deep P bands were still able to supplement this and provide an additional yield benefit.

a)



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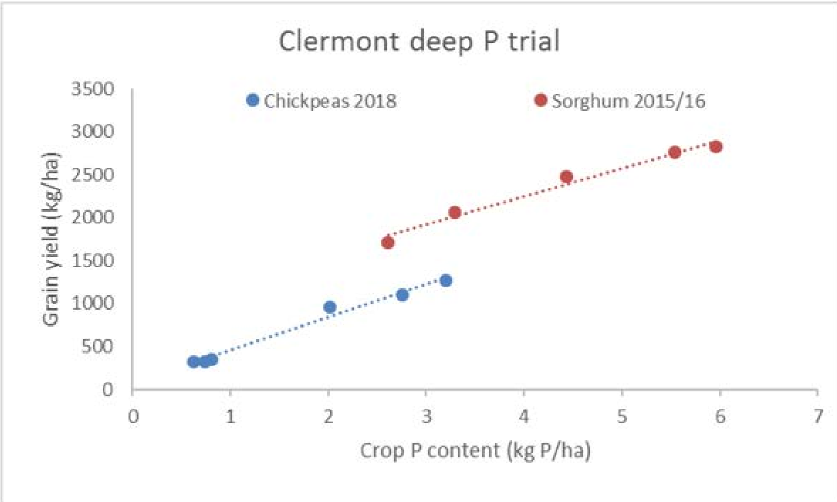


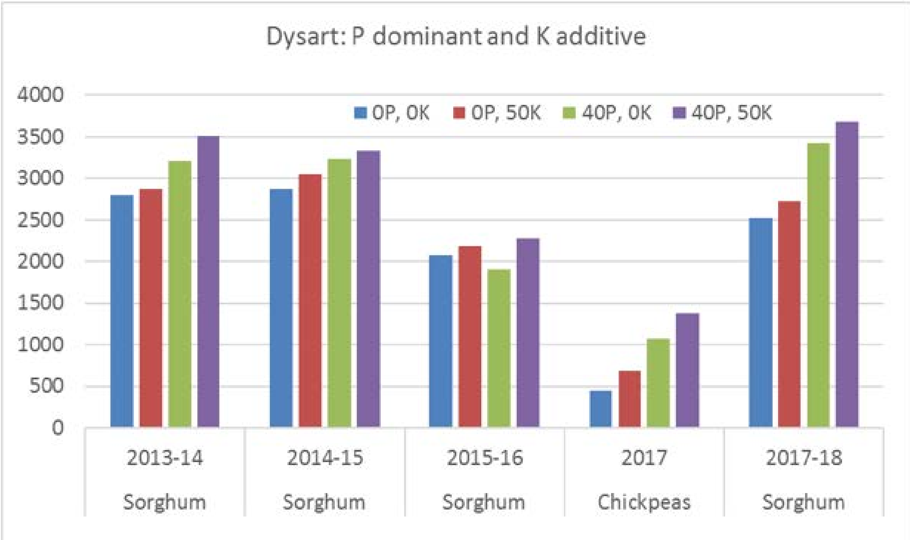
Figure 3. (a) Cumulative in-crop rainfall and (b) the relationship between crop P content and grain yield for consecutive crops of sorghum (2015/16) and chickpea (2018) grown at a site near Clermont, in Central Queensland (Sands et al., 2019)

Choice of product to address multiple nutrient limitations

As native fertility has been eroded by negative nutrient budgets and/or inappropriate placement, there are an increasing number of instances of complex nutrient limitations that require compound fertilisers to address multiple constraints, with the relative severity of each constraint changing from season to season. Perhaps the best example has been the emergence of widespread examples of K deficiency in recent (drier) seasons, but which can 'disappear' in more favourable ones. This is an example of the impact of increasingly depleted and more stratified K reserves, and is an issue that adds complexity to fertility management programs. Soil testing benchmarks for subsoil nutrients are improving as a result of current programs, but at best they are only likely to ring alarm bells for the different constraints, rather than predict the relative importance of each in future (uncertain) seasonal conditions. Examples provided in Figure 4, again from sites in CQ, show fields where subsoil P and K would both be considered limiting to productivity, but the responses to deep placed P and K have varied with crop and seasonal conditions. Assuming enough N is applied, the site at Dysart shows a dominant P constraint which is evident in most seasons, and a smaller K limitation that is only visible once the P constraint has been overcome. The Gindie site, on the other hand, has limitations of both P and K, but the relative importance of each constraint seems to depend on the crop choice and/or seasonal conditions. In both cases, the appropriate agronomic response would be to apply both nutrients, but the relative economic returns of adding K to the fertiliser program (as opposed to higher/more frequent P additions) would be different.

The emergence of multiple constraints such as those shown in Figure 4 require a greater understanding of the implications of co-location of different products, especially in concentrated bands applied at high(er) rates, less frequently. There is evidence that effective utilisation of banded K, at least in Vertosols, is dependent on co-location with a nutrient like P to encourage root proliferation around the K source (Figure 5 - Bell et al., 2017). However, there is also evidence that there can be negative interactions between P and K applied together in concentrated bands that can reduce the availability of both nutrients. There is an existing investment (UQ00086) exploring the reactions that occur in bands containing N, P and K, and the implications of changing the products and the in-band concentrations on nutrient availability. Current findings suggest that more acidic the band the more likely there will be reduced P availability, which explains why the response to triple superphosphate has been almost uniformly poor. Use MAP or even DAP in preference, and if in lighter textured, neutral to acidic soils DAP looks to be more beneficial than MAP. Adding K to a band of MAP or DAP will reduce the availability of P to a small extent in a concentrated band, but the effects are far less than those from choosing the wrong form of P fertiliser. Minimise the negative effects of adding K by reducing the in band concentration (ie. band spacing of 50cm and not 100cm) and increasing the soil-fertiliser mixing as much as possible (ie. use tines and not discs).

a)



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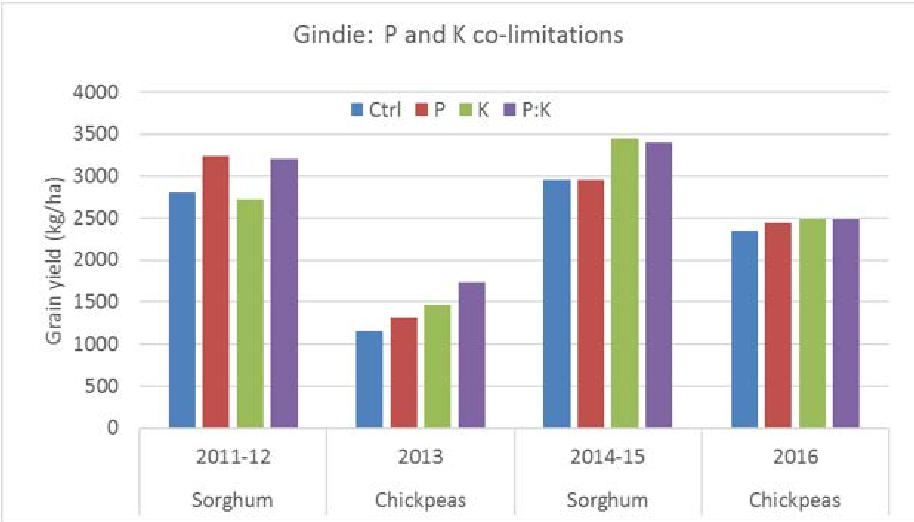

Figure 4. Examples of combinations of P and K limitations to crop performance at (a) Dysart and (b) Gindie, and the response to deep banded applications of those nutrients alone, or in combination

What are the key farming systems characteristics complicating nutrient management?

The changing nutrient demands in dryland grains systems, especially on Vertosols, are driven by the combination of nutrient removal that has not been balanced by nutrient addition (especially in subsoil layers), and the reliance of our cropping systems on stored soil water for long (and in some cases all) of the growing season. Crops need access to adequate supplies of water and nutrients to perform, and while crop roots can acquire water from a soil layer with little to no nutrient, they certainly can't acquire nutrients from soil layers with little or no available moisture. The co-location of water, nutrients and active crop roots enable successful crop production. Historically our cropping systems have been successful because (i) soils originally had moderate or higher reserves of organic and inorganic nutrients; (ii) there were sufficient reserves of those nutrients at depth so the crop could still perform when the topsoil was dry; and (iii) our modern farming systems are now much better at capturing water in the soil profile for later crop use.

Our soils are becoming increasingly characterised by low organic matter, with reserves of P and K that are concentrated in shallow topsoil layers and depleted at depth. Our typical fertiliser management program applies all nutrients into those topsoil layers, with the immobile ones like P and K staying there, and the mobile nutrients like N applied late in the fallow or at planting, when there is no wetting front to move the N deeper into the subsoil layers. Without that wetting front, even mobile nutrients like N are not able to move far enough into the soil profile to match the distribution of water – at least for the targeted crop season. We also grow a very low frequency of legumes in our crop rotation, which increases overall fertiliser demand and produces residues that are slow to decompose and release nutrients during the fallow and for the following crop. This means that nutrients like N are mineralised later in the fallow, again with less chance to move deeper into the soil profile for co-location with stored water.

