CHINCHILLA
QUEENSLAND
JULY 2020

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

grdc.com.au

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,
Gillian Meppem
Senior Regional Manager North

P PO Box 5367 Kingston, ACT 2604 Australia
T +61 2 6166 4500 **F** +61 2 6166 4599 **E** grdc@grdc.com.au

Contents

Summer crops: relative water use efficiencies and legacy impacts in farming systems....................................4
Lindsay Bell, Brook Anderson, Darren Aisthorpe, Andrew Verrell, Jon Baird, Andrew Erbacher, Jayne Gentry and David Lawrence

Nutritional strategies to support productive farming systems..10
Michael Bell, David Lester and Doug Sands

5 years of Nitrogen research – Have we got the system right?..22
Richard Daniel, Rachel Norton, Anthony Mitchell, Linda Bailey, Denielle Kilby, Branko Duric and Lawrie Price

Dryland and irrigated winter-sown sorghum 34
Joe Eyre, Erin Wilkus, Daniel Rodriguez, Loretta Serafin, Mark Hellyer, Andrew Bishop, Ian Broad, Darren Aisthorpe and Jane Auer

Growing competitive sorghum and mungbean crops to suppress summer weeds...43
Michael Widderick, Adam McKiernan, Greg Harvey, Linda Heuke, Michael Walsh and Asad Shabbir

Labour and machinery requirements: Implications of different crop sequences..54
Julius Kotir, Lindsay Bell, John Kirkegaard, Jeremy Whish and Kojo Atta Aikins

The impact of harvest management in chickpeas – desiccation and front of header losses 62
Richard Daniel, Linda Bailey, Denielle Kilby, Branko Duric, Richard Black and Lawrie Price

Commercial harvest loss assessments in chickpeas..69
Ed Offner, Jess Mickelborough and Edward Britten

Measuring and predicting plant available water capacity (PAWC) to drive decision-making and crop resourcing: extrapolating data in the Central Darling Downs from limited site numbers across paddocks helped by soil-landscape understanding...76
Mark Thomas, Brett Cocks, Uta Stockmann, Mark Glover, Jenet Austin, John Gallant and Kirsten Verburg

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

DISCLAIMER

This publication has been prepared by the Grains Research and Development Corporation, on the basis of information available at the time of publication without any independent verification. Neither the Corporation and its editors nor any contributor to this publication represent that the contents of this publication are accurate or complete; nor do we accept any omissions in the contents, however they may arise. Readers who act on the information in this publication do so at their risk. The Corporation and contributors may identify products by proprietary or trade names to help readers identify any products of any manufacturer referred to. Other products may perform as well or better than those specifically referred to.

CAUTION: RESEARCH ON UNREGISTERED PESTICIDE USE

Any research with unregistered pesticides or unregistered products reported in this document does not constitute a recommendation for that particular use by the authors, the authors' organisations or the management committee. All pesticide applications must be in accord with the currently registered label for that particular pesticide, crop, pest, use pattern and region.

Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.
® Registered trademark

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

Lindsay Bell[1], Brook Anderson[1], Darren Aisthorpe[2], Andrew Verrell[3], Jon Baird[3], Andrew Erbacher[2], Jayne Gentry[2] and David Lawrence[2]

[1] CSIRO Agriculture and Food
[2] Department of Agriculture and Fisheries, Queensland
[3] New South Wales Department of Primary Industries

Key words

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

GRDC codes

CSA00050, DAQ00192

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.

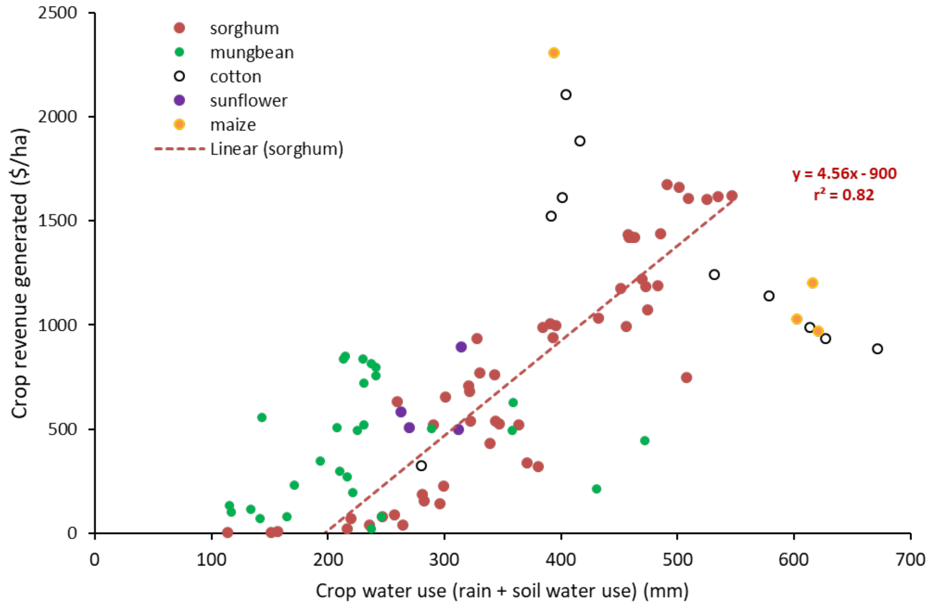


Figure 1. Relationships between crop water use (in-crop rainfall + soil water extraction) and crop revenue generated amongst 100 summer crops grown in farming systems experiments 2015-2019 (sorghum n= 51, mungbean n = 28, cotton n = 10, sunflower n = 4, maize n = 5).

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	14.1	5.37
	Cotton	149	-23	126	17/18	12.8	4.85
	Maize	168	-67	101	Mungbean	5.0	1.06
	Cotton	149	-67	82	17/18	3.4	0.75
18/19	Sorghum	2	+91	93	Not sown	-	-
	Cotton	-16	+64	48	yet	-	-
17/18	Sorghum	48	+24	72	Mungbean	4.75	1.62
	Mungbean	30	+58	88	19/20	3.59	1.12
18/19	Sorghum	-10	+45	35	Mungbean	2.33	0.59
	Mungbean	-26	+112	76	19/20	2.15	0.61
17/18	Sorghum	38	+29	67	Sorghum	7.96	2.80
	Sunflower	2	+39	41	18/19	7.38	2.94
	Sorghum	41	+42	83	Mungbean	2.35	0.74
	Sunflower	3	+22	25	18/19	2.23	0.75

References

Erbacher A., Gentry J., Bell L., Lawrence D., Baird J., Dunn M., Aisthorpe A. and Brooke G. (2020). Nitrogen and water dynamics in farming systems – multi-year impact of crop sequences. Proceedings from the GRDC Grains Research Update, Goondiwindi March 2020. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2020/03/nitrogen-and-water-dynamics-in-farming-systems-multi-year-impact-of-crop-sequences

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We would like to thank the project teams and collaborators contributing to the management and implementation of the farming systems experiments across the northern region.

Contact details

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

Nutritional strategies to support productive farming systems

Michael Bell[1], David Lester[2] and Doug Sands[3]

[1] University of Queensland Gatton Campus
[2] Department of Agriculture and Forestry, Toowoomba
[3] Department of Agriculture and Forestry, Emerald

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.

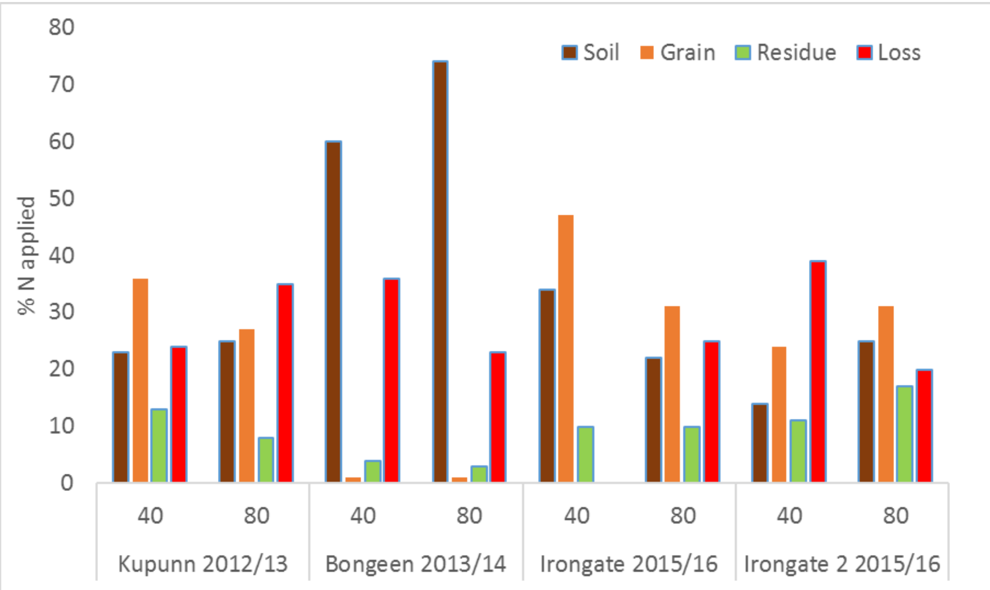


Figure 1. Partitioning of fertiliser N between soil, plant and environmental loss pools for summer sorghum crops grown on the Darling Downs in UQ00066 from 2012-2016

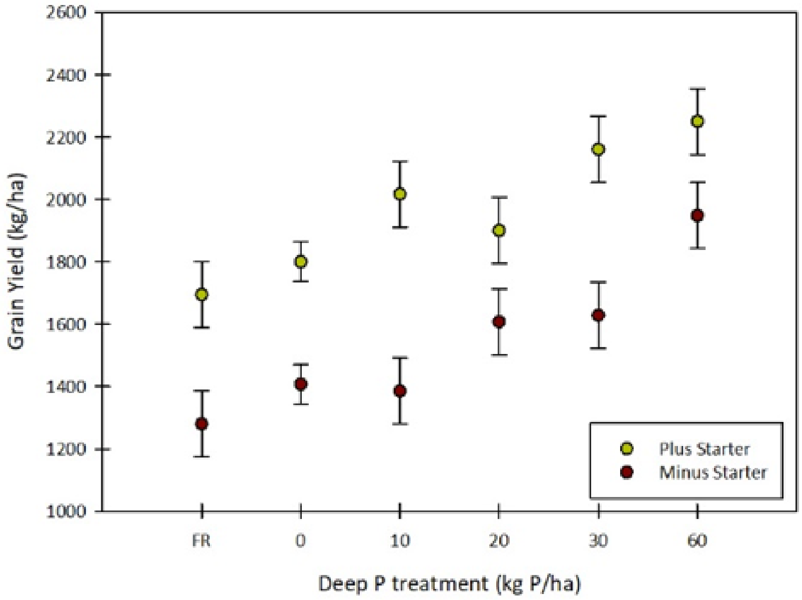
All studies have shown there can be significant amounts of residual N in the soil at the end of the growing season. Large amounts of that N are often found in quite shallow parts of the soil profile (ie. the 0-10cm and possibly 10-20cm layers) and still strongly centred on the fertiliser bands, despite 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.

a)



b)

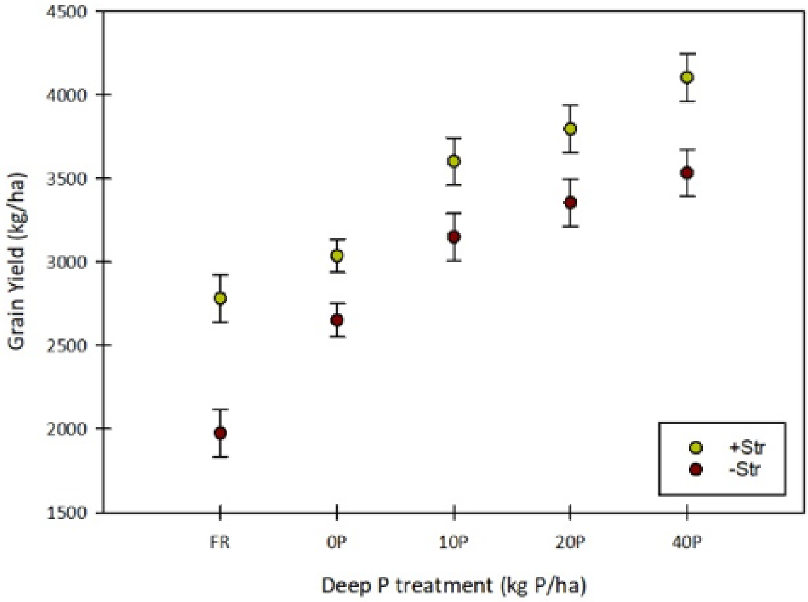


Figure 2. Response to different rates of deep P with and without applications of starter P fertiliser in (a) a wheat crop at Condamine in 2018 wheat, and (b) a sorghum crop at Dysart in 2018/19 grain yield for deep-placed P treatments (kg P/ha) with or without starter application. The vertical bars represent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

b)

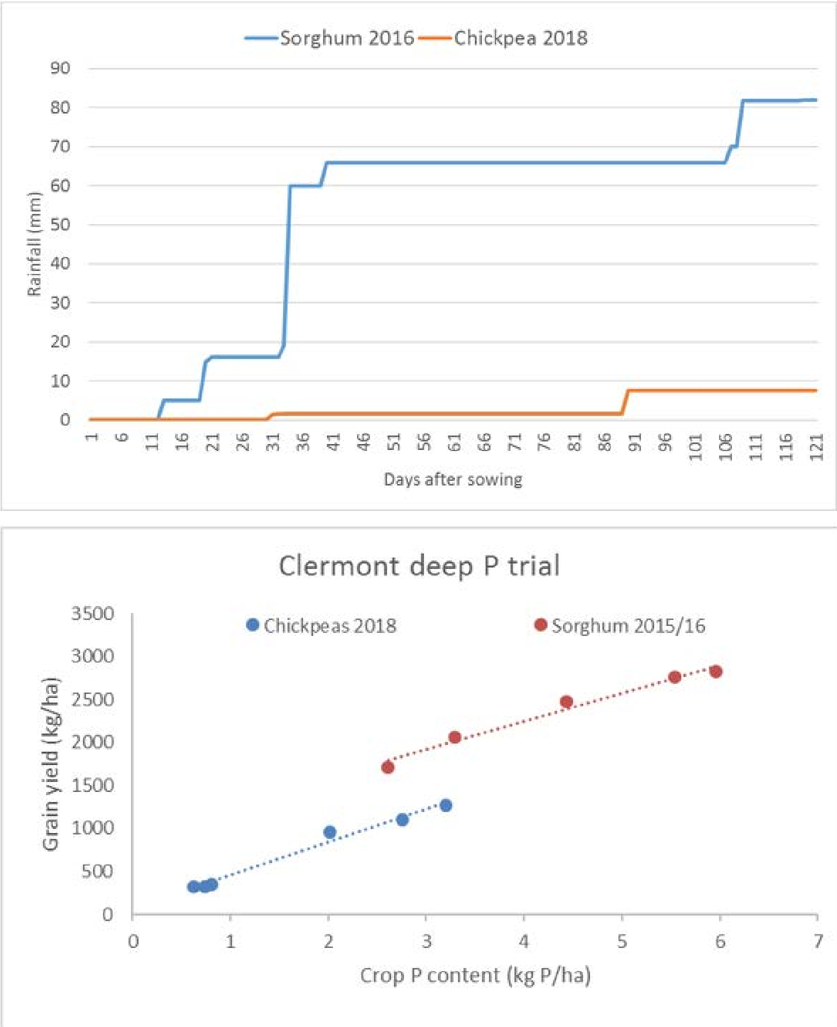


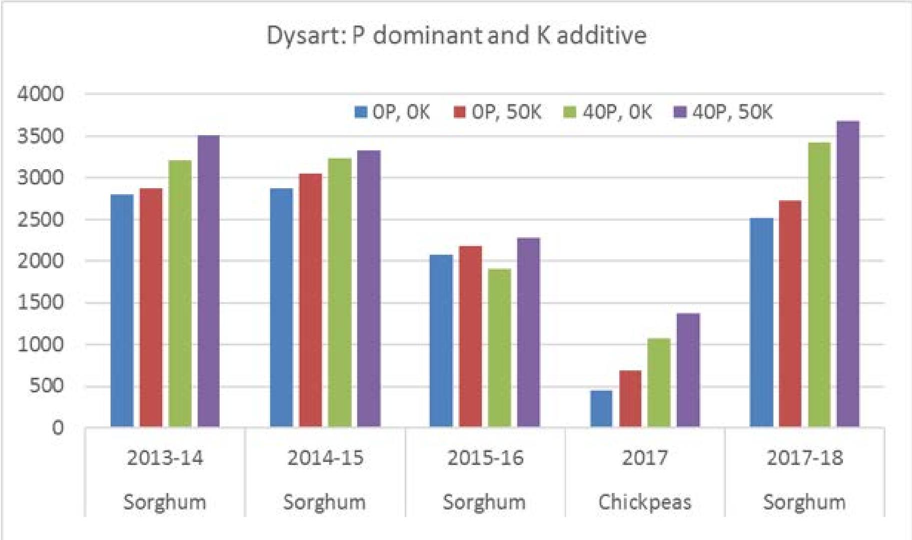
Figure 3. (a) Cumulative in-crop rainfall and (b) the relationship between crop P content and grain yield for consecutive crops of sorghum (2015/16) and chickpea (2018) grown at a site near Clermont, in Central Queensland (Sands et al., 2019)

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)



b)

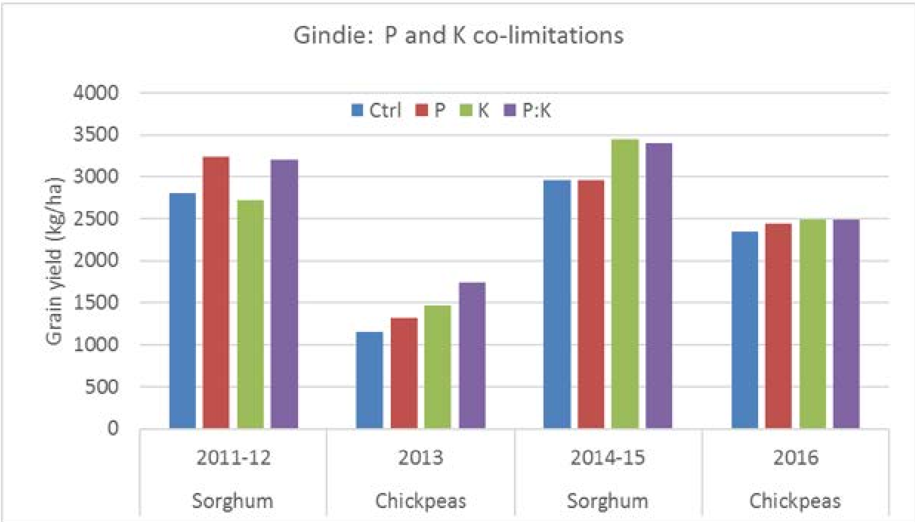


Figure 4. Examples of combinations of P and K limitations to crop performance at (a) Dysart and (b) Gindie, and the response to deep banded applications of those nutrients alone, or in combination

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.

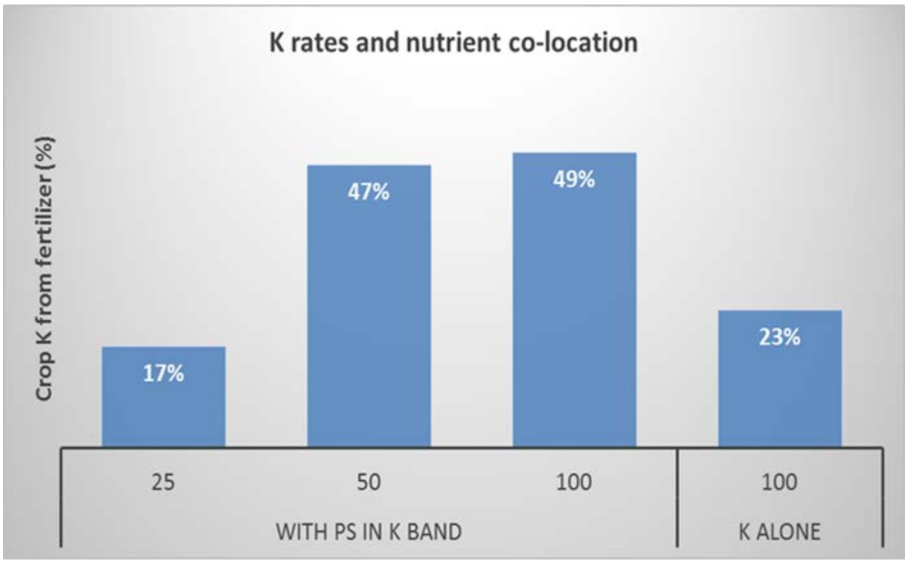


Figure 5. The impact of rate of applied K and co-location of K with other nutrients in a band (in this case P and S) on the proportion of crop K that was derived from applied fertiliser

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.

References

Bell M, Schwenke G and Lester D (2016). Understanding and managing N loss pathways. GRDC Updates in Coonabarabran and Goondiwindi, March 2016. (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/understanding-and-managing-n-loss-pathways)

Bell MJ, Mallarino AP, Moody PW, Thompson ML and Murrell AS (2017). Soil characteristics and cultural practices that influence potassium recovery efficiency and placement decisions. Proc., Frontiers of Potassium Workshop, Rome 25-27 January 2017.

Johnston AM and Bruulsema TW (2014). 4R Nutrient Stewardship for Improved Nutrient Use Efficiency. Procedia Engineering 83: 365 – 370

Daniel R, Norton R, Mitchell A, Bailey L, Kilby D and Duric B (2018). Nitrogen use (in)efficiency in wheat – key messages from 2014-2017. GRDC Update Goondiwindi, March 2018. (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/03/nitrogen-use-n-efficiency-in-wheat)

Lester D and Bell M (2019a). Responses to phosphorus and potassium by grain crops in southern Queensland. Pp. 26-29. In: Weir D and Grundy T (Eds). Queensland Grains Research 2018-19. Regional Research Agronomy Report, QDAF.

Lester D, Bell M and Hagan J (2019b). Deep P update 2019 – Multi-year grain yield impacts and economic returns for southern Queensland cropping. GRDC Update Warra, March 2019. (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2019/03/deep-p-update-2019-multi-year-grain-yield-impacts-and-economic-returns-for-southern-queensland-cropping)

Sands D, Bell M and Lester D (2018). Getting nutrition right in Central Queensland. GRDC Updates at Emerald and Biloela, December 2018. (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/12/getting-nutrition-right-in-central-queensland)

Sands D, Lester D, Bell M and Hagan J (2019). Responses to deep placement of phosphorus and potassium in chickpea – Clermont. Pp 45-52. In: Weir D and Grundy T (Eds). Queensland Grains Research 2018-19. Regional Research Agronomy Report, QDAF.

Schwenke GD, Haigh BM (2019) Can split or delayed application of N fertiliser to grain sorghum reduce soil N_2O emissions from sub-tropical Vertosols and maintain grain yields? Soil Research 57(8), 859-874.

Acknowledgements

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

Contact details

Mike Bell
University of Queensland
Gatton Campus
Ph: 0429 600 730
Email: m.bell4@uq.edu.au

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

Richard Daniel, Rachel Norton, Anthony Mitchell, Linda Bailey, Denielle Kilby, Branko Duric and Lawrie Price, Northern Grower Alliance

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 GregoryⓅ		EGA GregoryⓅ		SuntopⓅ		LancerⓅ, SuntopⓅ & 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.

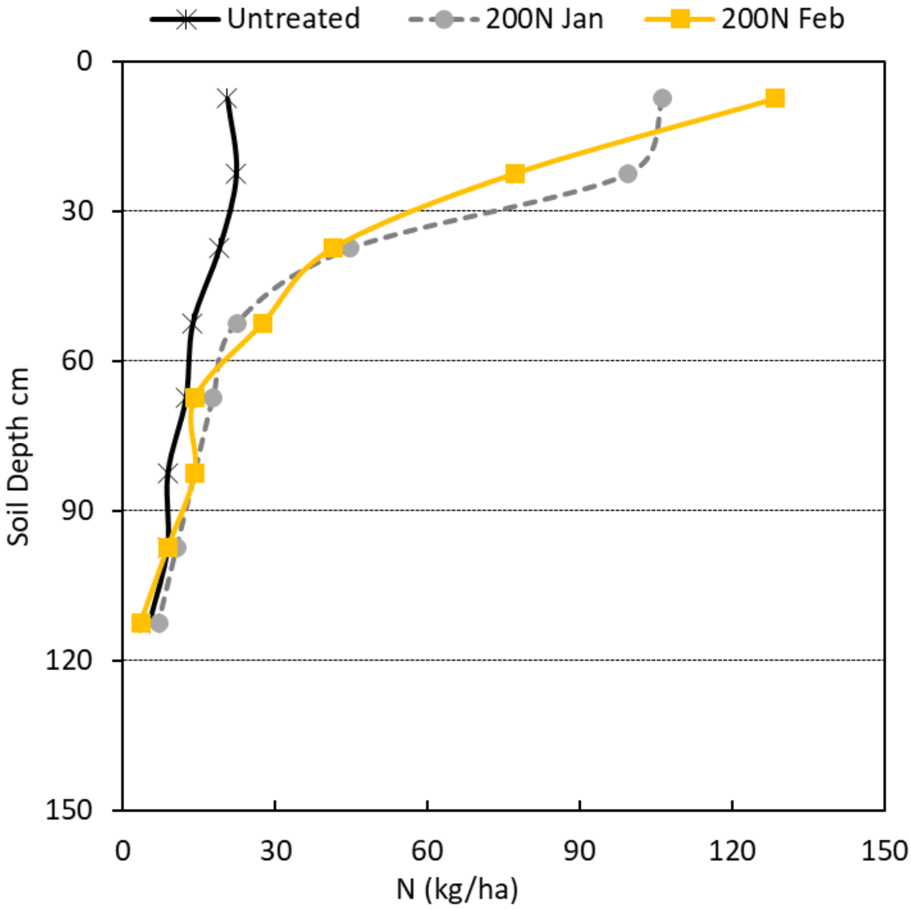


Figure 1. Soil distribution of N at Mullaley at planting (May 2017) following application of urea in January or February 2017. 175mm of rain was recorded between the January application and planting. 140mm of rain was recorded between the February application and planting.
(NB: Both N applications were 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.)

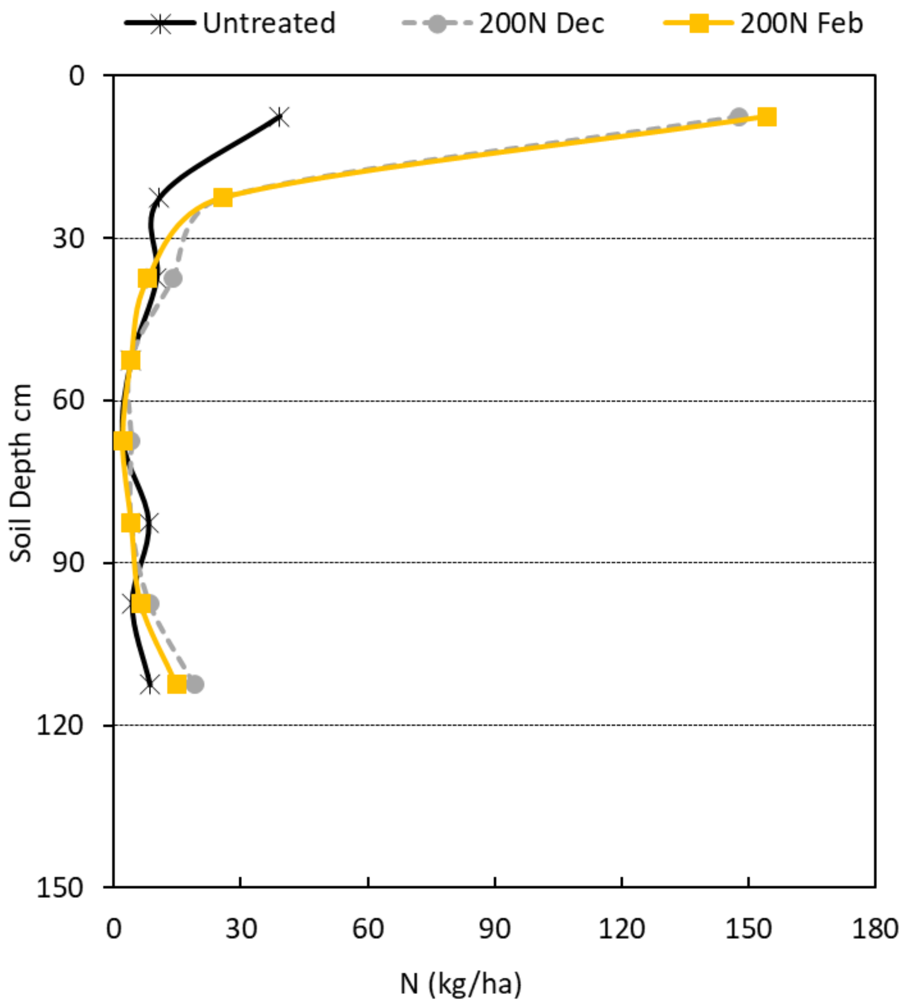


Figure 2. Soil distribution of N at Tulloona at planting (June 2016) following application of urea in December 2015 or February 2016. 225mm of rain was recorded between the December application (spread and incorporated) and planting. 65mm of rain was recorded between the February application (spread 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.

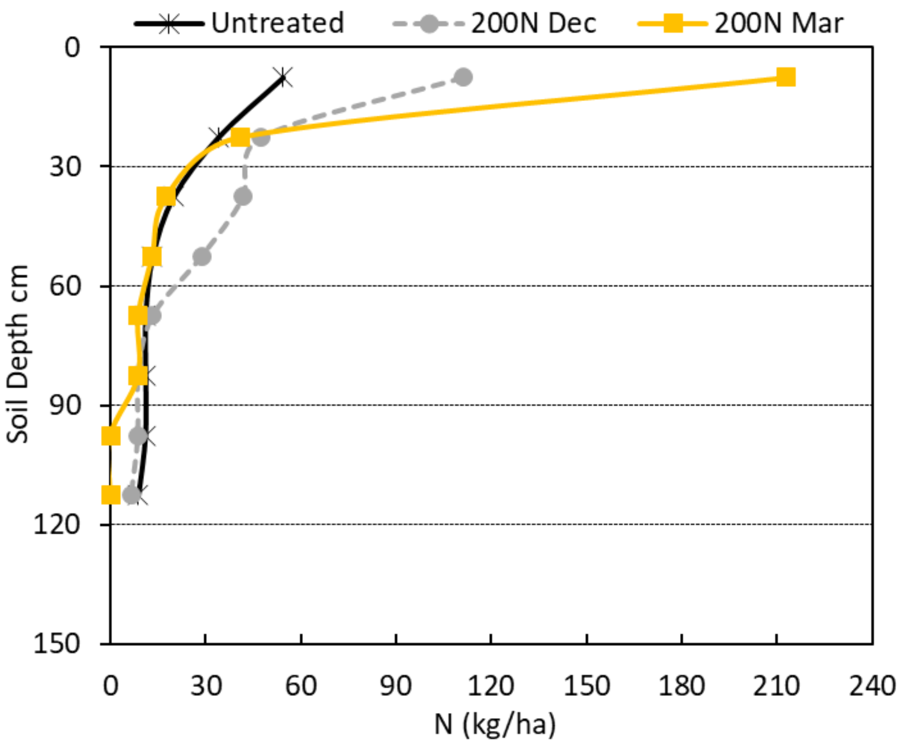
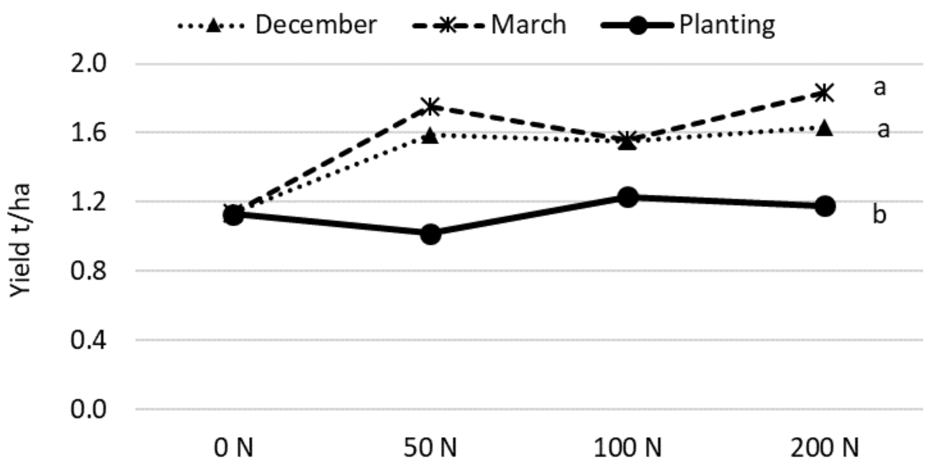


Figure 3. Soil distribution of N at Billa Billa at planting (May 2017) following application of urea in December 2016 or March 2017. 279mm of rain was recorded between the December application and planting. 154mm of rain was recorded between the March application and planting.
(NB: Both applications 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*

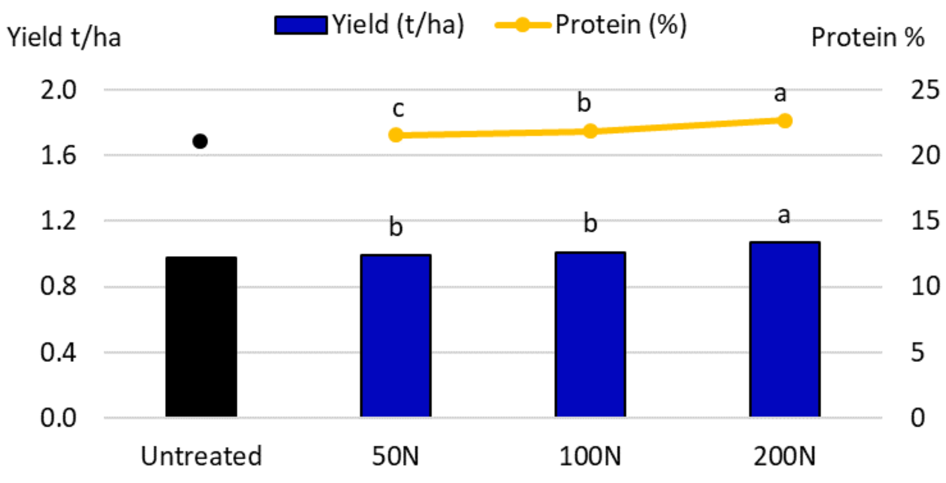
NB Sampling method - 4 individual 0-120cm depth cores taken per plot. Samples were separated into 0-30 and 30-90cm intervals with each depth bulked and a single sub sample taken for analysis. 4 replicates sampled in each treatment

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.

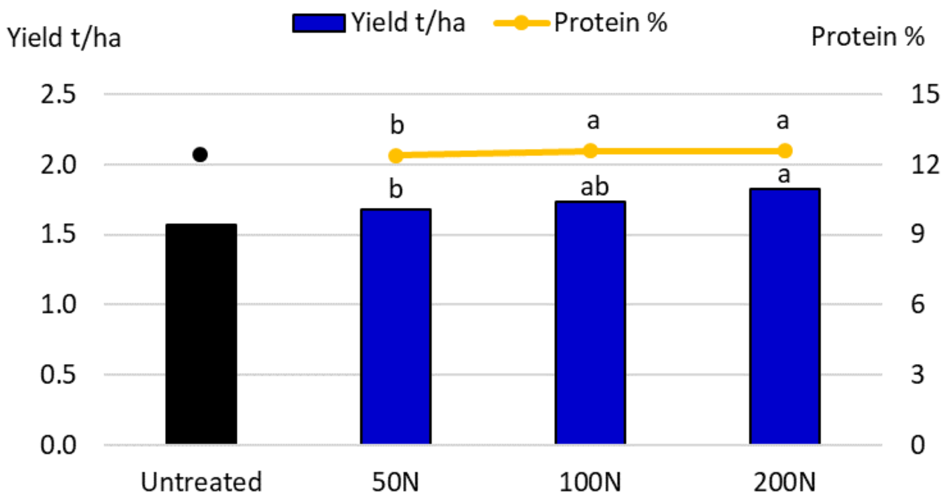
NB At the Tulloona site, ~60 % of the additional soil N was still found in the top 45cm with 45% found between 15 and 45cm. At the Macalister site, ~49 % of the additional soil N was still found in the top 45cm with 31% found between 15 and 45cm.

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.

Acknowledgements

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

NGA would particularly like to acknowledge the assistance from our trial co-operators during this series of trials: Scott Ferguson, Jason Schelberg, Lee Maxwell, The Frater Family, Drew Penberthy, Michael Leddingham, Hugh Ball, Simon Doolin, George Picton, Peter Butler and Anthony Martin, together with Kalyx staff for trial planting, maintenance and harvest. In addition we would like to thank AGT and Pacific Seeds for seed supply.

Contact details

Richard Daniel
Northern Grower Alliance
Ph: 07 4639 5344
Email: richard.daniel@nga.org.au

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

Dryland and irrigated winter-sown sorghum

Joe Eyre[1], Erin Wilkus[1], Daniel Rodriguez[1], Loretta Serafin[2], Mark Hellyer[2], Andrew Bishop[2], Ian Broad[3], Darren Aisthorpe[4] and Jane Auer[4]

[1] UQ-QAAFI Queensland
[2] NSW DPI, Tamworth
[3] QDAF, Toowoomba
[4] QDAF, Emerald

Key words

frost tolerance, GxExM, grain sorghum, heat stress, soil temperature

GRDC code

UOQ 1808-001RTX

Take home messages

- Winter sowing sorghum didn't penalise yields in eight trials sites from Liverpool plains to Central Queensland and across two seasons
- In dryland cropping, winter sown sorghum provides additional sowing opportunities, reduces the chances of heat stress, and increases the chances of double cropping a winter crop
- In irrigated cropping, ratooned winter sown sorghum can compete with cotton on profits and is less risky
- Commercially available hybrids can successfully germinate and emerge in cooler soils than previously recommended, though the seed must be tested for vigour at low temperatures
- Sorghum seedlings can withstand mild frost, though so far, we haven't been able to frost kill a crop, meaning that frost risk is unknown.

Background

Water stress and extreme heat at flowering are common stresses limiting yield in sorghum across the Northern Grains Region. Earlier sowing of sorghum could avoid heat and water stress at flowering. However earlier sowing or winter sowing of sorghum in southern Queensland requires the crop to be sown into soil moisture in cold soils.

Dryland farmers are already successfully sowing maize and sorghum earlier than recommended, though the benefits for yield and the cropping system and the likely risks are not known. Previous research by Muchow, et al., (1994) identified that winter sown sorghum crops show high yield potentials with increased frost risk and a larger canopy increasing water stress risk. However, these risks require re-evaluation because frost risk thresholds (thresholds were assumed in previous research) are unknown and modern hybrids have a smaller canopy.

In irrigated systems, sorghum is a profitable option when irrigation water is limited, though it is often assumed to be a less profitable option than cotton in fully irrigated systems. Winter-sowing and opportunistically ratooning sorghum allows growers to manage risk when water supply is limiting at the beginning of the season and intensify production and profits if rainfall is greater than expected.

Previous research shows that ratooned irrigated sorghum crops yield 80% of the sown crop yield on average (Gerik et al., 1990). Growers in Central Queensland successfully ratoon irrigated sorghum crops, though questions remain on the suitability of the system in southern regions and crop sequences.

Here we report on irrigated and dryland trials conducted by UQ-QAAFI in the 2018-2019 seasons. This series of trials is part of the multi-environment sorghum agronomy experiment in collaboration with DAFQ and NSW DPI. The experiment was designed to develop a data set to support the present trend in advancing sowing times of sorghum and assess potential benefits and risks from adopting the strategy at the crop and cropping system levels.