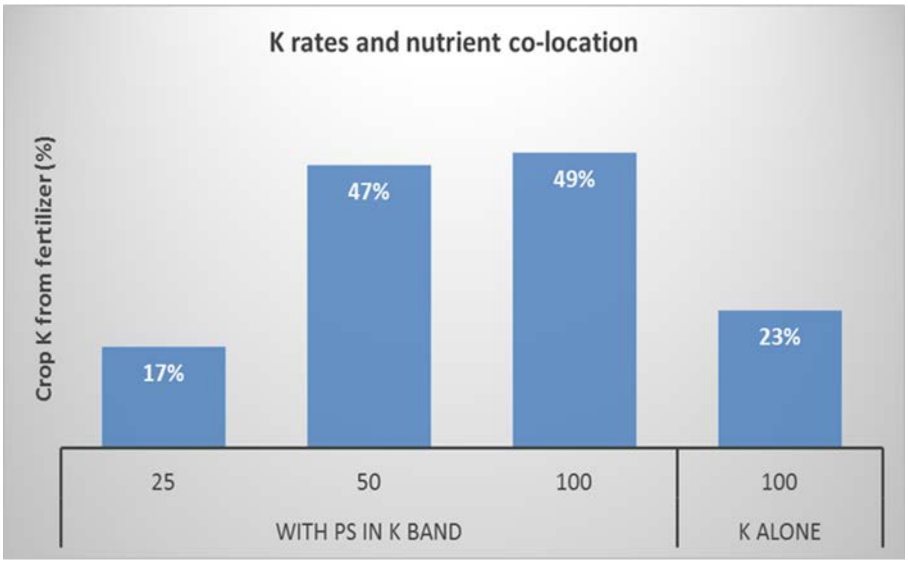

Figure 5. The impact of rate of applied K and co-location of K with other nutrients in a band (in this case P and S) on the proportion of crop K that was derived from applied fertiliser

The net result is an increasing frequency of dislocated reserves of stored soil water and nutrients, with in-crop rainfall at critical stages being a major determinant of whether the crop will be able to acquire the nutrients to achieve the water-limited yield potential. Unless our management systems change to address these issues, there will inevitably be a decline in overall water use efficiency across the cropping system, with an increasing frequency of poor or unprofitable crops. The changes that we think are needed require a stronger focus be placed on the 'forgotten' 3R's – right product (product choice/combination), in the right place, at the right time.

In the concluding section of this paper, we provide a brief outline of what we feel are going to be key strategies that need to be considered in future nutrient management programs. We note that a number of these have not yet been extensively validated, or are simply hypotheses that are worthy of testing. However, they do provide what we think are opportunities to address some of the main nutrient supply issues outlined in the preceding sections of this paper.

Future nutrient management opportunities

In general

- Focus more on feeding the soil to support the farming system, in addition to targeting the next crop in the rotation sequence. This will involve applying nutrients at a time and in a part of the soil profile that maximises the chance of having nutrients co-located with water when future crops need it. Making those decisions once the profile water has largely accumulated and the planting decision is more certain is resulting in frequent spatial dislocation between nutrient and water supply
- Where possible, legume crops should be grown with greater frequency, as they reduce the fertiliser N demand. This will allow diversion of money from the fertiliser budget spent on N into other nutrients that can be exploited across the rotation

- Be adaptive in your fertiliser management program. Respond to the opportunities that are offered to put the right nutrient in the right place at the right time and chose the right combination of products to match the soil nutrient status. This will involve a good understanding of the variation in profile nutrient status from field to field, and also understanding how seasonal conditions may impact on those application decisions.

For specific nutrients

Nitrogen (N)

- Understanding the soil water holding and drainage characteristics is critical, as strategies appropriate for heavy clays will not be suitable for lighter textured soils. For example, in clay soils you should be prepared consider changing the timing of at least some of the fertiliser N input, so it is applied into dry soils at the beginning of a fallow. The Daniel et al. (2018) paper showed nice examples of how early fallow N applications can increase the proportion of fertiliser N that is accumulated in deeper profile layers, potentially ensuring N availability with deep water to enable continued growth when the crop is experiencing dry periods. The greater efficiency of recovery of distributed 'soil' N compared to freshly applied fertiliser may allow possible rate reductions that could help to offset any interest paid on early fertiliser investment
- Be aware when conditions have changed from the 'normal' upon which your current fertiliser strategies have been based. For example, what would differences in (especially shallow) profile moisture status at the beginning of a fallow mean for the denitrification risk to early N applications? How should you respond to an unusually large crop that has depleted the soil N profile and left stubble that is low in N? How would you respond to an unseasonal rainfall event after N applications had been made?
- Legume residues should better synchronise the release of N with the recharge of profile moisture during a fallow. This should result in soil N that is more readily accessible during a following crop, as well as a lower fertiliser N requirement.

Phosphorus (P) and Potassium (K)

- Don't ignore starter fertilisers, but also be aware that they are not an effective solution to meeting crop P demand in most seasons, and adding K to starter blends can impact the 'salt' risk to crop establishment
- While there is no requirement for starter K to meet early growth demands, starter P has an important role to play in early season growth and establishing yield potential, even though the amount of P acquired from the starter P band is quite small. There may be opportunities to reduce the rates of P applied at planting if uniform distribution along the seeding trench can be maintained, where fluid forms of P may possibly having a role. The 'saved' P should be diverted into increased rates or frequencies of deep P application
- Starter P is especially important in very dry seasonal conditions, and can have an unusually large impact on crop P uptake due to restricted access to the rest of the P-rich topsoil. Under these conditions, starter P can also have a large impact on secondary root growth and improved soil P access
- Deep P and K work – use them. Question marks still exist about the length of the residual effect, and some of the risks from co-locating products in a band. Minimise the risk by applying products in more closely spaced bands (i.e. at lower in-band concentrations) more often (i.e. lower application rates)
- Remember that the main subsoil constraint has generally been P, so get the P rate right and complement that with additional K as funds allow
- Don't let subsoil P and K fall too far! Whilst we have got some great responses to deep P (and K) bands, and they are certainly economic, we have not seen evidence that a deep banded

application (of P at least) is sufficient to completely overcome a severe deficiency. The band is a very small proportion of the soil volume, and when roots proliferate around a band, they dry it out. Unless the band area re-wets during the season, allowing roots a second opportunity to access the banded nutrient, the amount of nutrient recovered will be limited. In short, bands provide a useful but not luxury supply. Nutrient concentrations in foliage and grains still show signs of crops that are still P deficient in many situations, and it is obvious that the greater the volume of subsoil that can be fertilised (more bands, more often) the greater the chance we have of meeting crop demand.

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5 years of Nitrogen research – Have we got the system right?

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Key words

Nitrogen, efficiency, soil movement, timing

GRDC code

NGA00004

Take home messages

- Over the 14 trials from 2014 to 2017, the efficiency of nitrogen (N) grain recovery from soil N was ~4 times that of fertiliser N that was applied in the year of cropping
- Maintaining high soil N levels is critical for cereal production efficiency due to the poor fertiliser N grain recovery
- Testing of grain, stubble and soil at harvest was able to account for a mean level of ~79% of the applied fertiliser N over 23 comparisons, however in 4 of the 23 comparisons, testing only accounted for 30-50% applied fertiliser N
- The majority of the additional N at harvest was recovered in the soil and averaged ~65% of the applied quantity
- The slow and shallow fertiliser N movement in soil is likely to be impacting on grain recovery efficiency
- Strategies to get fertiliser N deeper, more quickly, may provide useful efficiencies in uptake and reduce potential losses
- Strategies that can improve N contribution from the legume phase will be highly productive
- Fallow N fertiliser applications are likely to provide a benefit over at planting application in years with low in-crop rainfall.

Background

Northern Grower Alliance (NGA) have been heavily involved in nitrogen (N) management trials in wheat since 2012. The focus has always been on methods to improve the efficiency and economics of N nutrition in wheat but the specific focus shifted over time:

1) 2012-2014: Economics and fit of late application
2) 2014-2018: Impact of application method and timing.

In addition to generating answers on the two main themes, a large body of data had been created on N uptake efficiency together with measurements of soil movement and fate of N.

Rather than focusing on individual trial results, this paper focuses on N management 'system implications' and challenges whether we really have got the system right.