Trial details

Two trials were sown in the 2018-2019 season at Surat and Warra, Qld. Trials included three times of sowing, four plant populations and nine commercial hybrids (Table 1). In addition, after the harvest of the second time of sowing at Surat, the crop residues were mulched, fertilised, irrigated and allowed to ratoon into a second harvest. A third time of sowing occurred at the same time when sowing 2 was ratooned (Table 1). This allowed us to also compare the yield of the ratooned sorghum crop with the yield of a sown crop.

Table 1. Winter-sown sorghum agronomy trial locations and treatments

Time of sowing (TOS)	Sowing date	Target plant population (pl/m^2)	Hybrids
"Austin Downs" Surat, Qld (irrigated)		3, 6, 9, 12	MR Buster, MR Apollo, MR Taurus, Agitator, Cracker, HGS 114, A66, G33, G44
1	8th August 2018		
2	28th August 2018 & ratooned		
3	24th January 2019		
"Wywurrie", Warra, Qld (dryland)			
1	27th July 2018		
2	19th October 2018		
3	9th November 2018		

Results and discussion

Optimum flowering windows

Crop growth conditions around flowering are important in determining final grain number and grain yield. At flowering, grain number can be reduced by temperature extremes, both heat and chilling (i.e. cold but non-freezing temperatures). Analyses of long-term climate records (see CliMate App), can be used to quantify the likelihood of these stresses around flowering and identify ideal flowering windows.

For example, Figure 1A shows that chilling or heat stress temperatures are least likely in narrow and regionally specific windows during spring and autumn. These windows have a lower likelihood of heat (>38°C) and chilling (<13°C) events in a 10-day period corresponding to the sensitive flowering phase. However, the impacts of extreme temperatures on yield depend on duration of the heat/chilling exposure, crop water status and cultivar. Research on the relationships between extreme temperatures and the yield of early sown sorghum will continue throughout the GRDC funded project "Optimising Sorghum Agronomy".

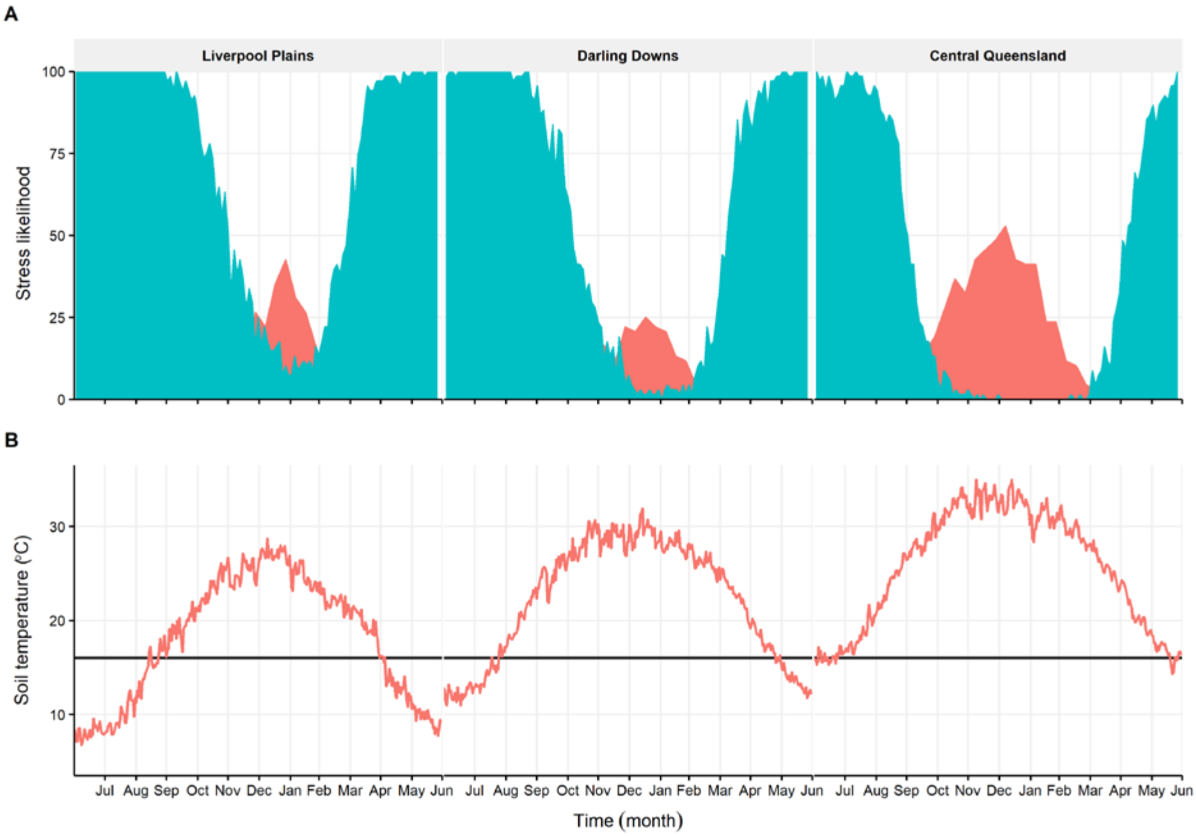


Figure 1. The likelihood or percentage of seasons exposed to heat (>38°C; **red**) or chilling (<13°C; **blue**) during a 10-day temperature sensitive period around flowering (A); and (B) the mean 9:00 am soil temperature measured at 50 mm depth in three sorghum growing regions, the Liverpool Plains, Darling Downs and Central Queensland. The horizontal line in Figure 3B shows the recommended minimum seeding depth temperature threshold for sorghum. (Note: 9:00am soil temperatures are shown because high quality long-term data for the conventional 8:00 am or minimum daily 100 mm deep soil temperatures were not available).

Targeting optimum flowering windows

The easiest way for growers to move the flowering window is to plant at a different time to their standard sowing time or to select a quicker maturity hybrid. As there is limited variation in maturity type among the commercial hybrids, moving the sowing window is the more effective option. This means sowing sorghum crops much earlier than normal, potentially moving sowing into the months of July and August depending on local climate. Soil temperatures during this period are cooler than the recommended (>16-18°C measured at sowing depth during the coolest period of the day or 8:00am; Figure 1B). Long-term trends show that July to August soil temperatures are coldest in the southern regions of Darling Downs and Liverpool Plains. However, time of sowing decisions require information on each field because of varying weather, topography, soil type, water content and ground cover, all of which strongly influence seedbed temperature.

Regardless of the sowing time, achieving rapid and uniform crop establishment is also required to realise yield potential. The decision on sowing time will then need to evaluate the trade-off between likely benefits of reducing heat stress around flowering, with the higher risk of early frost damage, higher establishment losses and potential for less even crop canopy uniformity.

Temperature effects on sorghum germination in 2018-2019

Planting sorghum into moist soils at extremely low or high temperatures can reduce crop establishment and reduce crop uniformity. Crop establishment is the result of several distinct plant development stages including seed germination, emergence, root proliferation and leaf growth. Here we studied the impact of extreme temperatures on the germination for a range of commercial sorghum hybrids in the lab.

Results showed that the lowest and highest observed seedbed temperatures from Figure 1B, reduced the proportion of sorghum seeds that successfully germinated in the lab (Figure 2).

Eight of the ten most widely grown sorghum hybrids showed germination values greater than 90%, when incubated with ideal moisture and at constant temperatures between 13 and 32.1°C (Figure 2). At 9.4°C, two of the ten tested hybrid seedlots still showed germination values larger than 90%.

Higher temperatures (≥34.9°C) reduced the germination of five out of the ten tested seedlots, yet three hybrids showed germination rates greater than 90% at extreme hot temperatures (39.5°C).

In these experiments, seeds were exposed to constant high temperatures for multiple days, whereas in the field, seedbed temperatures fluctuate diurnally. Maximum daily seedbed temperatures of 45°C were recorded during the 2018-2019 sorghum agronomy trial at Emerald, though those temperatures only exceeded the high thresholds for a short period each day (< 1 hour).

Seed production, storage, handling, seed treatment and genetics will all determine the germination rate for each hybrid-seedlot. Therefore, germination must be evaluated every year for each hybrid-seedlot. Understanding the drivers for low germination in Australian germplasm remains a priority research question.

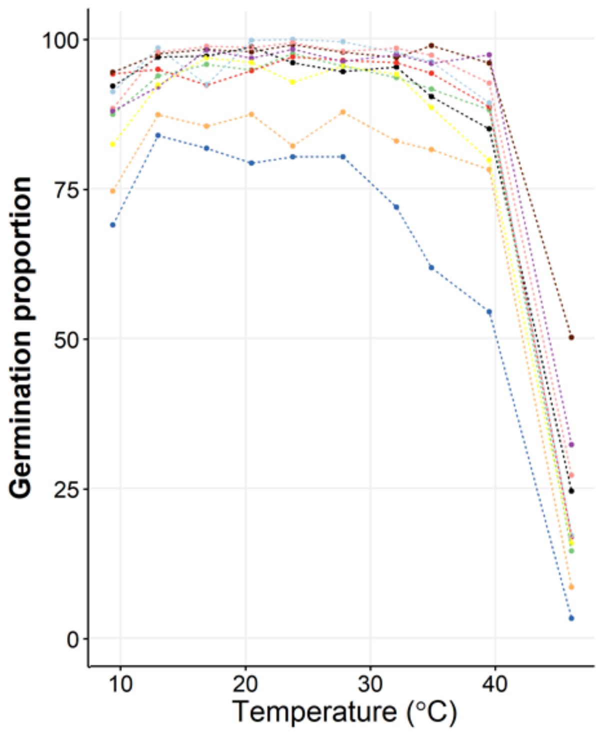


Figure 2. The proportion of sorghum seeds that successfully germinated when incubated at constant temperatures. Each colour represents one hybrid seedlot but they are not identified as the experiment doesn't differentiate if the result is due to genetic, seed production or storage factors.

2018-2019 temperature effects on predicted time required for successful sorghum germination

Low temperatures delay the period from sowing to germination and emergence. Therefore, quantifying the number of growing degree days is important. Growing degree days (GDD) are a measure of the accumulation heat and are used to predict plant development. GDD = ∑(Tmax – Tmin)/2 – Tbase. Tmax and Tmin are the daily maximum and minimum temperatures. Tbase is a crop specific minimum temperature for development. Here we estimated the required number of cumulative heat units for ten commercial hybrid seedlots under a controlled temperature environment. The results show that the first 10% of seeds germinate with 5 days but it took 9 days to achieve >90% germination at Surat in 2018 (Figure. 3). Results also show that germination time is similar across diverse sites on some dates, but germination timing is also highly variable for different sowing dates at any site (Figure. 3).

This means that July-August soil temperatures ≥9.4°C do not limit germination of commercially available sorghum hybrid-seedlots. However, germination will take a long time and will be spread over several days, meaning that the seedbed must remain moist for at least 9 days for successful germination and longer for emergence.

Investigations into the impacts of low seedbed temperatures on emergence continue in 2019-2020 through the GRDC funded project "Optimising Sorghum Agronomy".

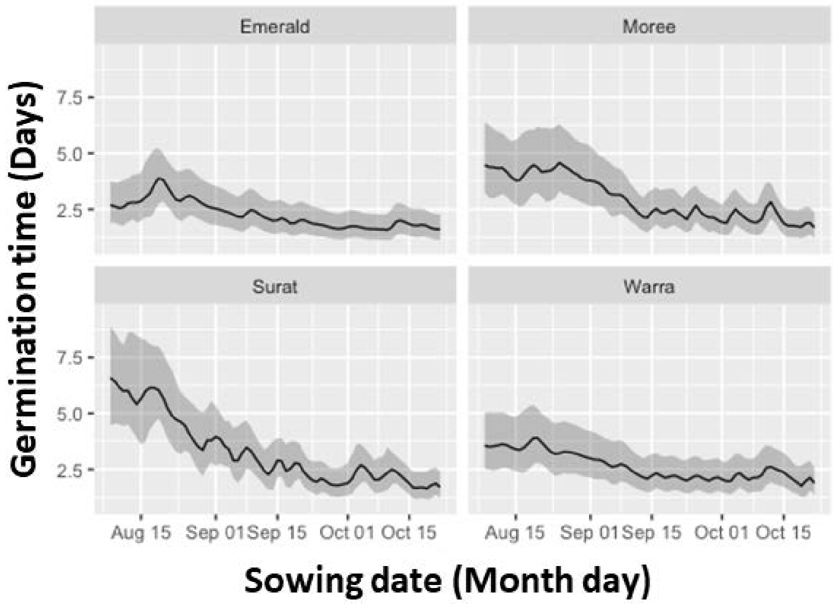


Figure 3. The predicted number of days from sowing until germination for sowing dates between 1st August and November 2018 based on seedbed temperatures recorded at four on-farm trial sites. Black line shows 50% seed germination and the grey shading shows the spread from 10 to 90% germinated seeds. (Note: data is for seed germination and not for crop emergence which will take far longer)

Climatic conditions for 2018-2019 trials

The 8:00am seedbed temperature at Surat for sowing time one was 8°C and it emerged 20 days later with seedbed temperatures of 10°C. Seedlings survived two mild frosts (~0°C) in late August and mid-September (Figure 1C). The earliest flowering hybrids in the first time of sowing had the highest photo-thermal quotient during flowering, meaning that growth and yield formation potential was greatest (Figure 4A). Flowering time of the latest flowering hybrids in the first time of sowing overlapped with the earliest flowering hybrids for the second time of sowing, meaning that combinations of hybrid and sowing time are required to target flowering (Figure 4A). Water was sufficiently available for all treatments, except irrigation ran out before time of sowing three finished flowering (Figure 4B). Maximum temperatures were high for all sowing times (Figure 4C).

Seedbed temperatures at 8:00 am measured at sowing depth (75mm) for the first time of sowing were 12°C and seed germinated 2 days later on the 30th July. Soil temperatures decreased to 10°C and seedlings emerged between 8 and 17th August. The first time of sowing at Warra had four consecutive frost days with minimum daily temperatures of 0, -4, -5 and -2°C without seedling death (Figure 5C). Pre-flowering rainfalls prevented water stress at flowering for time of sowing one and two, but time of sowing three was water stressed at flowering (Figure 5B). High temperatures occurred during flowering for all three sowing times (Figure 5C).

Figure 4. Photothermal quotient (A), rainfall (B) and ambient temperatures (C) at Surat, Qld for the 2018-2019 summer cropping season. The two yellow rectangles indicate the overlapping flowering timing for the 8th and 28th August 2018 sowing dates and 24th January and ratoon crop flowering dates, respectively. Solid blue and red lines represent daily maximum and minimum temperatures, respectively. Dashed horizontal represent the reported minimum (blue) and maximum (red) temperatures stress thresholds at flowering and frost (black).

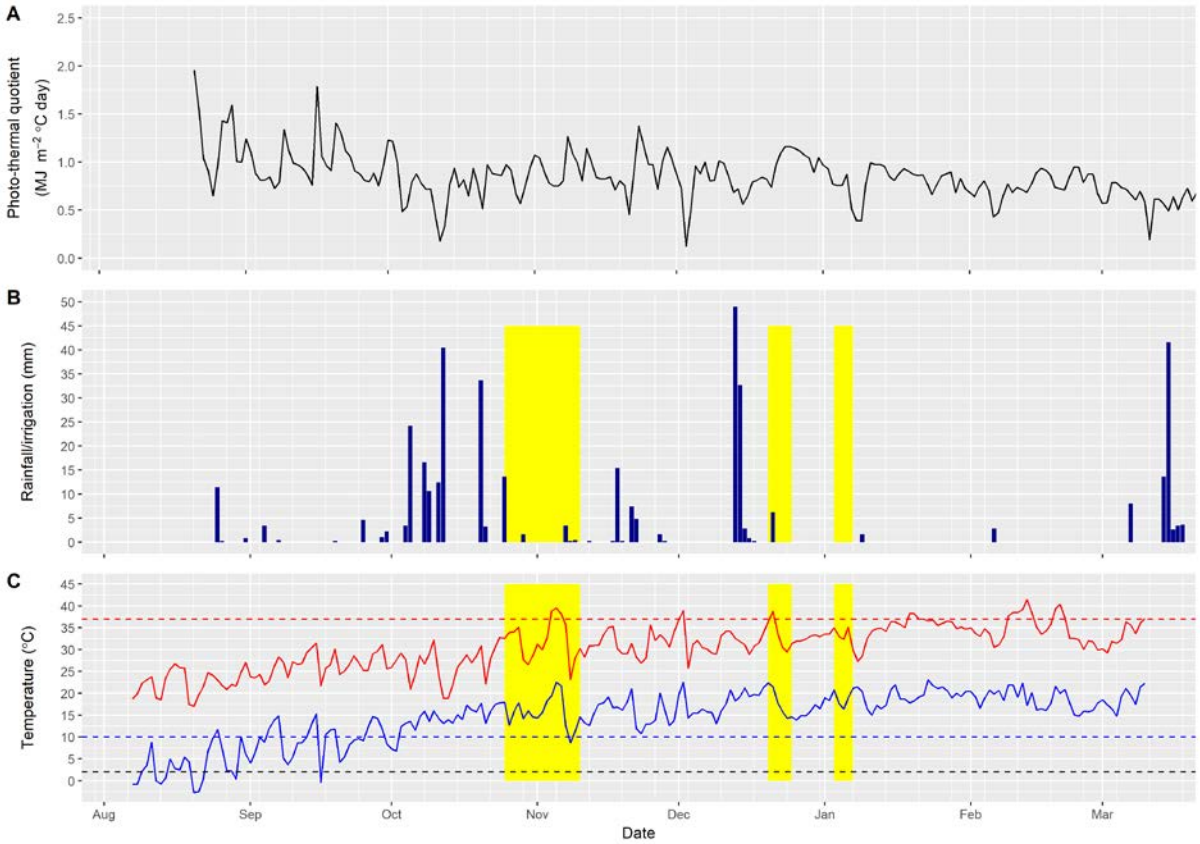


Figure 5. Photothermal quotient (A), rainfall (B) and ambient temperatures (C) at Warra, Qld for the 2018-2019 summer cropping season. The three yellow rectangles indicate flowering timing for each sowing date (see **Table 1**). Solid blue and red lines represent daily maximum and minimum temperatures, respectively. Dashed horizontal represent the reported minimum (blue) and maximum (red) temperatures stress thresholds at flowering and frost (black).

Winter sown sorghum yields

We expect high yields for early sown sorghum crops when water is sufficient, because sunny spring days with cool temperatures (high photo-thermal quotient) should maximise growth rate. However, cool non-freezing "chilling" temperatures can stress some crops and cultivars. Low temperature limits for sorghum growth and development are not characterised for modern Australian hybrids.

At Surat, grain yields averaged across all hybrids were approximately 10 t/ha (11.3 t/ha at 13% moisture content) for all plant populations sown on 8th and 28th of August (i.e. time of sowing 1 & 2; Figure 6). Lack of tillering and water stress contributed to lower yields for time of sowing three (sown 29th Jan 2019) at Surat. The ratooned time of sowing two (28th Aug 2018) crop yielded approximately 75% of the sown time of sowing two crop yield, but similar yield to time of sowing three (24th Jan 2019). The ratoon crop yields were similar to reported yield potential, but time of sowing three that grow during a similar time showed a yield gap. This result will be further analysed in the new GRDC funded project that investigates the impacts of early sowing and ratooning on root growth and water stress.

At Warra, grain yields averaged across all hybrids decreased with latter sowing dates, especially for lowest plant population densities (Fig 6) despite substantially lower pre-flowering rainfall (Figure 5C).

These results mean that sorghum crops can be sown much earlier without yield penalty, supporting 2017-2018 results. Further research on sorghum growth, development and root function at frost and chilling temperatures is required to understand early sown sorghum yield potential.