Grain nitrogen recovery

Grain N recovery in wheat has been calculated in trials from 14 individual locations conducted during the 2014-2017 seasons. A wide range of production conditions have been experienced with yields ranging from ~1 to 5t/ha. Three steps were taken in calculating the grain N recovery from fertiliser:

1. Grain N recovery for each treatment was calculated as yield (kg/ha) x % protein/100 x 0.175
2. 'Net' grain N recovery was then calculated by deducting the grain N recovery in the untreated (unfertilised treatment)

3. % grain N recovery was calculated by dividing the net recovery by the amount of N applied

Table 1. % grain N recovery from urea applications in 15 trials, 2014-2017

Season	2014		2015		2016		2017	
Method/ timing	All IBS		Drilled in fallow/IBS/ PSPE		Incorporated in fallow/IBS/ PSPE		Spread in fallow x 2/PSPE	
Variety(s)	EGA Gregoryᶈ		EGA Gregoryᶈ		Suntopᶈ		Lancerᶈ, Suntopᶈ & 5 other varieties	
# of trials	4		5		3		3	
	Mean	**Range**	**Mean**	**Range**	**Mean**	**Range**	**Mean**	**Range**
Urea 50 kg N/ha	21%	13-34%	30%	<0-45%	23%	16-27%	15%	10-19%
Urea 100 kg N/ha	16%	12-26%	19%	<0-31%	18%	12-23%	9%	7-12%
Urea 200 kg N/ha	9%	5-17%	11%	<0-17%	10%	8-12%	5%	3-6%

NB Data from two trials at Billa Billa 2017 site included. IBS = Incorporated By Sowing, PSPE = Spread Post Sowing Pre Emergent. Recovery data for each urea rate was generated from one application timing in 2014 but 3 timings in all 2015-2017 trials.

Key points

1. As expected, the % grain N recovery reduces as the N application rate increases.
2. Trials were conducted over a range of varieties with no indication of a consistent difference in response to fertiliser N rate between varieties.
3. Most applications were incorporated but some were surface spread and not incorporated.
4. No indication of difference between incorporated versus spread but not incorporated.
5. Recoveries appeared lower in 2017 – low in-crop rain, low yields with reduced N responses.

Grain N recovery from available soil N was also calculated for all trials in 2016 and 2017. Soil N was measured to 120cm at both planting and harvest. (Data from 2014 and 2015 was not included as soil N was only assessed during the fallow for site selection and often to 60cm depth). Two steps were taken in calculating the grain N recovery from soil N:

1. The quantity of soil N 'used' was calculated by the amount in the soil at planting minus the amount at harvest.
2. % grain N recovery was calculated by dividing the untreated grain N recovery by the amount of soil N used.

NB: an estimate of the quantity of N mineralised during the cropping season was not included for any calculation but was assumed to be consistent for all treatments. Inclusion of an estimate of mineralised N would lower the % grain recovery for both soil and fertiliser but is unlikely to change the relative differences.

Table 2. % grain N recovery from soil only, fertiliser only or combined soil and fertiliser application in 6 trials 2016-2017

Season	2016		2017	
Number of trials	3		3	
N 'source'	Mean	Range	Mean	Range
Soil only	98%	73-112%	62%	55-70%
Fertiliser only	23%	16-27%	15%	10-19%
Soil & fertiliser	62%	54-74%	40%	33-46%

NB: The mean and range used for 'fertiliser only' is for the most efficient rate (50 kg N/ha) from Table 1.

Key points

1. The % grain N recovery when calculated on combined soil and fertiliser quantities is in line with industry convention (~40-60% N efficiency depending on year).
2. However, **each kg of soil N was ~4 times more efficient** (range 3-6 times) in producing yield and protein than each kg of fertiliser N – even when fertiliser was applied at the most efficient rate.

Situations of concern

N fertiliser recommendations are generally based on setting a target for yield and protein and then ensuring a quantity of soil and fertiliser N that is generally double that target (i.e. working on a 40-60% grain N recovery efficiency). This approach is generally effective, but on the basis of these results, will struggle when soil N levels become low. Common examples would be:

- Soil N levels are heavily depleted following an unexpectedly very high yielding crop (e.g. in 2012); and
- Following a very dry fallow where mineralisation is greatly reduced.

In these situations, N fertiliser application rates may need to be increased to commercially impractical and uneconomic levels to achieve the expected outcome. In some situations with very low starting N quantities, a change from cereal to a legume may be a much better option.

Why is the fertiliser efficiency so low in the year of cropping?

Movement of N

One possible reason for the low observed efficiency of grain N recovery from fertiliser applied in the year of cropping may be the amount and speed of N movement in soil. During 2015-2017 a primary objective has been to evaluate the impact of N application into a dry soil profile during the fallow. The hypothesis was that the applied N would move further with fallow rain events so that N would be deeper and more uniformly distributed by planting.

Figures 1 and 2 are indicative of the results achieved following N application during the fallow in 2015/16 and 2016/17.

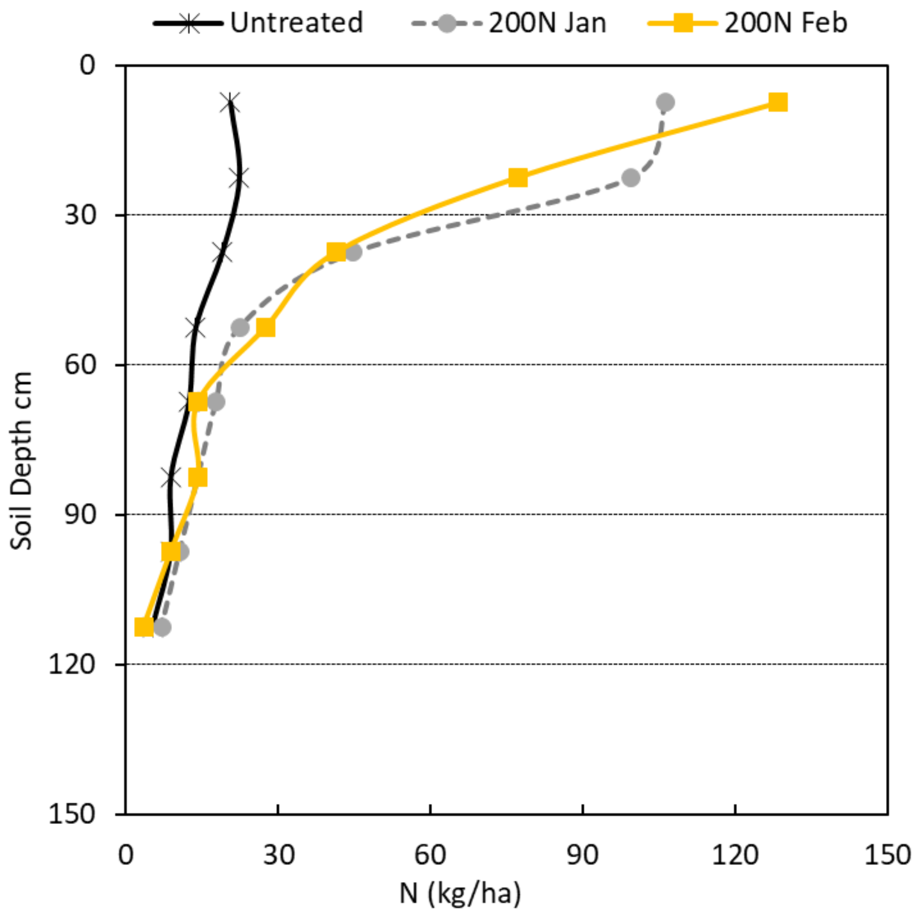


Figure 1. Soil distribution of N at Mullaley at planting (May 2017) following application of urea in January or February 2017. 175mm of rain was recorded between the January application and planting. 140mm of rain was recorded between the February application and planting.
(NB: Both N applications were spread and not incorporated. Sampling method - 6 individual 0-120cm depth cores taken per plot. Samples from each depth were bulked with a single sub sample taken for analysis. Not replicated.)

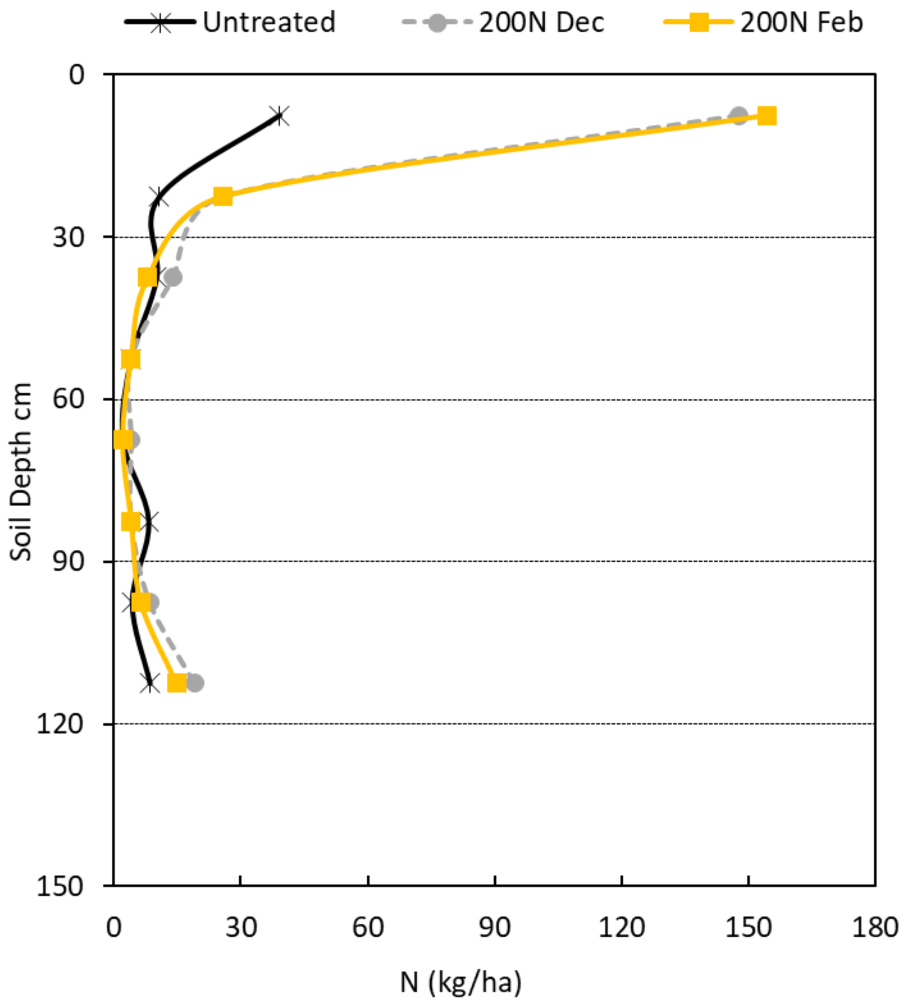


Figure 2. Soil distribution of N at Tulloona at planting (June 2016) following application of urea in December 2015 or February 2016. 225mm of rain was recorded between the December application (spread and incorporated) and planting. 65mm of rain was recorded between the February application (spread and not incorporated) and planting.
(NB: Sampling method - 6 individual 0-120cm depth cores taken per plot. Samples from each depth were bulked with a single sub sample taken for analysis. Not replicated.)

Key points

1. Even in a dry soil profile, the movement of N in these trials (predominantly vertosol soil types) was slower and shallower than expected.
2. The majority of N applied in fallow (either surface spread or incorporated to depths of ~3-5cm) was still in the 0-15cm soil segment at planting.
3. Sampling in smaller increments e.g. 5cm may reveal clearer differences in movement between application timings.

Implications of reduced N movement

The slower observed movement of N in soil may explain why in 10 of the 11 application timing trials there has not been a significant advantage from fallow N application compared to N applied at planting - as long as there were reasonable levels of in-crop rain. The 2017 season was however characterised by useful fallow rains (particularly in March) but with very low levels of in-crop rain (particularly June-September).

Billa Billa 2017

The site at Billa Billa in 2017 was the first to show a significant benefit from both fallow N applications compared to the same quantity applied at planting (or in-crop).

Figure 3 shows the distribution of soil N at planting from fallow application with the majority of N in the 0-15cm depth for both December and March 2017 applications, but with apparent increased movement from the December application. This site had the deepest movement of N recorded in any of the trials in 2016 or 2017.

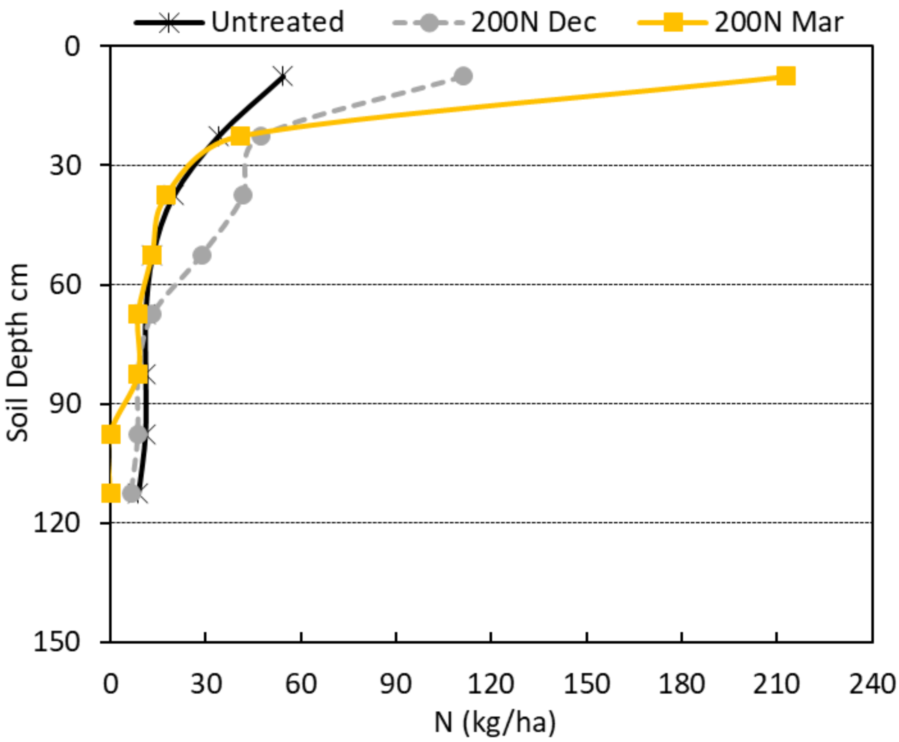
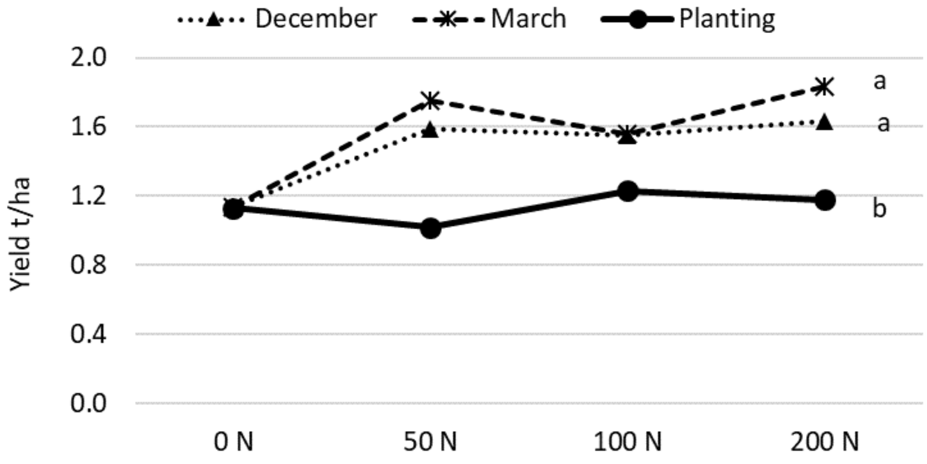


Figure 3. Soil distribution of N at Billa Billa at planting (May 2017) following application of urea in December 2016 or March 2017. 279mm of rain was recorded between the December application and planting. 154mm of rain was recorded between the March application and planting.
(NB: Both applications spread and not incorporated. Sampling method - 6 individual 0-120cm depth cores taken per plot. Samples from each depth were bulked with a single sub sample taken for analysis. Not replicated.)

Figure 4 shows the yield results (variety Lancer⏀) at this site. There was no significant N response from fertiliser applied at planting (or in-crop) at this site, with only 71mm of in-crop rain received between planting and the end of September. However applications in December or March provided a significant increase in both yield and protein (not presented).



p<0.01, LSD=0.19

Figure 4. Effect of application timing and N rate on yield, Billa Billa 2017
(Treatments that share the same letter are not significantly different at P=0.05. All N rates were spread only)

Table 3 shows the distribution of N (in excess of untreated levels) by soil depth at harvest and the quantities of rainfall recorded between application and planting or harvest.

Table 3. Depth distribution of soil N at harvest (in excess of untreated levels) from 200 kg N/ha applications, Billa Billa November 2017

	December spread	**March spread**	**Planting PSPE**	**In-crop Spread**
Rainfall - application to planting	279mm	154mm	-	-
Rainfall - application to harvest	465mm	340mm	186mm	160mm
Soil depth	**Additional soil N kg/ha v untreated at harvest**			
0-15cm	32	70	36	82
15-30cm	48	48	4	2
30-45cm	35	11	4	4
45-60cm	20	7	4	4

NB There was no indication of any movement of fertiliser applied N deeper than 60cm. Soil recovery from PSPE application was very low with only 1mm of rain recorded 4 days after application, followed by 9mm at 37-38 days after application.

Key points

1. Although the majority of N from December or March application was still in the 0-15cm zone at planting (Figure 3), the yield and protein results indicate it had moved deep enough to be available to the crop in a season with very low in-crop rainfall.
2. Increased benefit from fallow N application compared to application at planting are likely in situations with good levels of fallow rainfall but followed by low levels of in-crop rainfall.
3. The majority of excess N applied in December was recovered in the top 45cm at harvest after a total of 465mm of rainfall.
4. The majority of N applied in March was recovered in the top 30cm at harvest after a total of 340mm of rainfall.

NB Soil recovery from the PSPE application was very low in this trial with the first useful rainfall (9mm) 37 days after application. Unfortunately soil sampling was not planned/conducted in plots where N was incorporated by sowing for comparison.

How much nitrogen was actually recovered at harvest?