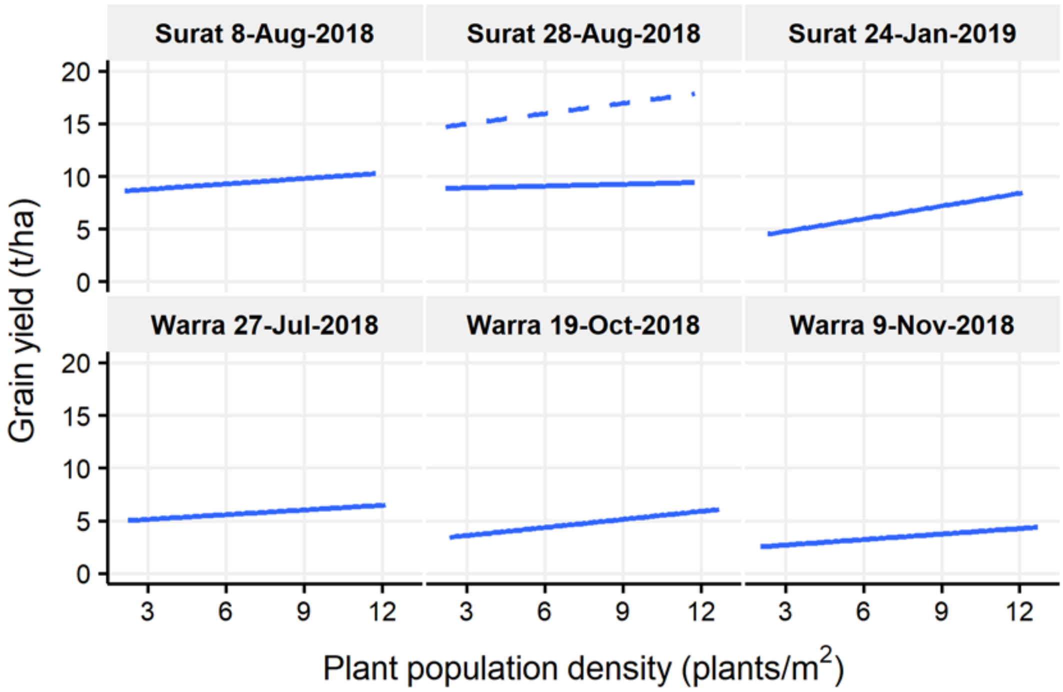


Figure 6. The effect of plant population density on sorghum grain yields averaged across all hybrids for three sowing times at Surat and Warra trial sites for the 2018-2019 summer cropping season. Solid lines indicate grain yield (dry weights) for sown crops and dashed lines show combined sown and ratoon crop yields for the Surat 28-Aug-2018 sowing.

Conclusion

Sorghum can be sown into soil moisture much earlier than recommended, but seedbed temperatures must be monitored in each field and the seed must have high germination rates at low temperatures. Treated stored seed from previous seasons should not be used.

Ratooning of sorghum provides an alternative to cotton, particularly in seasons with low water availability.

The Optimising Sorghum Agronomy project is developing agronomic packages for winter-sown sorghum. For more information follow us on Twitter @Queensland_fsr and at https://www.qld-fsr.info/

Acknowledgements

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

In particular, the support of the Bidstrup, Warra and Milla, Surat families is gratefully acknowledged.

Optimising sorghum agronomy is a collaboration between the Grains Research and Development Corporation, University of Queensland, NSW Department of Primary Industries and Queensland Department of Agriculture and Fisheries.

References

Gerik, T.J., Rosenthal, W.D. and Seavey, W.F. (1990) Phenology, early growth, and yield of planted and ratoon grain sorghum. Field Crops Research 23: 205-219. doi:https://doi.org/10.1016/0378-4290(90)90055-G.

Muchow, R.C., Hammer G.L. and Vanderlip, R.L. (1994) Assessing climatic risk to sorghum production in water-limited subtropical environments II. Effects of planting date, soil water at planting, and cultivar phenology. Field Crops Research 36: 235-246. doi:https://doi.org/10.1016/0378-4290(94)90115-5.

Contact details

Joseph Eyre
QAAFI - The University of Queensland
Gatton Campus, Gatton, Qld 4343
Mb: 0467 737 237
Email: j.eyre@uq.edu.au

Daniel Rodriguez
QAAFI - The University of Queensland
Gatton Campus, Gatton, Qld 4343
Mb: 0434 075 094
Email: d.rodriguez@uq.edu.au

Growing competitive sorghum and mungbean crops to suppress summer weeds

Michael Widderick[1], Adam McKiernan[1], Greg Harvey[1], Linda Heuke[2], Michael Walsh[3] and Asad Shabbir[3]

[1] Queensland Department of Agriculture and Fisheries, Toowoomba, Qld
[2] University of Sydney, Narrabri, NSW
[3] University of Sydney, Camden, NSW

Key words

crop competition, sorghum, mungbean, feathertop Rhodes grass, awnless barnyard grass

GRDC code

US00084

Take home message

- Feathertop Rhodes grass (FTR) and awnless barnyard grass (ABG) are both difficult to control summer grass weeds with both species prone to herbicide resistance evolution
- Growing a competitive sorghum or mungbean crop can reduce growth and seed production of FTR and ABG
- ABG is more susceptible to the impacts of crop competition than FTR
- Sorghum competitiveness can be increased by growing the crop at a narrow row spacing (50 cm) and increased density (10 to 15 plants/m^2)
- Mungbean competitiveness is most effectively increased through the use of narrow row spacing (25 and 50 cm)
- Consider growing a competitive summer crop to take pressure off relying solely on in-crop herbicides for summer grass control.

Introduction

Herbicides are a main stay of weed control in conservation cropping systems. However, reliance on herbicides for weed control has caused widespread herbicide resistance.

Key summer weeds in the northern region are feathertop Rhodes grass (*Chloris virgata*) (FTR) and awnless barnyard grass (*Echinochloa colona*) (ABG). Both weeds have populations confirmed as resistant to glyphosate and there has recently been confirmed cases of group A (haloxyfop) resistance in FTR.

To minimise further resistance and to retain herbicide efficacy, non-chemical weed control tactics, such as growing a competitive crop, are needed. A competitive crop can suppress in-crop weeds and reduce total reliance on herbicides for weed control. There are a number of agronomic approaches that lead to increased crop competition including, narrow row spacing, increased plant density, as well as species and cultivar choice. Each of these approaches can provide an advantage to the crop over weeds in competition for water, nutrients, light and space.

In the northern cropping region, sorghum is a key summer crop. However, there are challenges in controlling summer grass weeds in this crop due to the lack of herbicide options and the wide row spacing commonly used.

Mungbean is another commonly grown summer crop, which as a broad leaf crop, provides an opportunity to apply grass selective herbicides pre- or post-plant or post-emergence for summer grass weed control. However, mungbeans are poorly competitive and like sorghum, are commonly grown in wide rows, greatly reducing competition against in-crop weeds when compared to narrower row spacings.

This paper highlights key findings from four years of research on the impact of competitive sorghum and mungbean crops on the growth and reproductive development of FTR and ABG.

Materials and methods

Field experiments, duplicated in SE Qld (Hermitage) and NW NSW (Narrabri), investigated the effects of narrow row spacing, increasing crop plant density and cultivar choice of sorghum and mungbean on competition with weeds. In each experiment, herbicides were not applied, and artificial weed populations were established either through sowing weed seeds and thinning to target population (Hermitage), or by transplanting weeds into the crop (Narrabri). Target crop and weed populations were established in fixed quadrats where crop and weed growth were measured. Three mungbean varieties Crystal⦶, Jade⦶ and Satin⦶, selected for cultivars comparison, are protected under the Plant Breeders Rights Act 1994.

Results

Sorghum

Row spacing

Over the 2018/19 summer growing season, at both Hermitage and Narrabri, sorghum cultivars Taurus, 85G33 and Rippa were grown at row spacings of 50 and 100 cm and a crop density of 10 plants/m^2. At both sites, there was a competitive advantage for sorghum grown at 50 cm row spacing. Only data from the Hermitage site are shown here, but the effect was mirrored at the Narrabri site.

Reducing row spacing from 100 to 50 cm reduced (P=0.002) the biomass of ABG plants by 55% (Figure 1A). Similarly, ABG seed production was reduced (P<0.001) at the 50 cm row spacing (Figure 1B).

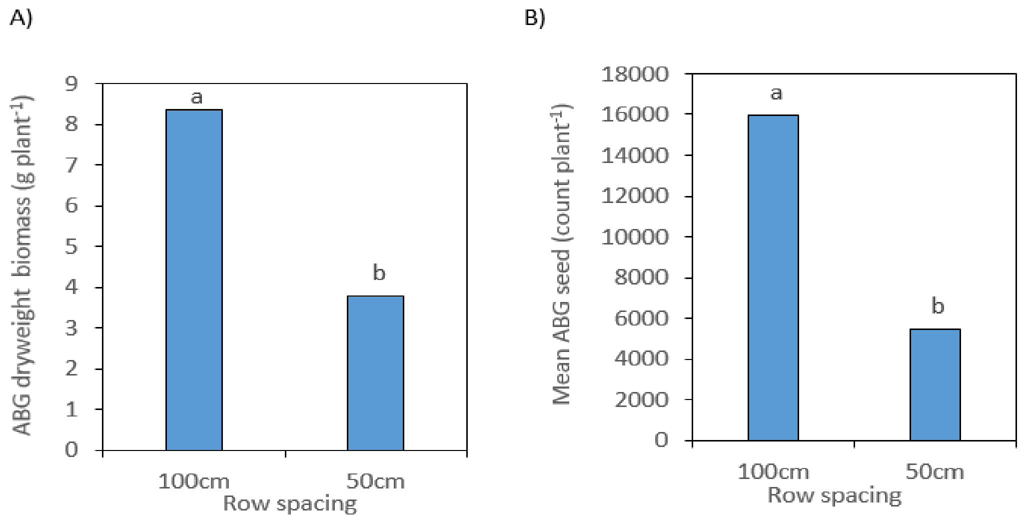


Figure 1. Awnless barnyard grass (ABG) A) biomass and B) seed production as affected by sorghum row spacing at Hermitage, Qld 2018/19. Within each graph, different letters indicate significant (*P*<0.05) difference after pairwise comparison.

Narrow row spacing in sorghum reduced FTR biomass (P<0.001) and seed production (P<0.001) (Figure 2). At the 50 cm row spacing, biomass and seed production were 48 and 56% lower, respectively.

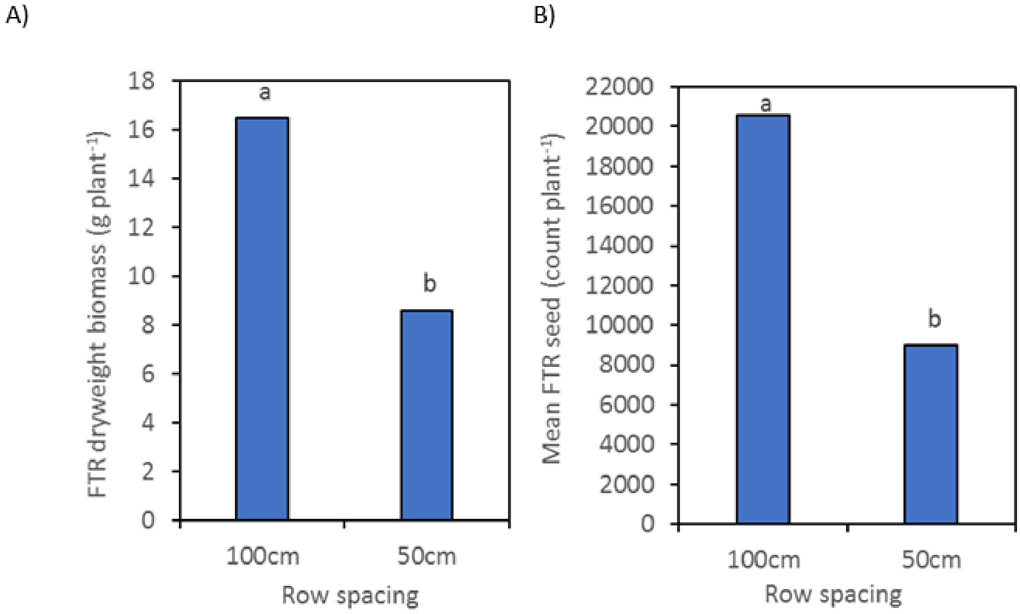


Figure 2. Feathertop Rhodes grass (FTR) A) biomass and B) seed production as affected by sorghum row spacing at Hermitage, Qld 2018/19. Within each graph, different letters indicate significant (*P*<0.05) difference.

Crop density

Increased sorghum plant density reduced the growth and seed production of both FTR and ABG. In a 2017/18 field trial at Hermitage, an increasing sorghum density significantly reduced both ABG (P=0.001) and FTR (P=0.004) seed production (Figure 3).

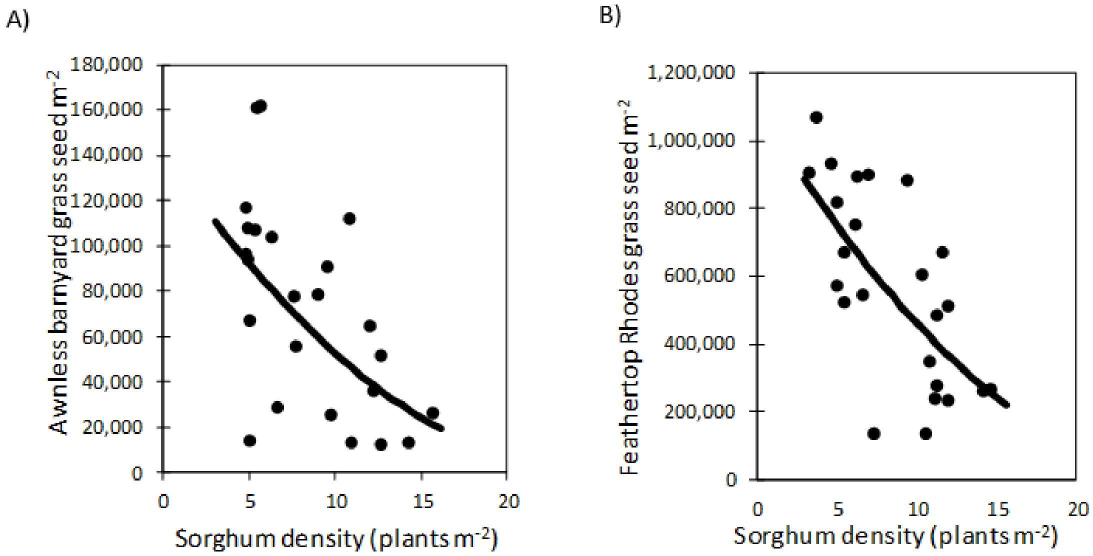


Figure 3. Relationship between sorghum plant density and seed production of A) awnless barnyard grass and B) feathertop Rhodes grass, Hermitage, Qld 2017/18.

Increasing sorghum plant density and narrower row spacing similarly reduced growth of ABG in the Narrabri trial (Figure 4). Weed biomass at a narrow row spacing of 50 cm was lower at each corresponding crop density than at a wide row spacing of 100 cm. Within each row spacing, the ABG biomass was lower at a high sorghum density (15 plants m^{-2}) compared with a low sorghum density (5 plants m^{-2}).

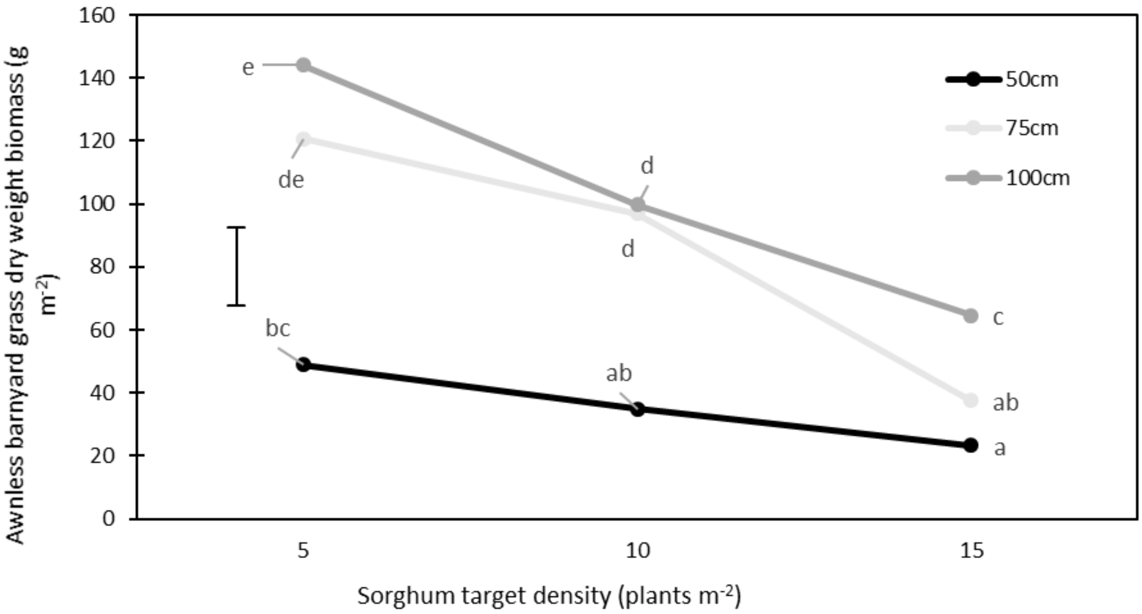


Figure 4. Effect of sorghum row spacing and crop density on awnless barnyard grass biomass. Narrabri, NSW 2017/18. Data points with a different letter are significantly different (P=0.05). LSD = 24.7.

Cultivar

At the Hermitage site, sorghum cultivar had no impact on the suppression of either FTR or ABG. In contrast, at the Narrabri site, the biomass production of ABG was significantly reduced by the Rippa cultivar (P=0.04) compared to Taurus (Figure 5). However, in this same trial, the seed production of ABG was not affected by sorghum cultivar (P=0.599).

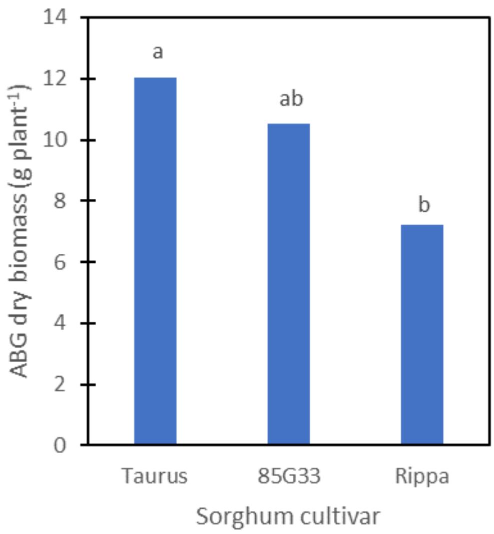


Figure 5. Awnless barnyard grass (ABG) biomass as affected by sorghum cultivar at Narrabri, NSW 2018/19. Different letters indicate significant (*P*<0.05) difference after pairwise comparison.

Crop yield

In most of the field trials, sorghum grown at narrower row spacing or higher crop density had no impact on crop yield. This demonstrates that, the use of agronomic practices of narrower row spacings and increased crop plant densities that increased sorghum competition effects on weeds, did not reduce yields. In fact, in one of the Narrabri field trials, increased sorghum density and narrow row spacing resulted in yield increases (Figure 6). At both sites, there were no differences in yield between cultivars.