Assessment of the fertiliser N fate (in grain, soil and stubble) was conducted in 2015, 2016 and 2017 but with no attempt to estimate the residual N in the root system. Table 4 shows the mean quantities of N, in excess of the level where no fertiliser N was added. In 2015, results were only assessed for 200 kg N/ha applied and incorporated by sowing. Results in 2016 and 2017 are a mean of 4 application timings. In 2016, 3 of the 4 applications were spread and not incorporated with all applications spread and not incorporated in 2017.

Table 4. Mean levels of N (kg N/ha) in grain, stubble and soil samples at harvest following application of 200 kg N/ha, in excess of untreated levels, 8 trials 2015-2017

Season	2015		2016		2017	
Number of trials	3		3		2	
	Mean	Range	Mean	Range	Mean	Range
Grain	0	-16-21	20	5-39	8	3-13
Stubble	17	6-48	17	3-43	8	1-26
Soil	79	58-102	136	50-221	128	54-234
Total	**96**	**85-134**	**174**	**66-263**	**143**	**60-258**

Key points

1. Over 23 individual application timing comparisons, ~79% of the applied rate was recovered between grain, stubble and soil.
2. On average ~21% of the applied N was not able to be accounted for in grain, stubble or soil.
3. The majority of additional N was recovered in the soil and on average accounted for 65% of the applied N.
4. In 18 of 23 comparisons, testing accounted for more than 60% of the applied N.
5. The lowest recoveries were from 2 sites in 2015 where N was incorporated by sowing – both 40-50%, one site in 2016 from spreading on wet soil at GS30 – 30-40% and one in 2017 from application PSPE – 30-40%.
6. Grain recovery is likely to be the most accurate measure with stubble and soil more variable due to issues such as sampling and uniformity of spreading.

Was nitrogen still available for the following crop?

Two of the trial sites from 2016 (Tulloona and Macalister) were planted to winter crop in 2017 and were monitored for response and benefits in the 'year 2' crop. Table 5 shows the soil test results taken at planting and harvest in year 2.

Table 5. Soil N levels (kg N/ha) at Tulloona and Macalister following application of N at different rates applied at wheat planting in 2016

	Tulloona		Macalister	
N rate at sowing in 2016	April 2017	Oct 2017	Aug 2017	Dec 2017
Untreated	53 b	29 b	78 c	44 b
50 kg N/ha IBS	76 b	32 b	99 bc	46 b
100 kg N/ha IBS	71 b	21 b	131 b	80 b
200 kg N/ha IBS	162 a	122 a	237 a	178 a
P value	*<.01*	*.04*	*<.01*	*<.01*
LSD	*33*	*75*	*39*	*62*

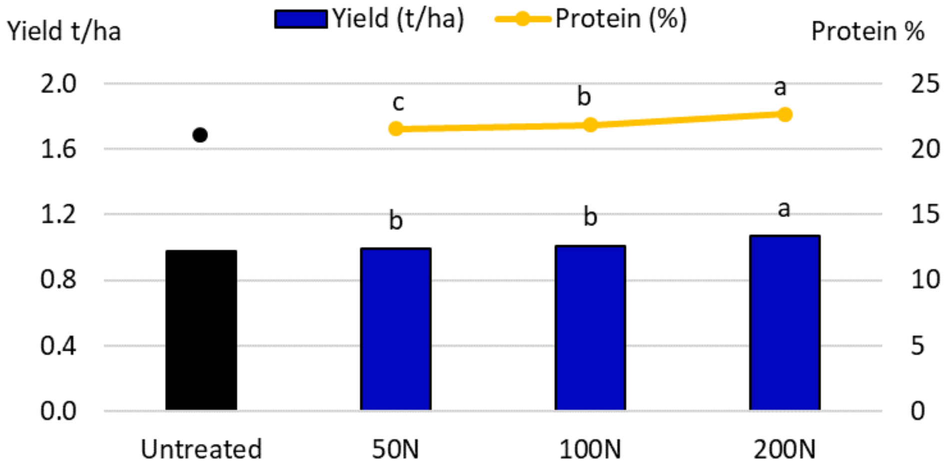
NB Sampling method - 4 individual 0-120cm depth cores taken per plot. Samples were separated into 0-30 and 30-90cm intervals with each depth bulked and a single sub sample taken for analysis. 4 replicates sampled in each treatment

Key points

1. The large LSD figures (least significant differences) highlight the variability that can occur with soil testing and that the number of soil samples collected should have been larger to account for this.
2. While acknowledging the above, soil testing ~12 months after N application (April and August 2017) showed significantly increased soil N levels in the 200 kg N/ha treatments (109-159 kg N/ha additional compared to untreated).
3. Differences were less clear from the 50-100 kg N/ha rates applied in 2016.
4. The lowest soil N levels at planting in 2017 were from the untreated samples.
5. At harvest of the year 2 crops, there was still an additional ~90-130 kg N/ha of soil N in plots that had received 200 kg N/ha in 2016.

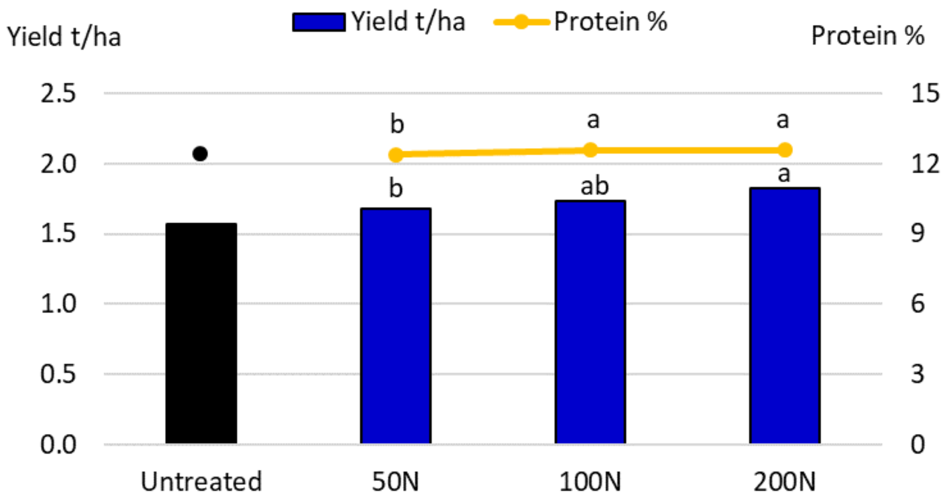
NB At the Tulloona site, ~60 % of the additional soil N was still found in the top 45cm with 45% found between 15 and 45cm. At the Macalister site, ~49 % of the additional soil N was still found in the top 45cm with 31% found between 15 and 45cm.

The Tulloona site was commercially planted to chickpeas and the Macalister site was planted to wheat. At Tulloona, at the end of September it was visually apparent that all plots that had received the 200 kg N/ha rate in year 1 were 'greener' than the remaining plots and the trial warranted harvest. Previous wheat results had indicated the most consistent N response was in grain protein, so yield and grain quality were assessed at both sites. Figures 5 and 6 show the yield and protein responses in year 2.



Yield: p=0.02, LSD=0.06 *Protein: p<0.01, LSD=0.29*

Figure 5. 2nd year impact of N rate - chickpeas, Tulloona 2017
(Treatments that share the same letter, within an assessment, are not significantly different at P=0.05. Results for each N rate are from a factorial of 3 timings x 2 varieties. Untreated not analysed and included for comparison only)



Yield: p=0.02, LSD=0.10 *Protein: p<0.01, LSD=0.1*

Figure 6. 2nd year impact of N rate - wheat, Macalister 2017
(Treatments that share the same letter, within an assessment, are not significantly different at P=0.05. Results for each N rate are from a factorial of 3 timings x 2 varieties. Untreated not analysed and included for comparison only)

Key points

1. Significant increases in both yield and grain protein were recorded in year 2 from the 200 kg N/ha rates applied in 2016 compared to the 50 kg N/ha rate at both sites.
2. Although soil testing did not show a significant difference in soil N between the 50 and 100 kg N/ha rates, there was a significant increase in grain protein recorded in both crops from the 100 kg N/ha treatments compared to the 50 kg N/ha rate.

Economic impact

Tulloona

- Wheat 2016: all nitrogen rates achieved at least break even in 2016 due to yield benefits (0.7-1.2t/ha) combined with increased grain quality in a ~4t/ha yielding situation
- Chickpeas 2017: although grain protein was increased by all rates of N applied in 2016, only the 200 kg N/ha rate resulted in a significant yield increase. This equated to an extra $60/ha net benefit
- Soil testing indicates an extra 90 kg N/ha is still available to benefit year 3 cropping from the 200kg N/ha applications.

Macalister

- Wheat 2016: there was no yield impact from applied N but increases in protein of ~2-3%. There was no net benefit with mean yields ~2.0-2.5t/ha
- Wheat 2017: significant yield increases were recorded from all 2016 rates compared to the untreated (0.1-0.25t/ha). Despite significantly increased protein from the 100 and 200 kg N/ha rates, all grain was H2 quality. Net benefits of $32-$73/ha were achieved in year 2
- The 50 kg N/ha rate was the only one to achieve a net benefit over the 2 years of ~$20/ha
- Soil testing indicates an extra 130 kg N/ha is still available to benefit year 3 cropping from the 200 kg N/ha applications.

Conclusions

This series of trials over 4 cropping seasons and 14 trial locations has provided results that question some of our current management practices.

- It has supported the general N grain recovery 'rule' applied in N budgeting of 40-60% of available soil and fertiliser N but highlighted a large difference in efficiency between the two sources
- It has highlighted the poor efficiency of fertiliser N grain recovery in the year of application with mean levels of ~15-20% applied N recovered in grain at common commercial rates (50 -100 kg N/ha)
- The relatively shallow and slow movement of the applied N is likely to be a major cause for this inefficiency
- Consider non-cereal options in paddocks with very low soil N levels
- Testing at harvest of grain, stubble and soil indicated nearly 80% of the applied N could be accounted for, although in a small number of situations this level dropped to as low as 30-50%
- There was no clear pattern of difference between urea surface spread or spread and shallow incorporated in terms of N recovery. They were both equally good (or bad)
- Initial assessment of response in 2nd year crops was encouraging with ~50% of the initial 200 kg N/ha rate still available for crop response in year 3
- At one of the two sites monitored in year 2, all of the net benefit from fertiliser occurred in year 2
- The errors associated with soil testing (e.g. core number, uniformity of sample mixing and sub sampling) make 'precise' recommendations on fertiliser N levels difficult.

Key industry challenges

- Ensure soil N levels do not continue to decline as the required levels of fertiliser N in the year of cropping would rapidly become uneconomic and impractical and cereal production less efficient
- We need to identify methods to get fertiliser N deeper in the profile, more quickly, to improve availability and efficiency

- Identify and if possible, manage the unaccounted losses from fertiliser N application.

Where to next?

The results from this work indicate we still have much to learn, or at least to refine, with the management of our most important and best understood nutrient for cereal production. Any practices that can improve the efficiency of N accumulation from the legume phase are going to be exceedingly valuable, together with methods to increase the efficiency of fertiliser N use in the year of cropping.

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Cereal disease management in 2020 – from famine to moving feast!

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Keywords

correct diagnosis, leaf diseases, stripe rust, net blotch, fungicide strategy, stay up to date, COVID-19

GRDC code

DAN00213: Grains Agronomy & Pathology Partnership - A strategic partnership between GRDC and NSW DPI

Take home messages

- 'We're all in this together'
- Ensure you know the latest resistance ratings of cereal varieties you have sown – they change
- Back to basics – destroy the green bridge – oh well, move on from this in 2020
- Ensure correct diagnosis – not everything is disease and if not fungicides won't help
- Timing is everything – protect the top three leaves. However, with stripe rust 'flattening the curve' helps
- Prophylactic or responsive in 2020 with tight fungicide supply? Is a 2-3 week wait for product in Spring a potential consequence?
- Seek information and advice – NSW DPI pathologists are here to help ('we're all in this together').

Introduction

Gotta love 2020! Prolonged drought, bushfires/dust storms, COVID-19 global pandemic, barley tariff, wet/cold and now early development of leaf diseases (stripe rust in wheat and net blotch in barley) in winter cereal crops.

The other significant issue at play is continued concerns around the availability of fungicides throughout the season. The only thing that is certain in 2020 is that whatever I write here will likely be outdated by August when we do the webinar. Hence, I'll try and stick to the principles of disease management.

1. Know resistance levels in varieties you are sowing – they do change!

At the time of writing continuing reports of stripe rust 'hotspots' in the early sown wheat variety DS Bennett⊕ are occurring. This has been a considerable surprise to some growers and their advisers as they thought this variety was rated R to stripe rust. Well it was in 2018, but with the detection of a new pathotype (198 E16 A+ J+ 17+, '198 pathotype') in Tasmania and Victoria in 2018, the rating of DS Bennett⊕ dropped to MS in 2019 sowing guides. The 198 pathotype was detected at 4 sites in NSW, 2 in Victoria and 1 in QLD in the 2019 season with further evaluation of stripe rust reactions to this pathotype seeing DS Bennett⊕ lowered to an S rating for 2020 variety guides. Ensure you are using the latest variety ratings which are updated annually to reflect the expected reactions to new pathotypes of different pathogens if required (Winter crop variety sowing guide 2020).

The resistance within the varieties does not change, rather it is pathogen which has adapted (mutated) to overcome a resistance gene(s) within a variety. This can therefore lower the resistance rating of varieties which rely on this particular resistance gene. How far the rating drops depends on what other resistance genes are sitting in the background within individual varieties. For example, with the 198 pathotype of stripe rust, DS Bennett⊕ has fallen from R to S, Illabo⊕ has dropped from

RMR to MR, whilst LRPB Kittyhawk⦶ remains unchanged at RMR. Some other big changes with varieties to the 198 pathotype are in LRPB Trojan⦶ which drops from MRMS to MSS and some durum varieties such as DBA Lillaroi⦶ and DBA Vittaroi⦶ which drop from RMR to MS. Note there have also been changes in leaf rust resistance ratings in wheat to a new Lr24 pathotype. It pays to stay up to date with the latest resistance ratings.

2. Destroy the green bridge is still important – volunteers are not good!

All rusts are what is termed '*biotrophs'* which simply means they need to host in a living plant to enable them to survive between crops. With wheat rusts, volunteer wheat plants are the green bridge, if they are from a susceptible variety. Removing these volunteers and hence the green bridge, delays the onset of rust epidemics if adopted widely. However, many growers have come off the back of a few tough years and with prolonged drought we all expected to have a reduced risk from green bridge build-up of rusts.

Volunteers which emerged on December/January rains were a valuable source of much needed feed and with great growing conditions there was unfortunately not enough stock to keep on top of the growth in many situations. Unfortunately, it has been reported that the growth was so good that some growers have even attempted to hang onto some of these volunteer crops and take to harvest. This, combined with an early seasonal break in 2020 in many regions of NSW and the widespread sowing of longer season wheat varieties, has resulted in a continuous 'green ramp' since January in many areas. The need to reduce input costs has also seen a reduction in the use of seed and in-furrow fungicide treatments for stripe rust which normally provide early protection and delay the onset of stripe rust in regions when used widely. The levels of stripe rust already present in long season wheat varieties across NSW will place pressure on plantings of susceptible main season varieties (potential 'second wave'?).

Some central NSW growers have also hung onto volunteer barley crops, attempting to take them to harvest. With prolonged wet/cold weather there have been issues with getting the heads to dry down, high levels of either spot or net-form of net blotch and weeds. At least with net blotch these situations are largely confined to the paddock where the problem was created. Hence, lesson learnt for the growers. Unfortunately, this is not the case with rust as the spores from infected crops can blow 100s of kilometres. Yes, 'we're all in this together' (COVID-19 parallel 1).

3. Monitor crops and get correct diagnosis

Do not get the impression from this paper that everything that is happening in cereal crops in 2020 is related to disease. Underlying issues with nutrient, herbicides, frost and other stresses are also causing some yellowing or discolouration of leaves in 2020. Physiological spotting not related to disease occurs especially in barley every year with 2020 being no exception. However, disease has clear patterns of distribution within and between paddocks, plants and even on individual leaves. The key message is testing is available which can be as simple as texting or emailing some good quality photos to NSW DPI pathologists (contact details below). This can be a quick way of ruling disease(s) in (or out), before pulling the sprayer out of the shed. If symptoms appear consistent with disease, we can then confirm this through testing of submitted samples. Testing and correct diagnosis is important (COVID-19 parallel 2). Also remember that all diseases have what's termed a '*latent period.'* Latent periods which vary in length and are basically the delay/number of days from when the fungal pathogen infects the plant and when symptoms (i.e. lesions or pustules) are visible on leaves. Hence, infections you see in your crop now are actually related to infection events that happened in the past. For example, stripe rust has a 10-14 day latent period, so hot spots that growers are seeing in their crops now started from infection events around or more than a fortnight ago (COVID-19 parallel 3).

4. Fungicide management – timing is everything

Fungicide application does not increase yield, rather it protects yield potential. Not all varieties will need extra protection from in-crop fungicide application if they have an adequate level of resistance to the disease of interest. For example, wheat varieties rated MR or better for stripe rust do not require fungicide management even though they may still show some infections at the seedling stage. The only caveat here is that we have seen some varieties (e.g. Suntop⚘ and Lancer⚘) take a bit more stripe rust when under high levels of background nitrogen nutrition which realistically only drops their rating by one category. That is, they DO NOT become 'suckers' under high N.

When it comes to protecting yield potential from development of leaf diseases in cereals it is the top three leaves (flag, flag-1 and flag-2) that need to be kept green for as long as possible. This is because these leaves intercept the most sunlight to drive grain filling and hence yield. In most barley varieties the flag leaf is smaller compared with wheat so the flag-1 is generally a bit more important with barley, but the surface area of the flag leaf sheath is big in barley and as such, is an important solar panel to protect. However, irrespective of exactly which of these three leaves do the heavy lifting, they all need to be protected in susceptible varieties if under disease pressure and weather conditions conducive to disease development are expected.