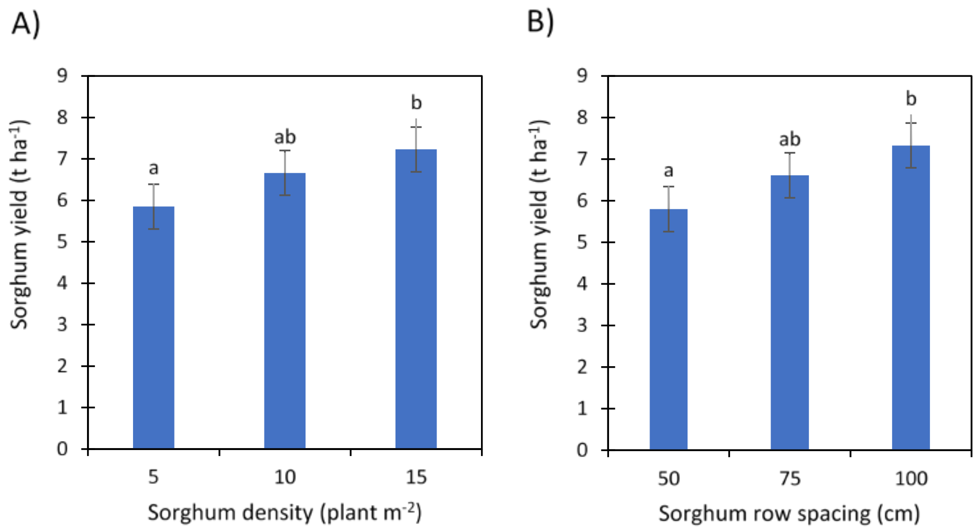


Figure 6. Effect of A) sorghum density and B) sorghum row spacing on sorghum grain yield, Narrabri, NSW 2017/18. Data points on each graph with a different letter are significantly different at P=0.05. LSD bar is shown on both graphs = 54.

Mungbean

Row spacing

Establishing mungbean crops in narrower row spacings consistently reduced the seed production and growth of both ABG and FTR in multiple field trials over four summer seasons. Hermitage site results are presented to indicate these consistent trends.

Mungbean grown at a narrower row spacing of 25 and 50 cm reduced the number of ABG seed produced compared to a wider row spacing of 75 cm (Figure 7A). Similarly, narrow row spacing reduced FTR seed production (Figure 7B).

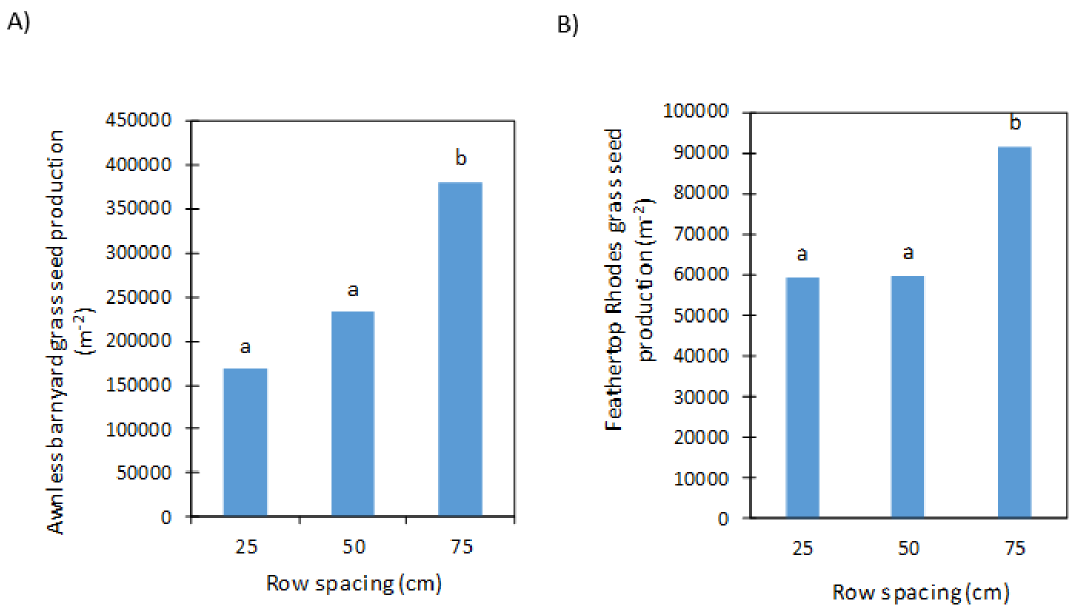


Figure 7. Effect of mungbean row spacing on A) feathertop Rhodes grass and B) awnless barnyard grass seed production, Hermitage, Qld 2016/17. Data with a different letter are significantly different (P=0.05). LSD=28,260 (A) and 125,934 (B).

Reducing row spacing from 75 to 50 and 25 cm decreased ABG biomass by 89% and 96%, respectively (Figure 8A). FTR biomass was also reduced (*P*=0.02) when row spacing was reduced from 75 to 25 cm (Figure 8B). There was no difference (P>0.05) in FTR biomass between 25 and 50 cm row spacing.

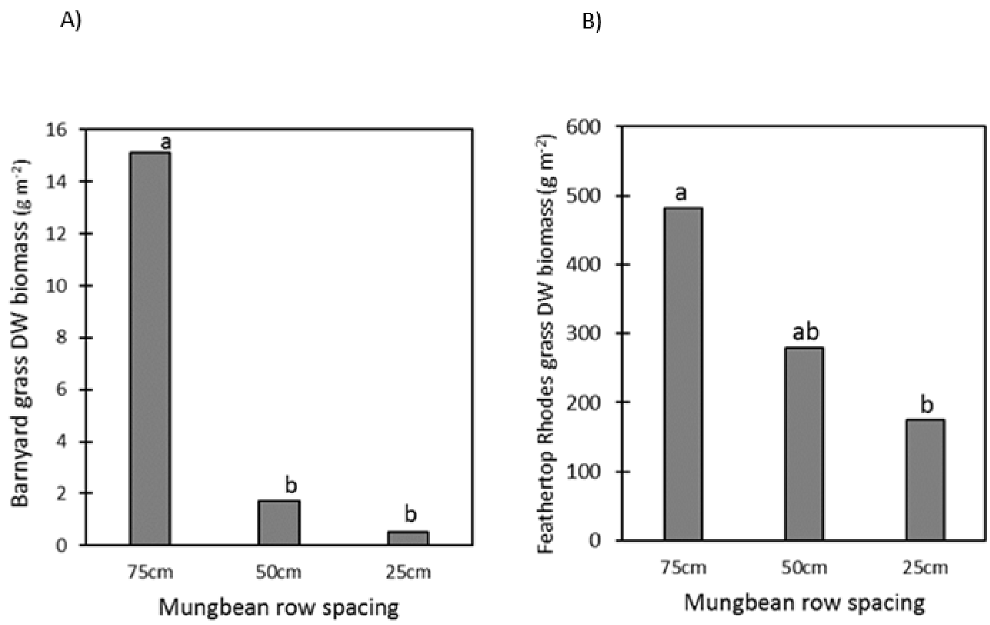


Figure 8. Effect of mungbean row spacing on the dry weight (DW) biomass of A) awnless barnyard grass and B) feathertop Rhodes grass at Hermitage, Qld 2017/18. Different letters indicate significant (*P*<0.05) difference after pairwise comparison.

Crop density

Across field sites, crop density consistently had no or little impact on the competitiveness of mungbean. Only at one Narrabri field trial was there an interaction (P=0.013) between row spacing and crop density for ABG biomass (Table 1). As row spacing widened, there was a general increase in ABG biomass at each mungbean plant density. Within each row spacing, crop density had no effect on ABG biomass, except for at 25 cm where a lower crop density of 20 plants m^{-2} had significantly greater biomass.

Table 1. Effect of mungbean row spacing and density on awnless barnyard grass dry weight biomass, Narrabri, NSW 2017/18. Back-transformed data presented with log-transformed numbers in parentheses. Numbers followed by a different letter are significantly different (P=0.05). LSD on transformed data = 0.4026.

Mungbean density (plants m^{-2})	Weed biomass (g m^{-2}) at each row spacing		
	25 cm	50 cm	75 cm
20	37.9 (3.7) b	47.8 (3.9) bc	62.4 (4.1) c
25	19.0 (3.0) a	46 (3.8) bc	64.2 (4.2) c
30	13.9 (2.7) a	33.7 (3.5) b	67.4 (4.3) c

Cultivar

The comparison of mungbean cultivars Crystal⊕, Jade-AU⊕ and Satin II⊕ across a range of row spacings identified a cultivar effect at Hermitage but not at Narrabri. Unfortunately, there was poor establishment of FTR, so only results for ABG are presented here. ABG biomass was the least when grown under the cultivar Satin II⊕ (Figure 9). While there was no difference between Crystal⊕ and Jade-AU⊕, the trend was for a lower ABG biomass in Jade-AU⊕. A similar effect was shown for ABG seed production with a significantly (P<0.001) lower number of seeds plant^{-1} in Satin IIⓓ and Jade-AUⓓ, but with the least seed being produced in Satin IIⓓ (Figure 9).

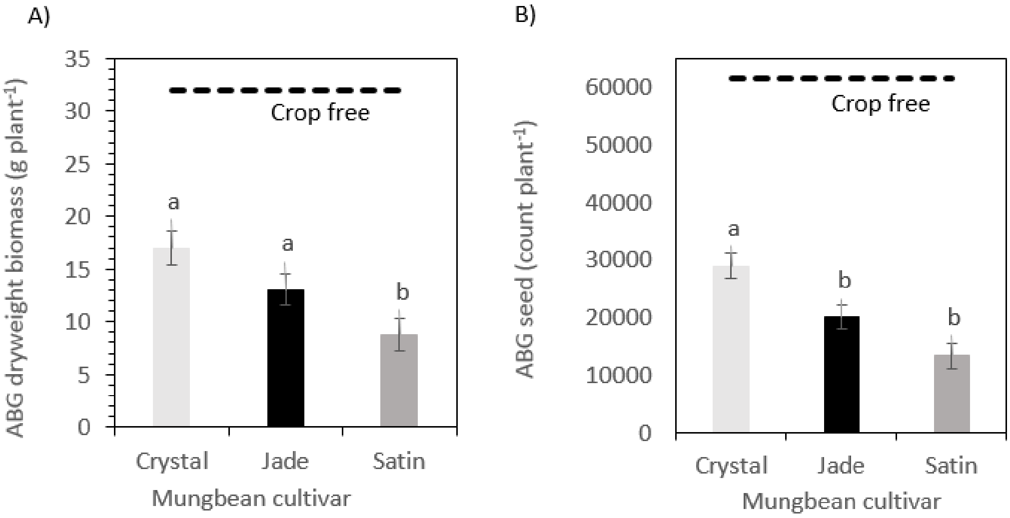


Figure 9. Awnless barnyard grass (ABG) A) biomass and B) seed count as affected by different mungbean cultivars at Hermitage, Qld 2018/19. Standard error bars are shown. Different letters indicate significant (*P*<0.05) difference after pairwise comparison. LSD = 4.1 (A) and 6934 (B). Crop free indicates mean ABG biomass and seed production in fallow plots.

Throughout the field trial, crop canopy cover (%) was assessed by analysing overhead crop photos. This enabled a comparison of potential shading effects of the mungbean cultivars (Figure 10). From 38 days after emergence (DAE) and until the final assessment at 72 DAE, Satin IIⓓ had the greatest canopy cover (P<0.001). While the canopy cover of Crystalⓓ and Jade-AUⓓ was not different at most sampling times, except for 51 DAE, where the canopy cover provided by Jade-AUⓓ was greater. These results help to explain why under Satin IIⓓ there was less ABG biomass and seed production.

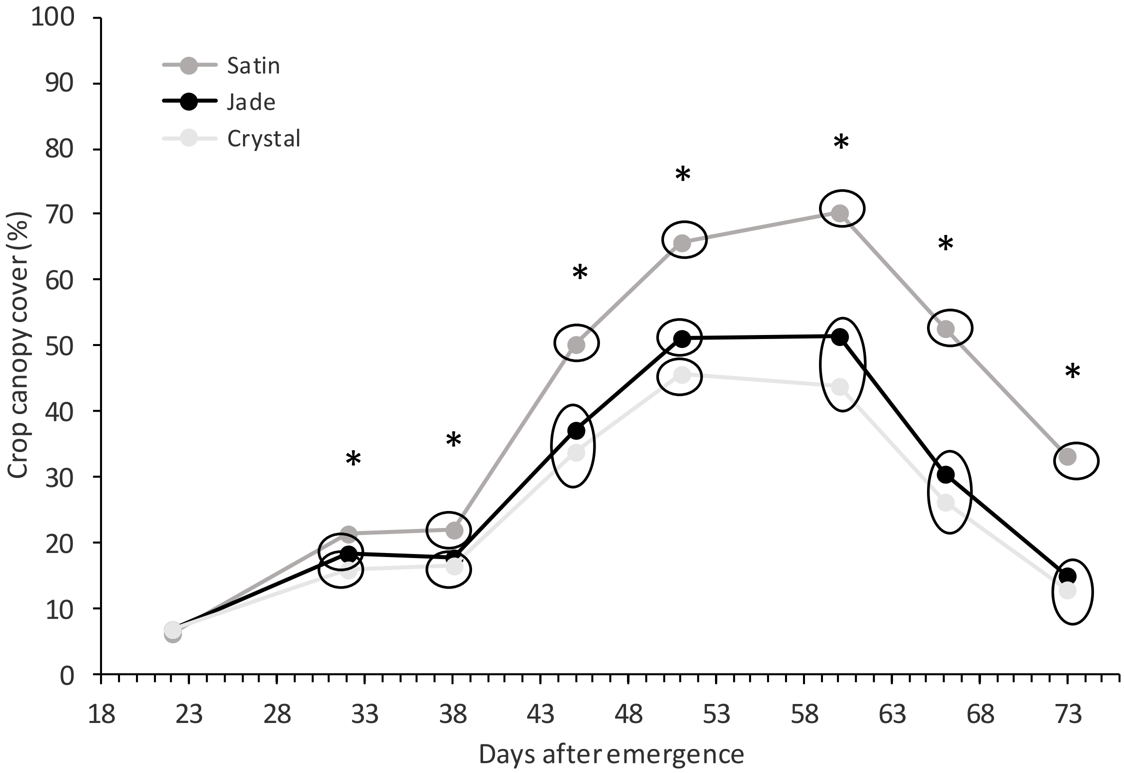


Figure 10. Canopy cover (%) over time of mungbean cultivars at Hermitage, Qld 2018/19. At each time of assessment, * denotes a significant difference. Points within an assessment time that are circled together are not significantly different. Overall LSD = 6.008.

Crop yield

There was not a consistent trend for mungbean yield in response to either row spacing or cultivar. However, across trials, mungbean yield was not affected by crop density. Differences in crop yield results are likely to be a seasonal response.

At one Hermitage trial, a higher yield was measured in plots of 25 cm rows (1.8 t ha^{-1}) compared to 50 cm rows (1.5 t ha^{-1}) or 75 cm rows (1.4 t ha^{-1}) (Figure 11). At the same Hermitage site, Satin II⦶, which was the most competitive cultivar, was also the highest (P<0.001) yielding cultivar (Figure 12). Crystal⦶, which was the least competitive, also had the lowest yield.

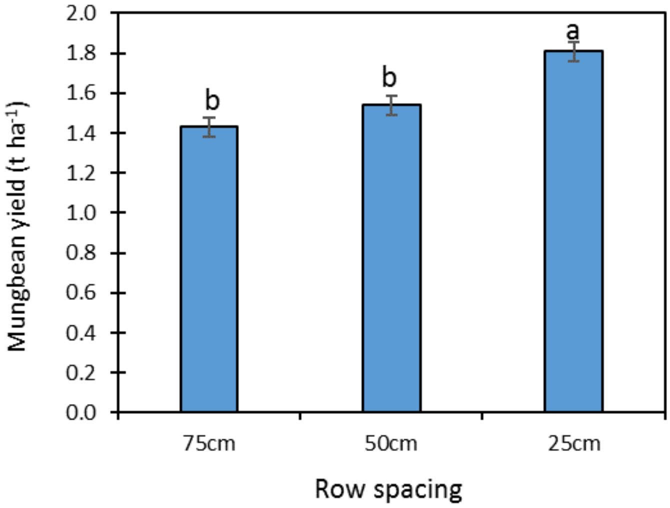


Figure 11. Effect of mungbean row spacing on crop yield at Hermitage, Qld 2017/18. Different letters indicate significant (P<0.05) difference after pairwise comparison for that graph. LSD = 0.1492. Standard error bars are shown.

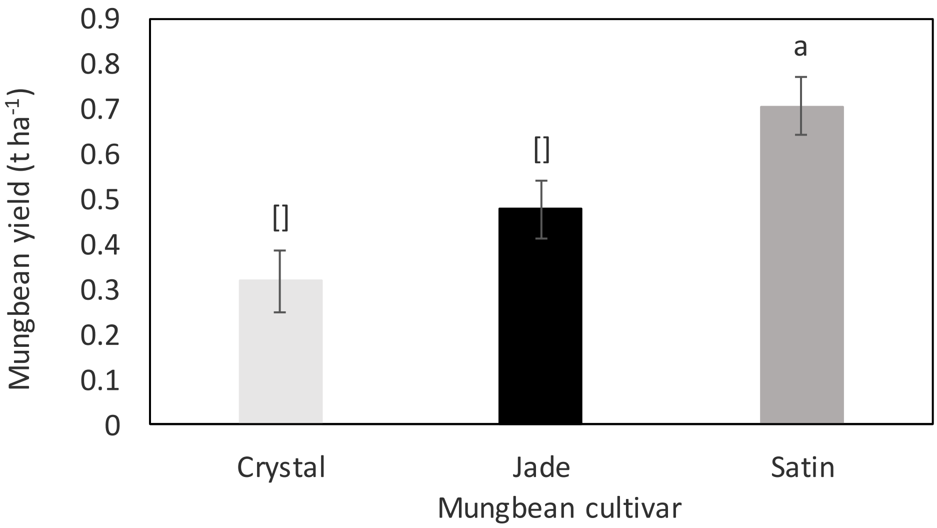


Figure 12. Yield of different mungbean cultivars at Hermitage, Qld 2018/19. Standard error bars are shown. Different letters indicate significant (*P*<0.05) difference after pairwise comparison. LSD = 0.124.

Conclusion

Our research shows there are weed control benefits in growing competitive sorghum and mungbean crops. Although some of the findings have differed between trials and seasons, results show narrow row spacing can improve competitiveness for both crops and is the approach that will likely have the largest and most consistent impact on weed growth and seed production. Increasing sorghum plant density also consistently increased the competitive effects of this crop against these weeds, whereas mungbean density had less impact. Cultivar choice may have an impact in both crops but is likely to be dependent upon seasonal conditions. Favourably, our results show that growing a competitive crop not only reduces weed competition and seed set but can improve or maintain crop yield.

Acknowledgements

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

Contact details

Michael Widderick (Principal Research Scientist)
Queensland Department of Agriculture and Fisheries
Ph: 07 4529 1325
Email: Michael.widderick@daf.qld.gov.au

Asad Shabbir (Postdoctoral Research Associate – Weed Ecology)
University of Sydney
Ph: 02 4651 9884
Email: asad.shabbir@sydney.edu.au

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

Labour and machinery requirements: Implications of different crop sequences

Julius H. Kotir[1], Lindsay W. Bell[1], John A. Kirkegaard[2], Jeremy Whish [3] and Kojo Atta Aikins[4]

[1] CSIRO Agriculture and Food, PO Box 102, Toowoomba QLD 4350
[2] CSIRO Agriculture and Food, GPO Box 1600, Canberra 2601, ACT
[3] CSIRO Agriculture & Food, 306 Carmody Road, St. Lucia, QLD, 4067
[4] Centre for Agricultural Engineering, USQ, Toowoomba, QLD 4350

Key words

labour demand, machinery capacity, crop rotation, labour productivity, farming system

GRDC code

9175454

Take home message

- Cropping intensity had a significant effect on labour requirements
- Diverse rotations may create higher labour demand and peak demands that may limit the adoption of diversified crop rotations in some farm businesses
- In moderate and lower rainfall environments, crop sequences with higher intensity may yield lower returns per unit of labour (i.e., more than 38% less) than those with lower crop intensities
- Cropping intensity is a critical determinant of labour organisation in the northern grain growing zone, more so than cropping diversity.

Introduction

Leading growers and advisers advocate sustainable rotations as a valuable strategy for northern farming systems within an increasingly challenging cropping environment (GRDC, 2011). Consequently, current farming systems research is focused on quantifying the impact of different cropping systems on farming system performance, including water use efficiency, N input & efficiency, grain yield, weed management, soil health effects, and profitability and risk at the paddock scale (Bell et al., 2015). While biophysical optimisation of the farming system may be possible to improve the efficiency of most cropping systems, key elements that are often ignored are how different cropping systems impact on whole-farm factors, such as requirements for labour and machinery resources. These farm-scale effects are critical because they modify farm productivity and profitability in the short and long term. Moreover, a consideration of these factors is crucial because they can influence the adoption of proposed cropping system innovations. Getting the most profitable results from a farm business requires a careful balance of limited resources to improve system performance and efficiency at an acceptable level of risk.