The flag-2 leaf is fully emerged at GS32 whilst the flag leaf is fully emerged at GS39. This is why a two spray strategy at GS32 followed by GS39 is effective in susceptible wheat varieties. This could equally be an up-front (seed or in-furrow) treatment followed by an in-crop spray at GS39. In barley, a two spray timing would be at ~GS32 and 49, with the latter spray timed to protect the flag leaf sheath. Leaves that are not emerged at the time of fungicide application are not protected as there is no systemic movement of foliar fungicides into new growth. Hence, early in-crop application prior to GS30-32 are questionable especially with 'necrotrophic' leaf diseases (e.g. yellow spot in wheat or net-blotches in barley) as leaves that emerge after foliar fungicide application are unprotected and exposed to continued infection from ongoing ascospore release from wheat or barley stubble, respectively within the paddock. The situation is more complicated with rusts such as stripe rust because, depending on coverage, a foliar fungicide application within an infected crop can eliminate the disease from a paddock. This can be to an extent that a new infection event from outside the paddock or successive cycles of the pathogen are required for the rust to build back up to damaging levels. That is, you have essentially flattened the curve of the stripe rust epidemic (COVID-19 parallel 4).

5. Prophylactic or responsive in 2020?

All fungicides have stronger preventative than curative activity against leaf diseases. This means that they are generally most effective when applied prior to or early in disease development rather than once the disease has established in a crop. Once lesions or pustules have developed on infected leaves and green leaf area has been lost, it cannot be restored by application of a foliar fungicide.

With tight fungicide supplies, prophylactic applications, if not warranted, could potentially leave growers short in spring when protection of key leaves is required and when spraying is most likely to provide maximum economic return. If the season remains wet and temperatures warm, which decreases the latent period for many leaf diseases, a 2-3 week wait for product in late winter - early spring could cause significant angst. Timing is everything with a foliar application at GS39 in late-winter - spring likely to be the best time to 'flatten the curve' on a leaf disease epidemic. If spraying crops prior to GS30, unless justified (i.e. stripe rust evident in MRMS or lower variety), then first consider the potential implications for your ability to hit a well-timed foliar fungicide application around GS39. 'Cheap insurance' in 2020 may be better addressed by keeping product in the shed for a targeted maximum benefit application at around GS39 (or possibly later in barley), rather than by a more questionable earlier prophylactic application. This situation could vary considerably between growers and change during the course of the season. Ensure you are talking with suppliers now before using up what you have on hand.

Conclusions

It is great to be having a relatively wet start to the winter cropping season across much of NSW and hopefully this continues. Consequently, leaf diseases are more likely to be more prevalent in wheat and barley crops than over the past three seasons. This may be the first experience for some newer agronomists in managing leaf diseases whilst the rest of us are drawing on medium-term memory. Be aware that some things have invariably changed during this time. Do not assume that the resistance levels in your wheat varieties are the same as three years ago, as new pathotypes of rust pathogens have developed and potentially distributed widely across NSW. Make sure you are using the latest resistance ratings and manage crops appropriately based on this.

Stay calm. Panicked decisions are not always the best decisions. Remember any disease you are seeing in your crops are from infection events that occurred 1-2 weeks ago so why do you need to spray in the next 5 minutes? Ensure you have the correct diagnosis as using up tight fungicide stocks on physiological, nutritional, environmental or herbicide related symptoms in leaves wastes product and may leave you short for spring when a timely fungicide application is more likely to have maximum economic benefit.

Remember 'we're all in this together' and NSW DPI pathologists are here to help.

Useful resources

Winter crop variety sowing guide 2020. NSW DPI

Agronomists and NSW DPI pathologists but never be shy to get a second opinion.

Useless resources

'Chicken little' old mate down the pub (if allowed) who is a little excited and full of 'information'. Two weeks in isolation suggested.

Glossy product brochures which claim one product is 'significantly' better than another. Yes, some actives have stronger activity than others but don't let it become a distraction. None of them can restore green leaf area if you have to wait 2-3 weeks to get them in the middle of an epidemic. Research shows that if you apply a registered product for the target leaf disease then timing is generally as or more important than product choice.

Tweets from world leaders.

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Summer crops: relative water use efficiencies and legacy impacts in farming systems

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Key words

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

GRDC codes

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Take home message

- While summer crops offer rotational options in the farming system, choose the correct crop to match your available soil water and crop history
- Sorghum is a reliable performer often exceeding other options in terms of $ returned per mm used
- Cotton and maize require higher water availability and produce less reliable WUE ($/mm). However, cotton has legacy impacts on water availability for subsequent crops that should be considered
- Mungbean can produce higher $/mm in low water availability situations (<200 mm of rain + soil water). Repeated sowings of mungbeans are likely to induce yield reductions due to disease
- Sorghum crops sown with > 150 mm of plant available water will maximise crop WUE and profitability. Every extra mm at sowing could be worth as much as $35-70 extra return/ha
- Higher density sorghum crops may provide greater crop competition against weeds and potential upside yield benefits in good season. We have seen limited legacy benefits (e.g. improved ground cover) or costs (e.g. greater soil water/nutrient extraction) for soil water or nutrient availability.

Introduction

Summer crops are becoming an increasingly important component of cropping systems in the summer-dominant rainfall zone. They are often useful for providing disease or weed management benefits when in rotation with winter crop dominated systems. While it is widely recognised that summer crops are often critical for improving the system sustainability, a key challenge is transitioning between summer and winter crops or phases in the crop sequence. This requires either double cropping or introducing long-fallows (>10 months) during transitions between the summer and winter crop phases. Hence understanding how effectively different summer crop options convert available water into grain yield and ultimately profit is critical to making better decisions about when summer crops may be used in the crop sequence. Further, differences in water extraction, subsequent fallow water and nitrogen accumulation are likely to influence how subsequent crops will perform or the period of fallow time required to reach critical sowing moisture levels. So, it is important to target the right summer crop option to the system.

This paper will report on several comparisons of relative water use efficiency of different summer crops, and effects of summer crop management practices (e.g. soil water at sowing, sorghum configuration and density) and their legacy impacts in the farming system.

Relative WUE ($/mm) of summer crop options

Over the past 4 years of experiments, different summer crop options have been grown in the same season and under common previous fallow length and starting moisture. Using this data, we have calculated for these various comparisons the crop water use efficiency as $ of income generated per mm of crop water use. This was done using long-term median crop prices and inputs for each of the crops, but these relative values would shift if prices for individual crops were more/less favourable compared to others.

Across a range of seasons and growing conditions, sorghum always exceeded mungbeans in terms of $ generated per mm. This was even though on several occasions mungbean crops use less water and often left significantly more residual soil water than the sorghum crops grown in the same conditions. Sorghum was only bettered in terms of crop WUE by a cotton crop at Pampas in summer 18/19 and sunflowers when they were sown as a double crop in 17/18.

Table 1. Crop water use efficiencies ($ gross margin per mm water used) comparisons between summer crops when grown in the same season with similar starting conditions (long fallow – LF, short fallow – SF, double crop – DC).

	Pampas 16/17 (LF)	**Pampas 17/18 (DC)**	**Pampas 17/18 (SF)**	**Pampas 18/19 (LF)**	**Pampas 18/19 (SF)**	**Pampas 19/20 (DC)**	**Pampas 19/20 (SF)**	**Billa Billa 16/17 (LF)**	**Narrabri 18/19 (LF)**
Sorghum	12.0	2.82	9.4	10.1	6.1			3.4	0.7
Mungbean	7.0		3.8		5.5	2.0	12.5	1.3	0.4
Cotton	6.4			15.8					
Maize	7.3								
Sunflower		11.4							
French millet						2.7	3.0		

Figure 1 shows the relationships between crop water use and crop income generated for 100 summer crops (sorghum, mungbean, cotton, sunflower and maize) that have been grown in our farming systems research over the past 5 years. This graph demonstrates that:

- In sorghum, a strong relationship was found between crop revenue and crop water use; on average $4.50 of income generated per mm of crop water use above 200mm. That is, 200mm of available water through in-crop rain or soil water at sowing is required before a positive return is generated
- Mungbeans show a higher return per mm at lower crop water use than sorghum, particularly when available crop water is less than 250mm
- Sunflowers produced a similar return per mm to sorghum in the few seasons when they were grown. This outcome would be greatly influenced by the price obtained for sunflowers which can be highly variable
- In maize and cotton, higher variation in returns per mm were observed. In some seasons, this exceeded sorghum but was lower in others.