The central objective of this research was to investigate the effects of innovative diversified cropping systems on labour resources in the grain-growing northern region of Australia. Specifically, we aimed to:

1. Determine the labour requirements for eight selected diversified rotational sequences across three different locations
2. Estimate the labour productivity in terms of $ returns to labour for each system, and

3. Develop labour calendars to identify periods of labour peaks and troughs and the seasonality of labour demand during the growing season.

This work is motivated to inform grain growers who must make operational, tactical or strategic decisions concerning the use of machinery and labour resources to improve the efficiency of their farming systems. The goal is to guide grain growers in their transition towards more profitable and diversified cropping systems.

Materials and methods

First, we simulated different crop consequences over 112 years (i.e. 1900 – 2012) using historical climate records in APSIM (Holzworth et al., 2014). These crop sequences represented typical rotations in the northern regions and were identified following focus group meetings with leading farmers and advisers throughout the northern cropping zone of Australia. Specifically, we focused our analysis on six rotational sequences across three sites. The rotations were selected to capture a range of cropping system intensity (i.e. the proportion of time when crops were growing) and crop diversity (i.e., the range of crops grown in the system) (Table 1). The sites analysed span high rainfall (Cecil Plains), medium rainfall (Goondiwindi) and a low rainfall zone (Mungindi) of the region. The crops in the sequences consisted of a variety of summer crops (sorghum and mungbeans),in APSIM, sown in December or January and winter growing crops (wheat, chickpea and faba bean), sown in May or June. The crop sequences simulated were all set so that crops were always sown at the end of their sowing window irrespective of soil water triggers being satisfied; this will have increased the likelihood of 'failed' crops compared to what might be expected on-farm.

Table 1. Specific crop rotations considered in the analysis

	High diversity		**Low diversity**	
System intensity	**Crop sequence**	**% time in crop**	**Crop sequence**	**% time in crop**
High intensity (> 1 crops/yr)	SChxWMgx	43	xWxWxCh	39
Moderate intensity (0.75-1.0 crops/yr)	SxSxSFbxWxCh xWxx	33	SxSxSChxx	34
Low intensity (0.5-0.75 crops/yr)	SxxChxWxx	28	WxxxChxxx	21

Notes: S = Sorghum, Ca = canola, Ch = Chickpea, Mg Mungbean, W= Wheat, Fb = Faba bean, x = fallow, xx = Long fallow

For each crop rotation, we calculated the labour requirement for operations including planting, spreading, spraying and harvesting. We obtained specific information on the machinery required for each of these operations, and information on a range of possible operating widths and working speeds from existing literature, local technical guides and through a consultation process with 26 farm advisers and growers (Table 2). The Effective Field Capacity (EFC), expressed as ha/hr was calculated for each implement to determine how much labour was required for each operation. An estimate of EFC was calculated as follows:

$$\text{EFC in (Ha/hr/yr)} = \frac{(\text{Speed (km/hr) x width (m)) x efficiency \%}}{10}$$

The labour required per operation was calculated by using the inverse of effective field capacity for each implement used for the specific operation and expressed as h/ha (hours/hectare). Consequently, we multiplied the number of hours of each field operation by 120% to account for downtime tasks, such as refilling, moving and cleaning of equipment. Using this process, we determined the labour required for four common field operations, namely sowing, spreading, spraying and harvesting. Total labour was calculated by adding together the hours worked per hectare on sowing, spreading, spraying and harvesting. Labour calendars were developed to determine peaks and troughs of labour throughout the year and the seasonality of labour demand. The sum of labour hours for each month were divided by number of days in each phase of the rotation to scale labour requirements on a monthly basis. Cropping area (ha) that can be completed per unit of labour at peak demand was determined by using the inverse of maximum peak value during the year for each crop sequence and multiplied by the total hours for the month (i.e. 240hrs), assuming a unit of labour worked 12 hours a day during peak periods.

Finally, we computed the labour productivity of each of the cropping systems. Labour productivity was calculated as gross margin per unit labour used (expressed as $/hr). It indicates the amount which each labour unit earns for the farm business. Thus, gross margin per unit labour was the estimated as the gross margin ($/ha) for each of the crop sequence , divided by the total labour required (hr/ha) for the sequence. The system GM was estimated as the difference between revenues on the one hand and variable costs on the other hand, including the cost for each crop.

Table 2. Mean machinery and labour parameters estimated from farm survey

Field operation	Implement	Crop	Working width (m)	Average speed (km/hr)	Field efficiency (%)	Effective field capacity (ha/hr)	Labour[a] (hr/ha)
Sowing	Air-seeder	Chickpea, fababean, mungbean, wheat, sorghum	12.75	9.00	80	9.18	0.13
Spreading	Fertiliser spreader	Chickpea, fababean, mungbean, sorghum, wheat	22.50	13.00	80	23.40	0.05
Spraying	Boom sprayer	Chickpea, fababean, mungbean, sorghum, wheat	28.00	21.44	70	42.00	0.02
		Summer and winter fallow spray	28.00	22.50	70	44.10	0.02
Harvesting	Header	Chickpea, fababean	12.00	8.00	80	7.68	0.16
		Mungbean	12.00	7.60	80	7.32	0.16
		Sorghum	12.00	11.13	80	10.56	0.11
		Wheat	12.00	10.63	80	10.02	0.11

Notes: [a]Labour hours are the inverse of the effective field capacity multiplied by labour adjustment factor of 1.2 to account for downturn tasks.

Results

Labour requirements and variability across diverse systems

The results showed that crop sequences have a direct influence on labour requirements, with some systems requiring a much higher labour input per hectare than others. Firstly, cropping system intensity was shown to have a large influence on total labour requirement. Higher intensity systems (e.g. SChxWMgx, xWxWxCh) required 30-40% greater labour inputs per hectare than lower intensity systems (e.g. WxxxChxxx) (Figure 1). In general, the results suggest that total labour requirement are highest in those sequences with a greater diversity of crops and high intensity relative to the rest. In terms of the different field operations, the proportion of labour required for the harvesting operation was nearly the same as sowing activity even though the latter was determined based on the combined machinery work rate of both air-seeder and row-crop planter (Figure 1). However, a significant proportion of labour was required for the spraying operations, attributable to the multiple in-crop sprays and when the system is fallow. Very little labour was required for fertiliser or manure spreading operations for the eight crop rotations, possibly because it is mostly performed concurrently with sowing.

Further analysis of total labour showed a wide range of variation (Figure 2). The lowest variability was observed in SxxChxWxFbxWxx (0.42 – 0.61 hr/ha/yr), followed by SxSxSChxx (0.44 – 0.77 hr/ha/yr), and the most variability was in the more diversified and moderately intensive system, SxSxSFbxWxChxWxx (0.37 – 0.74 hr/ha/yr). In general, the variability caused by crop types ranged from 0.31 – 0.85 hr/ha/yr. These variations might derive from one or more crops involved in the rotation and the associated labour resource input variations.

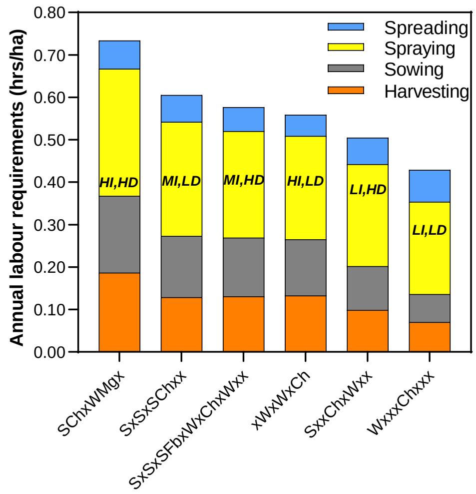


Figure 1. Labour requirements for different field operations as influenced by diversified crop sequences. Letters on top of bars represent High intensity (HI), Moderate Intensity (MI), Low Intensity (LI), High diversity (HD), and Low Diversity (LD).

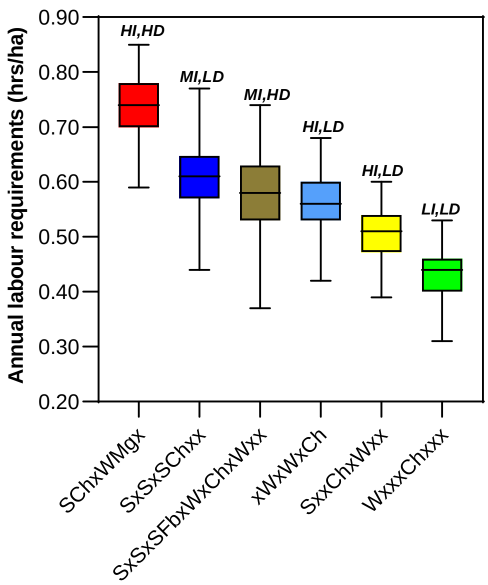


Figure 2. Total labour variability caused by diversified crop sequences. The vertical lines show the maximum and minimum values. The upper and lower edges of the boxes show the 75th and 25th percentiles, respectively, and the middle line in the box shows the median. Letters above the boxes represent High intensity (HI), Moderate Intensity (MI), Low Intensity (LI), High diversity (HD), and Low Diversity (LD).

Labour demand calendar

For every crop sequence, there is a calendar period during which labour requirements are at a maximum. Figures 3 shows when the peaks and troughs of labour occur throughout the year. For all sequences analysed, peak demand for labour occurred in May, July, November and in December when sowing and harvesting tend to be more intense. By contrast, there were periods of troughs and slack labour during the cropping season, and especially during February, August and September. The corresponding cropping area that can be covered by one labour unit when labour is at its peak ranged between 2,250 ha/month for the high intensity and more diverse system (SChxWMgx) to 3,700 ha/month with for low intensity and low diverse system (WxxxChxxx) (Table 3). The latter might be attributed to the rotation being less diverse (few crops), so labour did not have to be allocated to any other crops at peak times. In the former, it is the other way around. In general, a reduction in system intensity increased the area that can be covered during peak periods.

Peak periods, such as these, often require additional labour. Therefore, the results give growers a clear picture of when such extra labour might be required. However, the additional labour may often not be available. Therefore, technology or strategies that reduce the amount of labour required in the seasonal peaks is likely to increase farm profit. Moreover, identification of when these peaks and troughs of labour demand occur, allows the manager to decide how to best use the existing resources on the farm (both labour and machinery), plan ahead and plan for additional staff or resources as required. This process also helps highlight periods when staff can be encouraged to take leave and maintain a healthy work-life balance without impacting on the farming operation (GRDC, 2013). Taken together, these patterns of labour distribution imply that diverse rotations may create higher labour demand and seasonal peaks that might, in some cases, limit the adoption of diversified crop rotations in some farm businesses. This suggests that labour efficiency can be an important consideration when planning an appropriate crop sequence, diversity and intensity for a farm business.

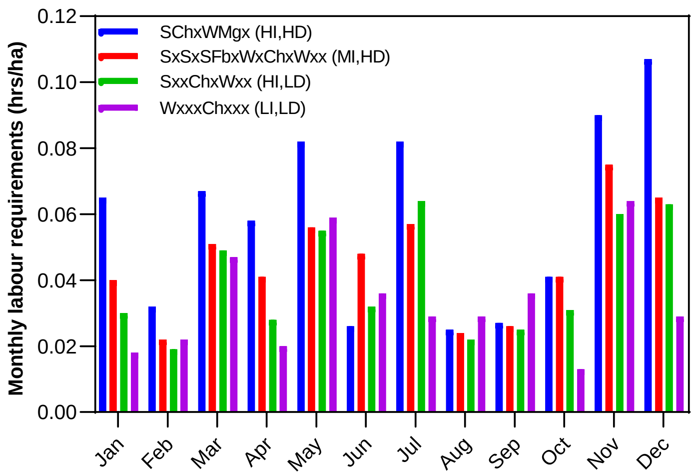


Figure 3. Monthly total labour requirements for diversified crop sequences. Letters in parenthesis represent High intensity (HI), Moderate Intensity (MI), Low Intensity (LI), High diversity (HD), and Low Diversity (LD).

Table 3. Area that can covered per month per labour unit at peak labour demand

	High diversity		Low diversity	
System intensity	**Crop sequence**	**Area (ha)**	**Crop sequence**	**Area (ha)**
High intensity (> 1)	SChxWMgx	2250	xWxWxCh	3100
Moderate intensity (0.75 – 1)	SxSxSFbxWxChxWxx	3200	SxSxSChxx	3100
Low intensity (0.5 – 0.75)	SxxChxWxx	2300	WxxxChxxx	3700

Notes: S = Sorghum, Ca = canola, Ch = Chickpea, Mg Mungbean, W= Wheat, Fb = Faba bean, x = fallow, xx = Long fallow
One labour unit is assumed to work a maximum of 240 hours per month.

Dollar returns on labour

While the above analysis shows that farming systems result in different labour demands, the ability of these systems to generate enough revenue to cover these additional inputs must also be considered. That is a higher return system has more capacity to pay for the higher labour inputs required, and vice versa. The results here show that the optimal labour productivity was achieved with quite different farming systems at the different production environments.

At the higher rainfall site (i.e. Cecil Plains) the returns per unit of labour for the moderate intensity and more diverse system (SxSxSFbxWxChxWxx) and the higher intensity and low diverse system (xWxWxCh) were identical, that is $1,524/hr and $1,525/hr, respectively. By comparison, the low intensity and less diverse system (WxxxChxxx) produced the lowest returns per unit of labour at $1,217/hr. Interestingly, the low intensity and less diverse systems (WxxxChxxx) also yielded higher returns to labour at both Goondiwindi ($743/hr) and Mungindi ($746/hr**)** due to the lower labour inputs, whereas the high intensity sequence (SChxWMgx) was relatively low averaging $539/hr because of the high labour input. At Goondiwindi, the return per unit of labour obtained for the high intensity and high diverse system SChxWMgx was about 38% less than that achieved with the low intensity and low diverse system (WxxxChxxx). At Mungindi, this difference increased to 143% less when the two systems were compared. Overall, the magnitude of labour productivity for all systems analysed is significantly greater in the higher rainfall environment of Cecil Plains than those presented in the moderate and harsher environments like Goondiwindi and Mungindi, respectively. This indicates that labour productivity in terms of $return per a unit of labour is unsurprisingly often higher in higher rainfall environments rather than in lower rainfall environments.

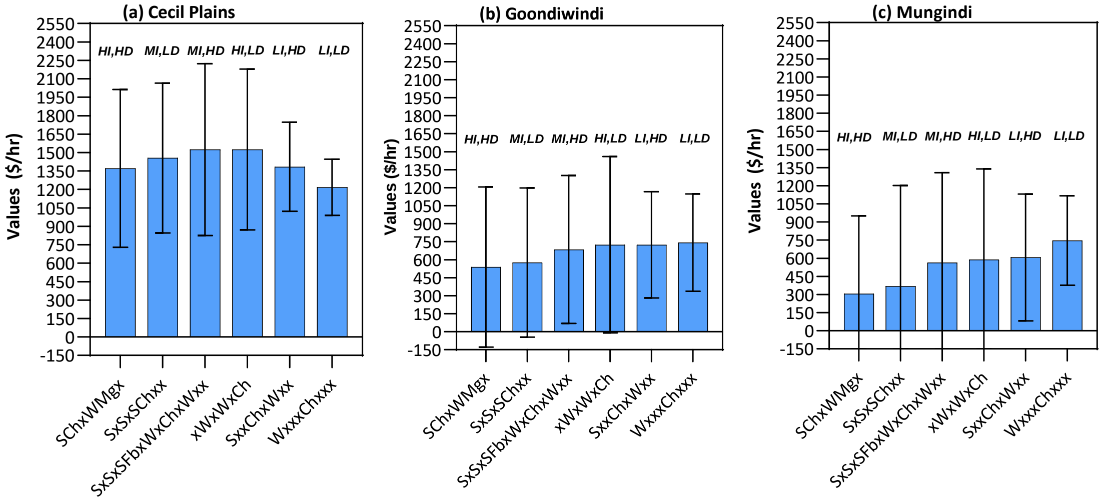


Figure 4. Mean GM returns per unit of labour as influenced by diversified crop sequences at (a) Pampas (b) Goondiwindi, and (c) Mungindi. Error bars represent the standard deviations. Letters on top of the bars represent High intensity (HI), Moderate Intensity (MI), Low Intensity (LI), High diversity (HD), and Low Diversity (LD).

Conclusion

While the farm labour resource is complex, awareness of issues that influence the need for labour at different times of the year, such as the diversity and intensity of cropping systems can directly assist farm resource planning. Efficient use of available labour can also have bearing on the selection of appropriate crop sequences and cropping intensities. This study showed how labour organisation is influenced by diversified crop rotations. The results showed that diversified crop rotations had a significant effect on labour requirements. The high intensity crop sequences required much higher labour input per hectare than the low intensive and less diverse systems. Therefore, reduced intensity of cropping may help decrease labour by saving working hours. Rotation selection can have a large impact on the $ returns per unit of labour with the more diverse systems achieving higher labour productivity. Our analysis highlights the importance of addressing labour productivity as labour resources are often scarce and availability can vary through the cropping season. It provides an important insight into the decisions growers face while aiming to maximise profit from limited available resources, such as labour., Labour productivity should not be evaluated in isolation as it is directly related to both the cost of labour and profit margins. In the next phase of this work, we intend evaluating the cost of labour in conjunction with crop machinery investment and cost per hectare, financial efficiency, and profitability.

Acknowledgements

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

References

Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES, 2018). Available from http://www.agriculture.gov.au/abares (accessed on June 12, 2019).

Bell, LW., Whish, J., Zull, A. and Gentry, J. (2015). Performance of current northern farming systems. GRDC Update paper. Available from: https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2015/09/performance-of-current-northern-farming-systems

GRDC (2011). Choosing Rotation Crops – North. Short-term profits, long-term payback. GRDC Fact Sheet. Available from: https://grdc.com.au/__data/assets/pdf_file/0024/223683/grdcfsbreakcropsnorthpdf.pdf.pdf (Accessed on May 16, 2020)

GRDC (2013). Filling the farm labour gap. Retrieved on January 12, 2018 from https://grdc.com.au/__data/assets/pdf_file/0021/126507/filling-the-labour-gap-fact-sheet.pdf.pdf

Hochman, Z., Prestwidge, D., & Carberry, P. S. (2014). Crop sequences in Australia's northern grain zone are less agronomically efficient than implied by the sum of their parts. *Agricultural Systems*, 129, 124-132

Holzworth DP, Huth NI, deVoil PG, et al. (2014) APSIM - Evolution towards a new generation of agricultural systems simulation. *Environmental Modelling and Software*, 62, 327-350.

Sinha, A. K., Shrivastava, A. K., Gautam, A. K., & Ahamad, S. (2016). A Decision Support System for Farm Mechanization with the Use of Computer Modelling For Soybean-Wheat Crop Rotation. *International Journal of Innovative Science Engineering and Technology*, 3(7).

The Australian Bureau of Statistic (ABS, 2018). Available from: https://www.abs.gov.au/ (accessed on June 12, 2019).

Contact details

Dr Julius Kotir
CSIRO Agriculture and Food
PO Box 102, Toowoomba Qld 4350, Australia
Mb: 0404 650 811
Email: Julius.kotir@csiro.au

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

Richard Daniel, Linda Bailey, Denielle Kilby, Branko Duric, Richard Black and Lawrie Price. 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).

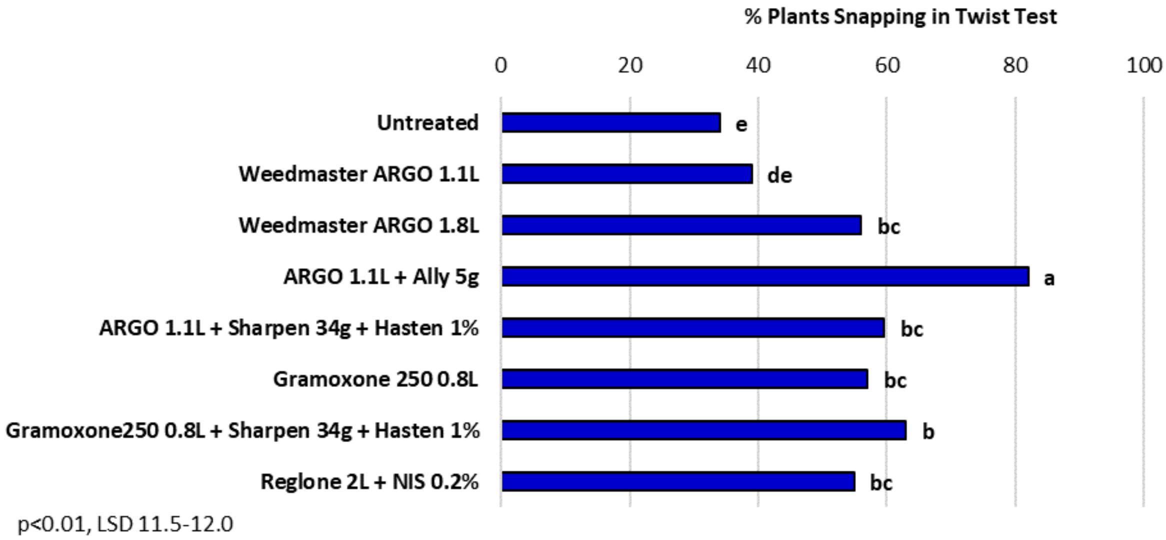
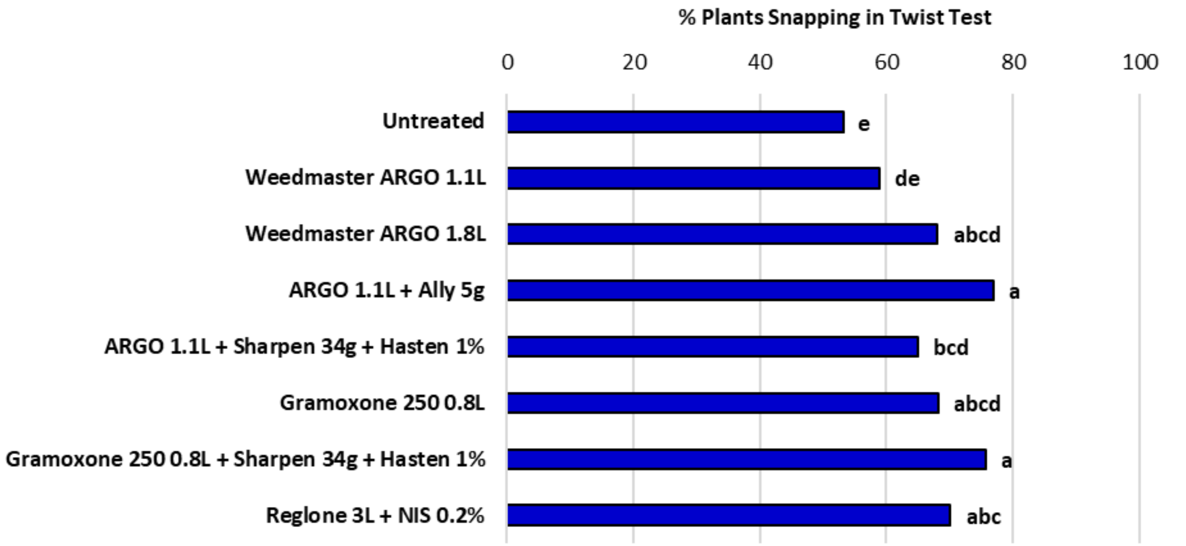


Figure 1. Stem twist test results 10-17 days after application, as an indication of stem dry down. *(Mean of 5 trials 2017)*

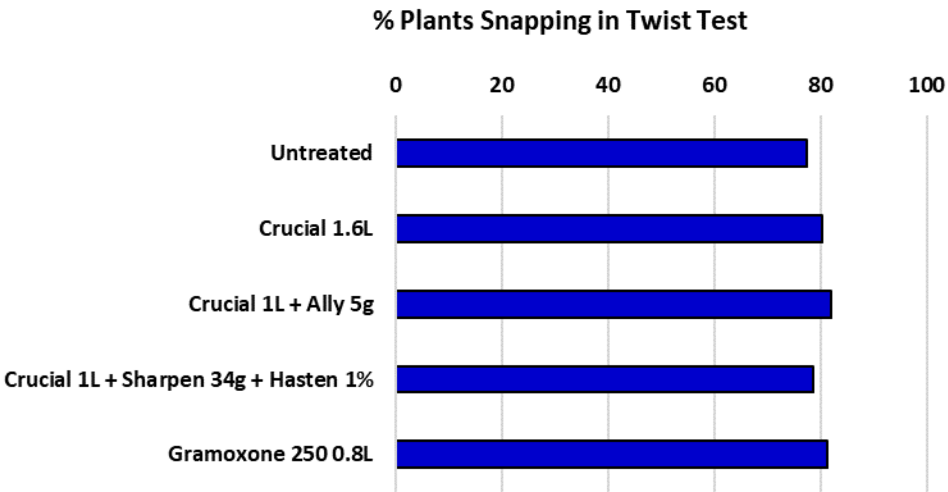
NIS = non-ionic surfactant



p<0.01, LSD 9.9-10.1

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



p=0.22, NSD

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.

Acknowledgements

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

NGA would particularly like to acknowledge the assistance from a large number of trial co-operators during this series of trials: Wade Bidstrup, Graham Butler, Jack Williamson, Sam Chaffey, Glen Kendall, Mark Cotter, Drew Penberthy, Nigel Melbourne, Ash Butler and Ross Durham.

Contact details

Richard Daniel
Northern Grower Alliance
Ph: 07 4639 5344
richard.daniel@nga.org.au

⅌ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994
® Registered Trademark

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⟨Ⴔ⟩**	**HatTrick⟨Ⴔ⟩**	**HatTrick⟨Ⴔ⟩**	**HatTrick⟨Ⴔ⟩**	**Seamer⟨Ⴔ⟩**	**Seamer⟨Ⴔ⟩**	**Kyabra⟨Ⴔ⟩**
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

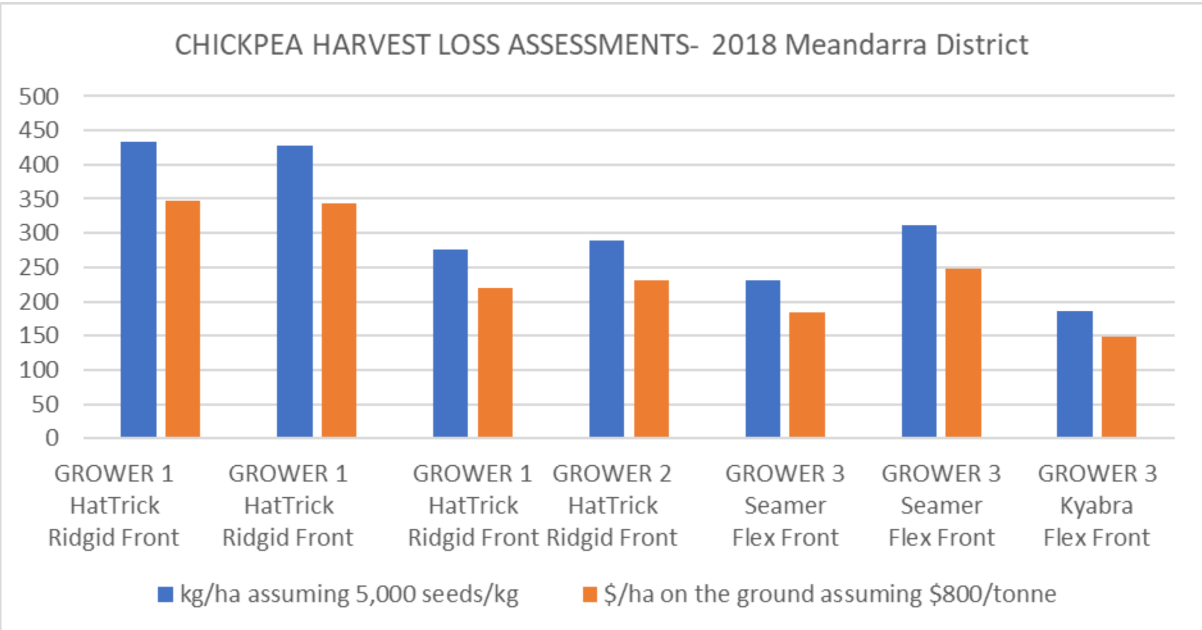


Figure 1. 2018 Pod loss at the header front
(HatTrick⟨Ⴔ⟩, Seamer⟨Ⴔ⟩ and Kyabra⟨Ⴔ⟩ are varieties protected under the Plant Breeders Rights Act 1994)

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⦶, 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⦶, 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**

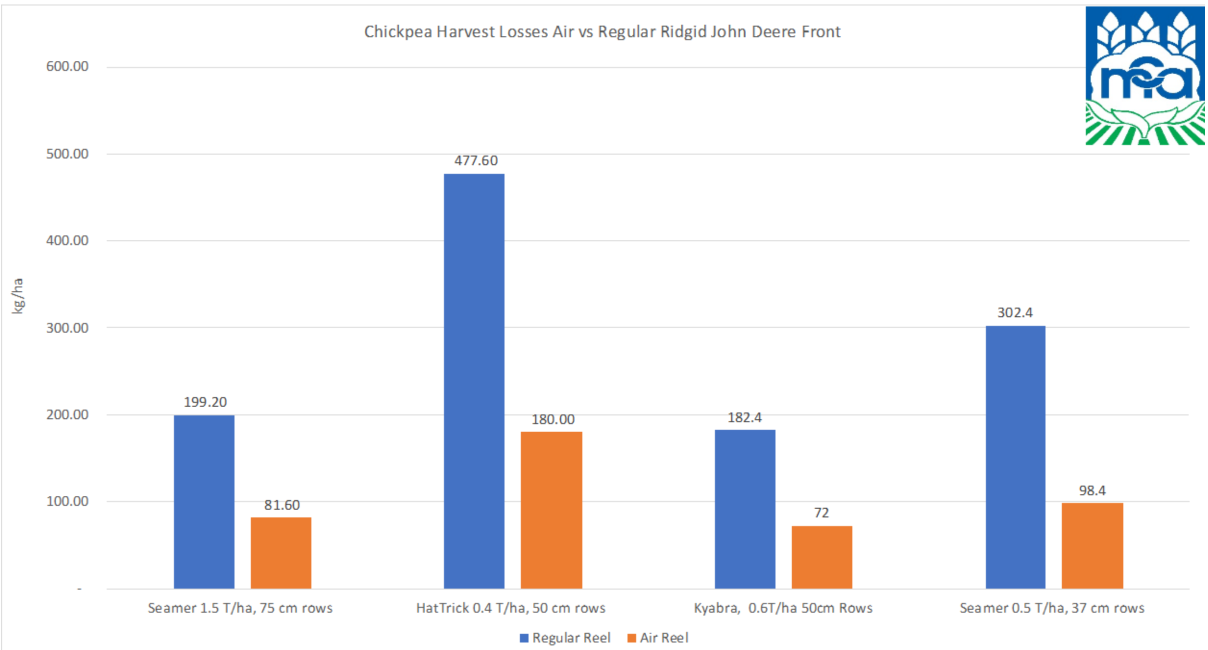


Figure 2. 2019 Harvest losses in chickpeas based on pod counts left on the ground after harvesting with a regular and an air assisted reel

(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

I would like to acknowledge Jess Mickelborough and Edward Britten for conducting the pod counts and tabling the information.

References

Cumming G. (editor) (2010). Northern mungbean best management practice training course, module 8 – desiccation harvest and storage.

Contact details

Ed Offner
Director/Consultant
MCA Agronomy Pty Ltd
PO Box 1034, GOONDIWINDI QLD 4390
Mb: 0409 712 011
Email: EdOffner@mcagoondi.com.au

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

® Registered Trademark

Measuring and predicting plant available water capacity (PAWC) to drive decision-making and crop resourcing: extrapolating data in the Central Darling Downs from limited site numbers across paddocks helped by soil-landscape understanding

Mark Thomas[1], Brett Cocks[2], Uta Stockmann[3], Mark Glover[3], Jenet Austin[4], John Gallant[4] and Kirsten Verburg[3]

[1] CSIRO Agriculture and Food, Adelaide SA
[2] CSIRO Agriculture and Food, Toowoomba Qld
[3] CSIRO Agriculture and Food, Canberra ACT
[4] CSIRO Land and Water, Canberra ACT

Key words

Plant Available Water Capacity (PAWC), PAWC estimation, APSoil, soil survey, soil processes, soil constraints, soil-landscapes

GRDC code

CSP00210

Take home messages

- Information regarding the plant available water (PAW) at a point in time, particularly at planting, can be useful in a range of crop management decisions. Estimating PAW, whether through use of a soil water monitoring device or a push probe, requires knowledge of the plant available water capacity (PAWC) and/or the crop lower limit (CLL)
- A wide variety of soils in the northern region have been characterised for PAWC and details are available to growers in the APSoil database, which can be viewed in Google Earth and in the 'SoilMapp' application for iPad
- Knowledge of physical and chemical soil properties like texture or particle size distribution and (sub) soil constraints helps interpret the size and shape of the PAWC profiles of different soils. It can also assist in choosing a similar soil from the APSoil database
- Knowing something about how soils are distributed across the landscape - helped by understanding how the soils have been formed - boosts the ability to find a suitable soil type in APSoil or from other publicly available local soil and land resources (mapping, resource guides and field manuals, etc.), or allows users to reasonably predict the PAWC at a site
- Once the match between the soil of interest and the soil type is made, the PAWC can be adjusted using soil, land and chemical information, and if necessary, should constraints to crop roots be noted in the soil profile.

Plant available water and crop management decisions

A key determinant of potential yield in dryland agriculture is the amount of water available to the crop, either from rainfall or stored soil water. In the GRDC northern region the contribution of stored soil water to crop productivity for both winter and summer cropping has long been recognized. The amount of stored soil water influences decisions to plant or wait (for the next opportunity or long fallow), to sow earlier or later (and associated variety choice) and the input level of resources such as nitrogen fertiliser.

The amount of stored soil water available to a crop - plant available water (PAW) – is affected by pre-season and in-season rainfall, infiltration, evaporation and transpiration. It also strongly depends on a soil's plant available water capacity (PAWC), which is the total amount of water a soil can store and release to different crops. The PAWC, or 'bucket size', depends on the soil's physical and chemical characteristics as well as the crop being grown.

Over the past 20 years, CSIRO in collaboration with state agencies, catchment management organisations, consultants and farmers has characterised more than 1100 sites around Australia for PAWC. The data are publicly available in the APSoil database, including via a Google Earth file and in the 'SoilMapp' application for iPad (see Resources section).

Many farmers and advisers, especially in southern Australia, are using the PAWC data in conjunction with Yield Prophet® to assist with crop management decisions. Yield Prophet® is a tool that interprets the predictions of the APSIM cropping systems model. It uses the information on PAWC along with on pre-season soil moisture and mineral nitrogen, agronomic inputs and local climate data to forecast, at any time during the growing season, the possible yield outcomes. Yield Prophet® simulates soil water and nitrogen dynamics as well as crop growth with the weather conditions experienced to date and then uses long term historical weather records to simulate what would have happened from this date onwards in each year of the climate record. The resulting range of expected yield outcomes can be compared with the expected outcomes of alternative varieties, time of sowing, topdressing, etc. to inform management decisions.

Others use the PAWC data more informally in conjunction with assessments of soil water (soil core, soil water monitoring device or depth of wet soil with a push probe) to estimate the amount of plant available water. Local rules of thumb are then used to inform the management decisions.

The APSoil database provides geo-referenced data (i.e. located on a map), but the PAWC characterisations are for points in the landscape. To use this information to predict PAWC for the soil in a paddock of interest, the challenge is to find a similar soil in the APSoil database. Similarities between soils are related to parent material and the conditions under which the soil formed, or the material was deposited. This is often related to landscape position. Information on soil-landscape associations, therefore, provide an avenue to assist with PAWC prediction. The soil-landscape information is captured by the soil surveys undertaken by state government departments and other research organisations and is increasingly becoming available online.

This paper describes the concepts behind PAWC and outlines where to find existing information. It discusses how soil-landscape associations can be used to inform extrapolation from existing PAWC sites and assist with predictions. This is illustrated by current work from the Central Darling Downs in which relationships between landscapes, soil and PAWC are being explored to inform better PAWC predictions for growers to inform management decisions.

Plant available water capacity (PAWC)

To characterise a soil's PAWC, or 'soil water bucket size', we need to determine (Figure 1a):

- drained upper limit (DUL) or field capacity – the amount of water a soil can hold against gravity;
- crop lower limit (CLL) – the amount of water remaining after a particular crop has extracted all the water available to it from the soil; and
- bulk density (BD) – the density of the soil, which is required to convert measurements of gravimetric water content to volumetric.

In addition, soil chemical data are obtained to provide an indication whether subsoil constraints (e.g. salinity, sodicity, boron and aluminium) may affect a soil's ability to store water, or the plant's ability to extract water from the soil.

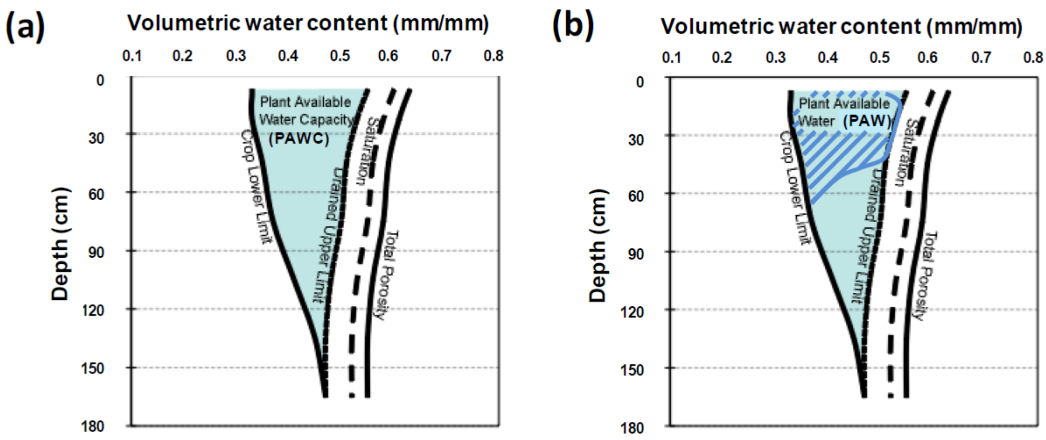


Figure 1. (a) The plant available water capacity (PAWC) is the total amount of water that each soil type can store and release to different crops and is defined by its drained upper limit (DUL) and its crop specific crop lower limit (CLL); (b) plant available water (PAW) represents the volume of water stored within the soil available to the plant at a point in time. It is defined by the difference between the current volumetric soil water content and the CLL.

Plant available water is the difference between the CLL and the volumetric soil water content (mm water/mm of soil) (Figure 1b). The latter can be assessed by soil coring (gravimetric moisture which is converted into a volumetric water content using the bulk density of the soil) or the use of soil water monitoring devices (requiring calibration to quantitatively report soil water content).

An approximate estimate of PAW can be obtained from knowledge of the PAWC (mm of available water/cm of soil depth down the profile) and the depth of wet soil (push probe or based on a feel of wet and dry limits using an uncalibrated soil water monitoring device).

Knowledge of PAW can inform management decisions and many growers in the GRDC Northern Region have, formally or informally, adopted this. Several papers at recent GRDC Updates have illustrated the impact of PAW at sowing on crop yield in the context of management decisions.