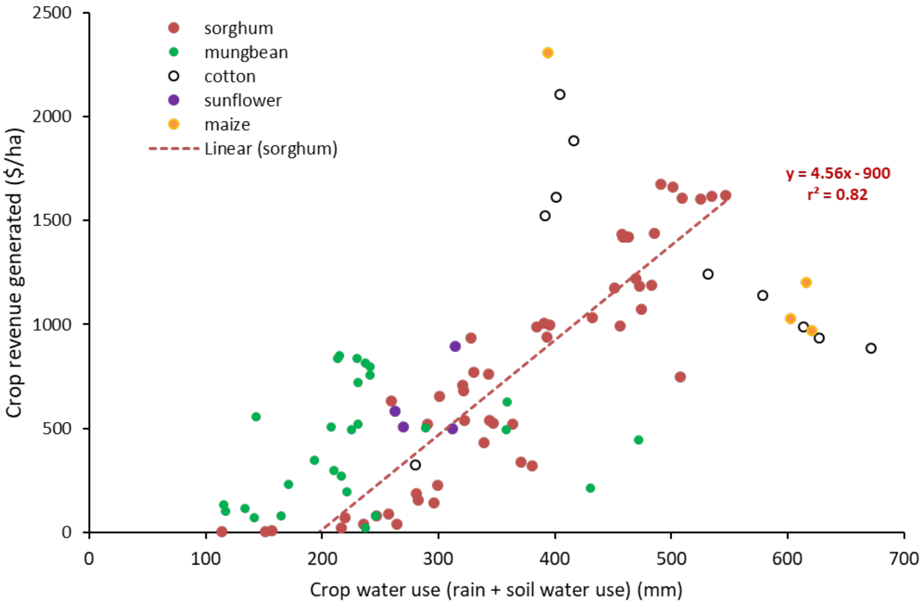

Figure 1. Relationships between crop water use (in-crop rainfall + soil water extraction) and crop revenue generated amongst 100 summer crops grown in farming systems experiments 2015-2019 (sorghum n= 51, mungbean n = 28, cotton n = 10, sunflower n = 4, maize n = 5).

Sowing soil water effects on sorghum crop performance

Soil water at sowing is critical for driving the efficiency of summer crops, especially sorghum. Here we compare the performance of sorghum crops grown in the same season with common nutrient and crop management but with significantly different soil water at sowing (Table 2). As expected, crops with higher soil water at sowing had higher grain yields. But, perhaps something less obvious was that the crops with more staring water regularly converted the available soil water more efficiently into grain and accordingly into profit. This effect was larger in seasons with limited in-crop rain, while the effect was diminished in the wetter growing season (i.e. Pampas 2016/17). This phenomenon occurs because it takes a critical amount of water to grow crop biomass, and hence when there is less available water at sowing there is less water left to efficiently convert any residual water into grain during grain filling. Hence, in wetter seasons this is less pronounced because the crop may still have enough available water to minimise this effect.

Across these studies we calculated the increase in crop return that was obtained for each extra mm of soil water available at sowing. While there was some variation in some seasons, this could be as high as $70 extra return per extra mm at sowing. These effects were largest where crops were sown on marginal soil water (< 100mm) and had limited in-crop rain (e.g. <300mm). These data clearly suggest that for sorghum to maximise its return per mm of water used, higher soil water at sowing is critical. Other analyses by Erbacher et al. (2020 Goondiwindi update paper), suggest plant available soil water at sowing of 150mm was required to optimise sorghum WUE.

Table 2. Starting soil water effects on sorghum crop performance and the marginal water use efficiency i.e. extra $ generated per mm of extra water available at sowing.

Site – year (in crop rain)	**PAW prior to sowing**	**Crop yield (t/ha)**	**Crop WUE (kg grain/mm)**	**Crop WUE ($/mm)**	**Marginal $/mm water at sowing**
Billa Billa 16 (118mm)	98	0.88	3.1	2.2	7.5
	194	1.52	4.1	3.6	
Pampas 16 (345mm)	153	6.12	13.4	12.5	7.2
	245	7.42	13.6	12.0	
Pampas 17 (230mm)	108	0.91	3.1	3.0	70.0
	163	4.52	9.4	9.8	
Pampas 18 (277mm)	62	2.70	7.9	6.1	32.4
	120	4.03	10.2	10.1	

Crop WUE and legacy effects of growing higher density sorghum crops

Integrated weed management practices involving greater in-crop competition with summer grass weeds is seeing interest in increasing sorghum density and narrowing row spacing. In addition to this weed benefit this is likely to have impacts on water and nutrient use efficiency of the crop and legacy impacts on subsequent water and nitrogen accumulation in fallows. It was hypothesised that the higher density sorghum would grow additional biomass which may or may not be converted into grain yield depending on the season. However, this greater biomass would contribute to greater and more even ground cover and improved fallow efficiency. Similarly, this may have impacts on nutrient cycling due to increased immobilisation of soil N from the higher residue with a high C:N ratio.

Across the 3 experimental comparisons we have implemented in our farming systems research, we found that consistently the higher density sorghum increased biomass production, but this was only translated into additional yield at Emerald in 17/18 (Table 3). At the other sites there was no significant yield penalty from growing this additional biomass and grain yields were comparable. Soil water extraction and crop water use was the same amongst the high and low density crops.

The higher biomass production in the higher density sorghum crops has required higher soil N extraction without an increase in grain yield and N. Hence, the nutrient use efficiency of these crops is lower. That is, such higher density crops will require a different nutrient strategy to ensure sufficient N in provided to maximise their yield potential.

Finally, while we anticipated there may be some benefits for improved soil water accumulation over the subsequent fallow following the higher density sorghum crops this was not shown resoundingly. In one season (Pampas 17/18) we did observe an extra 33mm was accumulated in the subsequent fallow after the higher density sorghum crop than the standard management. However, this was largely due to a drier soil profile at crop harvest and there was no significant difference in soil water at the end of the subsequent fallow in any of these cases. However, observations suggested there was greater uniformity of the soil water where more evenly distributed cover occurred following the narrower sorghum rows compared to wider row crops.

Table 3. Crop yield and legacy effects of growing higher density grain sorghum (i.e. 30% higher population & 0.5m compared with 1m row spacing) across 3 seasons in farming systems experiments.

Sorghum crop performance		**Emerald 17/18**	**Pampas 17/18**	**Pampas 18/19**
Sorghum grain yield (t/ha)	Standard	5.0	4.7	4.0
	High density	5.9	4.7	3.7
Sorghum biomass (t/ha)	Standard	11.6	14.1	9.1
	High Density	15.6	16.0	10.1
Sorghum WUE (kg grain/mm)	Standard	15.4	9.4	10.2
	High Density	18.4	10.4	9.6
Sorghum NUE (kg grain N/kg N used)	Standard		0.593	1.7
	High Density		0.484	1.1
Following fallow				
Soil water accumulation (mm)	Standard	+97	+63	+85
	High Density	+71	+96	+79
Mineral N accumulation (kg/ha)	Standard		+89	+107
	High Density		+116	+102

Legacy impacts of summer crop choices

Finally, here we make comparisons of the impacts of summer crops on residual soil water, accumulation during the subsequent fallow and effects on subsequent crop productivity in the sequence.

From these comparisons the legacy impacts of cotton in the farming system are clear, with lower soil water available for subsequent crops due to higher extraction and also lower fallow efficiencies (Table 4). This has translated into reductions in yield of 0.5 t/ha in sorghum and 0.3 t/ha in mungbeans when sown following cotton compared to maize.

Comparisons of sorghum with mungbean show little differences in residual soil water or soil water in the following crops. However, mungbean performance was affected by the preceding crop. ‘Mungbean after mungbean’ yield was 0.5 t/ha lower than ‘mungbean after sorghum’, despite starting with similar moisture after a long fallow (17/18). In contrast, mungbean yields were similar following short fallows out of sorghum and mungbean (18/19), even though the sorghum left less residual water. These effects are likely to be related to disease reductions rather than soil water or nutrient impacts.

Finally, a comparison between sorghum and sunflower legacy effects found little or any effects on subsequent fallow water accumulation or crop yields.

Table 4. Comparisons of legacy impacts of different summer crops on soil water accumulation and subsequent crop productivity in the crop sequence.

Crop year	Crop grown	Residual PAW (mm)	Soil water accumulation (mm)	Subsequent crop performance			
				PAW at sowing (mm)	Crop sown	Crop biomass (t/ha)	Grain yield (t/ha)
16/17	Maize	168	-6	162	Sorghum 17/18	14.1	5.37
	Cotton	149	-23	126		12.8	4.85
	Maize	168	-67	101	Mungbean 17/18	5.0	1.06
	Cotton	149	-67	82		3.4	0.75
18/19	Sorghum	2	+91	93	Not sown yet	-	-
	Cotton	-16	+64	48		-	-
17/18	Sorghum	48	+24	72	Mungbean 19/20	4.75	1.62
	Mungbean	30	+58	88		3.59	1.12
18/19	Sorghum	-10	+45	35	Mungbean 19/20	2.33	0.59
	Mungbean	-26	+112	76		2.15	0.61
17/18	Sorghum	38	+29	67	Sorghum 18/19	7.96	2.80
	Sunflower	2	+39	41		7.38	2.94
	Sorghum	41	+42	83	Mungbean 18/19	2.35	0.74
	Sunflower	3	+22	25		2.23	0.75

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