Field measurement of PAWC

Field measurement of DUL, CLL and BD are described in detail in the *GRDC PAWC Booklet* 'Estimating plant available water capacity' (see Resources section). Briefly, to determine the DUL an area of approximately 4 m x 4 m is slowly wet up using drip tubing that has been laid out in spiral (see Figure 2a). The area is covered with plastic to prevent evaporation and after the slow wetting up it is allowed to drain (see *GRDC PAWC booklet* for indicative rates of wetting up and drainage times). The soil is then sampled for soil moisture and bulk density.

The CLL is measured either opportunistically at the end of a very dry season or in an area protected by a rainout shelter between anthesis/flowering and time of sampling at harvest (Figure 2b). This method assumes the crop will have explored all available soil water to the maximum extent and it accounts for any subsoil constraints that affect the plant's ability to extract water from the soil.

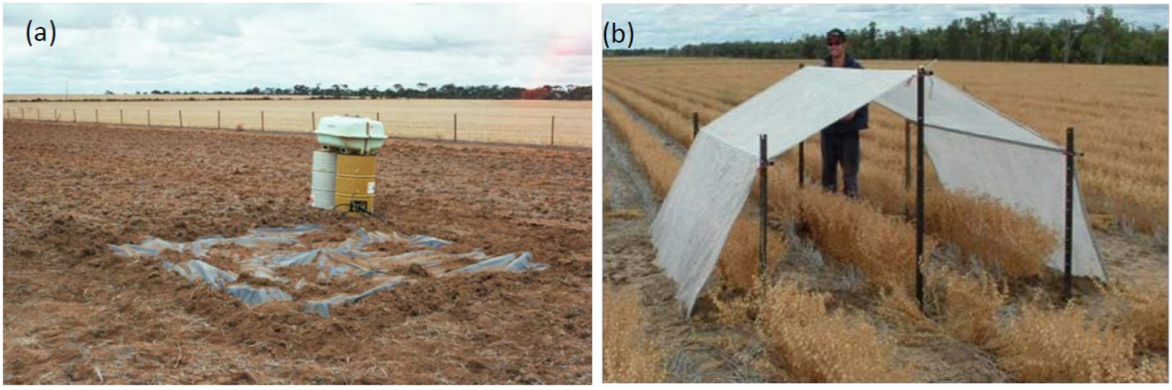


Figure 2. (a) Wetting up for DUL determination and (b) rainout shelter used for CLL determination (source: CSIRO).

Where to find existing information on PAWC

Characterisations of PAWC for more than 1100 soils across Australia have been collated in the APSoil database and are freely available to farmers, advisors and researchers. The database software and data can be downloaded from https://www.apsim.info/Products/APSoil.aspx. The characterisations can also be accessed via Google Earth (KML file from APSoil website) and in SoilMapp, an application for the iPad available from the App store. The industry yield forecasting tool Yield Prophet® also draws on this database.

In Google Earth the APSoil characterisation sites are marked by a shovel symbol (see Figure 3a), with information about the PAWC profile appearing in a pop-up box if one clicks on the site. The pop-up box also provides links to download the data in APSoil database or spreadsheet format.

In SoilMapp the APSoil sites are represented by green dots (see Figure 3b). Tapping on the map results in a pop-up that allows one to 'discover' nearby APSoil sites (tap green arrow) or other soil (survey) characterisations. The discovery screen then shows the PAWC characterisation as well as any other soil physical or chemical analysis data and available descriptive information.

Most of the PAWC data included in the APSoil database has been obtained through the field methodology outlined above, although for some soils estimates have been used for DUL or CLL. Some generic, estimated profiles are also available. While field measured profiles are mostly geo-referenced to the site of measurement (+/- accuracy of GPS unit), generic soils are identified with the nearest, or regional town.

Factors that influence PAWC

An important determinant of the PAWC is the soil's texture. The particle size distribution of sand, silt and clay determines how much water and how tightly it is held. Clay particles are small (<2 microns in size), but collectively have a larger surface area than sand particles occupying the same volume. This is important because water is held on the surface of soil particles which results in clay soils having the ability to hold more water than a sand. Because the spaces between the soil particles tend to be smaller in clays than in sands, plant roots have more difficulty accessing the space and the water is thus more tightly held in clay soils. This affects the amount of water a soil can hold against drainage (DUL) as well as how much of the water can be extracted by the crop (CLL).

The effect of texture on PAWC can be seen by comparing some of the APSoil characterisations from the GRDC northern region, as illustrated below (Figure 4). The soil's structure and its chemistry and mineralogy affect PAWC as well. For example, subsoil sodicity may impede internal drainage and subsoil constraints such as salinity, toxicity from aluminium or boron and extremely high-density subsoil may limit root exploration, sometimes reducing the PAWC bucket significantly.

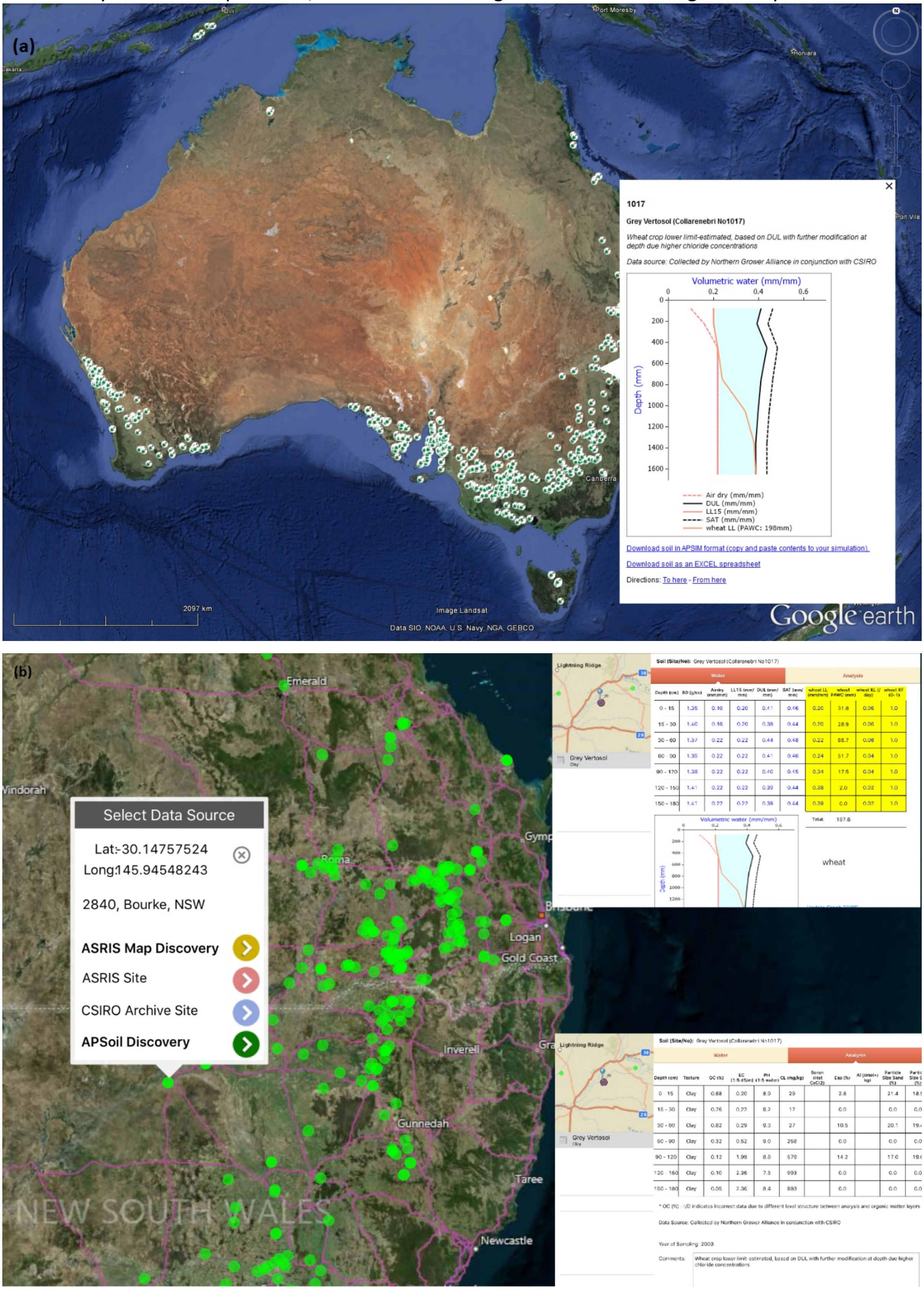


Figure 3. Access to geo-referenced soil PAWC characterisations of the APSoil database via (top) Google Earth and (bottom) SoilMapp (APSoil discovery screens as inserts).

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth (Figure 4b, c). Some APSoil characterisations only determined the CLL for a single crop. The CLL for deeper rooting crops are often considered the same, but care needs to be taken with such rules of thumb as different tolerances for subsoil constraints can cause variation between crops. A detailed explanation of the factors influencing PAWC is included in the *Soil Matters – Monitoring soil water and nutrients in dryland farming* book by Dalgliesh and Foale (1998).

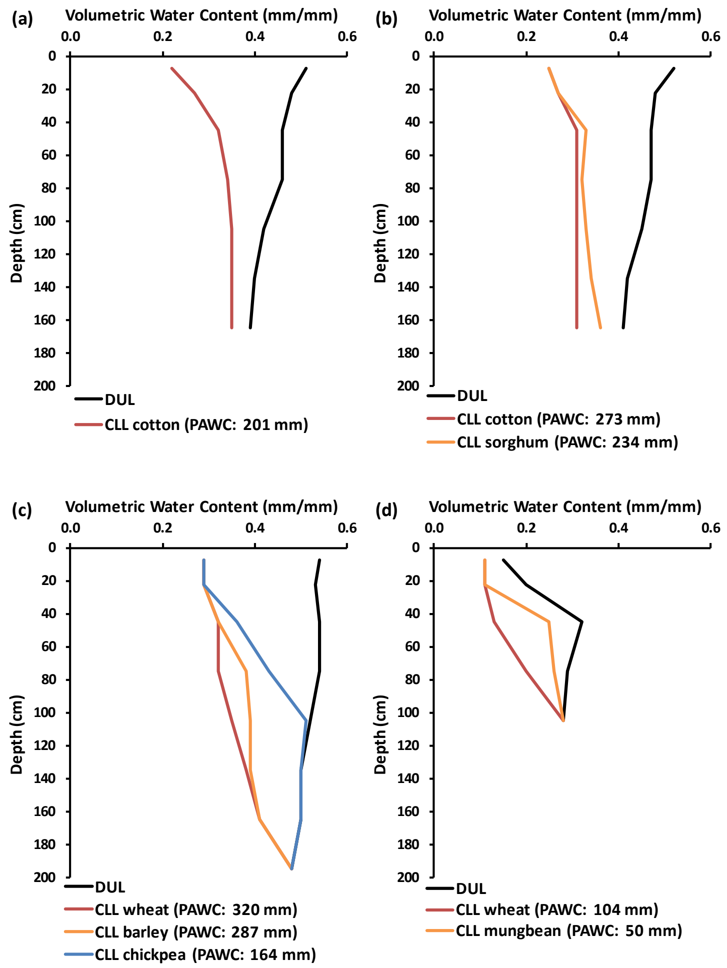


Figure 4. Selected soil PAWC characterisations from the central Darling Downs

(a,b) Variation within the broad level recent alluvial plains (LRA unit 1a) stems from the mixed basaltic and sandstone origin of the alluvium and from particle size of the sediments in response to position within the plains. The Condamine soil is a deep, coarse structured black cracking clay adjacent to the Condamine river. It has coarse sand and gravel throughout and moderate to high subsoil salinity, both of which limit PAWC to about 150-200 mm, as seen in the example of APSoil 8 from near Yandilla, Qld (a). The Anchorfield black cracking clay has a finer structure which is reflected in its larger PAWC (usually >250 mm) as illustrated by APSoil 6 from near Brookstead (b).

(c) The Waco soil is more common in the broad level older alluvial plains of basaltic alluvium. The high clay content of these soils along with the smectite clay minerals contributed by the basaltic origin are responsible for the severe cracking and self-mulching nature of these soils and their large PAWC (APSoil site 16 near Jimbour, Qld).

(d) The undulating to steep, low hills and rises of Walloon sandstone of the Brigalow Uplands (LRA unit 6b) are characterised by grey-brown cracking clays with brown sands over brown clays. The Diamondy soil of APSoil site 88 near Jinghi, Qld is a texture contrast soil with a hardsetting surface and impermeable subsoil. The lower PAWC (50-100 mm) is in response to the limited depth, lower water holding capacity of the sandy surface layer and sodicity and salinity at depth.

Linking central Darling Downs soil-landscapes to PAWC

When it is not feasible to measure PAWC locally, one can try to estimate it by extrapolating from existing characterisations. This is not an easy task. The nearest PAWC characterisation may not be the most appropriate as its soil properties could be quite different. The presence or level of subsoil constraints may vary too. The challenge is therefore, to find a PAWC characterisation for a soil with similar properties.

The soil properties that affect PAWC (texture, stones and gravel, chemical constraints) change within the landscape as a function of parent material and how the soil formed, or how soil material got there. These aspects are reflected in soil-landscape models that underpin soil survey maps. In the Central Darling Downs, soil and land mapping spanning the 1960s to 1990s have been drawn from, along with new survey, to create land resource area (LRA) mapping and associated documentation, including an overview of the soils and landscapes from a land and farming capability/limitations perspective (Harris et al., 1999b), the landscape and soils within them ("Field Manual", Harris et al., 1999a) and soil chemistry (Biggs et al.,1999) (see Resources section). Combined, the references describe the local soils and how they fit within the landscape.

The current project is testing whether we can draw on this information to predict PAWC or find a similar soil in the APSoil database. Below we illustrate for two transects how the soil properties change and are likely to affect PAWC.

The central Darling Downs is on southeast Queensland's western flanks of the Great Divide and covers an area of approximately 2M ha of the upper Condamine river catchment (Figure 5). The regional geology features basalt along the Great Divide that mostly overlays sandstones. The area forms a broad valley and the soil characteristics are governed by source materials (sediments, basalt, sometimes granites) and the sequence of weathering, erosion and redistribution, i.e. the history of soil development. The alluvial soils in the broad valley floor are generally very fertile clays, as are the soils on the upper basalts (clays, and loams).

The central Darling Downs area contains 73 APSoil characterisations shown in Figure 5. These include the earliest APSoil described, and because techniques were still evolving, many lack the physical and chemical data that is standard in the current protocol described in the *PAWC Booklet*.

Generally speaking the soils are suited to dryland cropping by virtue of the rainfall and soil types, e.g. deep clay or loamy soils often resulting in very high PAWCs (>250 mm).

Early in the study a conceptual understanding of soil processes was drawn together in discussion with local experts (Qld. government, agricultural advisers, growers) and through a desktop evaluation of data including terrain, soil mapping, geology, APSoil profiles, etc.. Following, a soil survey was devised based on transects along ridge-to-valley bottom soil sequences (toposequences), typically 15-20 km long. Four soil survey sites were positioned along each transect, with one site at an APSoil site to 'calibrate' our PAWC understanding. The remaining three sites spread to cover soil-landscape variations (Figure 5).

Soil samples were analysed for physical and chemical properties, and site and profile characteristics recorded (e.g. depth to bedrock, coarse fragments, rooting depth).

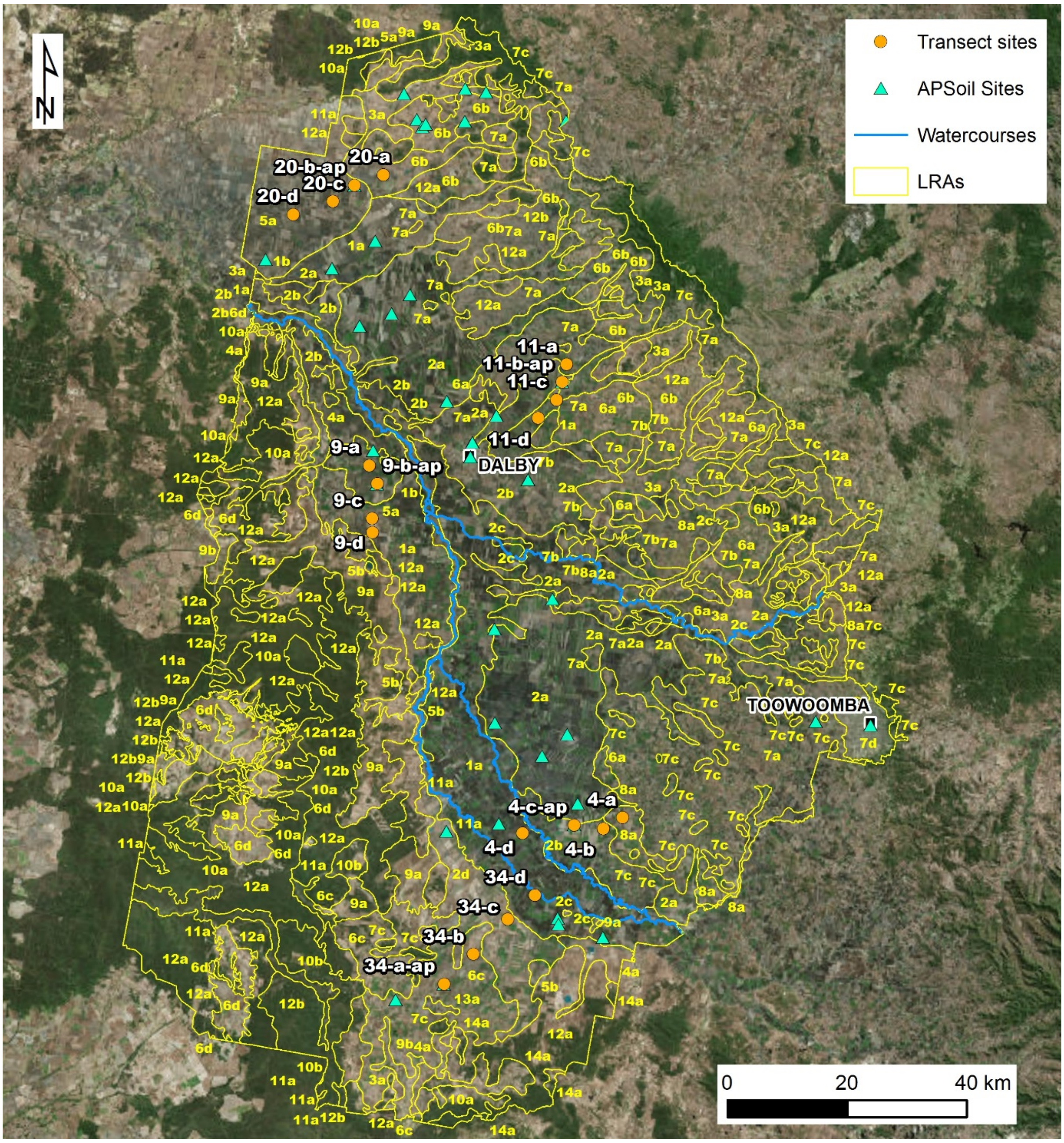


Figure 5. Survey transects and sampling points (orange dots) overlaid on LRA mapping

Using soil landscape information to help estimate PAWC

The current project is testing whether we can draw on the information that is available to growers in the Central Darling Downs information (e.g. from APSoil, SoilMapp, LRA mapping, etc.) to predict PAWC or find a similar soil in the APSoil database. The steps below indicate how this may be done. We illustrate the steps using one/two soil sampling transects undertaken in our project. The initial steps reflect those in the LRA *Field Manual*.

Step 1: Find the LRA for your site of interest.

a) A map of LRA is available through the Queensland Globe: https://qldglobe.information.qld.gov.au/. In this online mapping tool, select 'Add Layers', then choose 'Land resource area mapping' under 'Geoscientific information' and zoom into the area of interest.

b) Compare the LRA unit number with its description in Table 2.1 of the *Field Manual* and the diagrams of the relationships between different LRAs in Figure 2.2 of the *Field Manual* to confirm this LRA provides a good description of the landscape position of the location of interest.

Step 2: Consider the main differences between soils that are found within this LRA. Table 2.1 of the *Field Manual* lists the major soil types and indicative positions within the LRA are given in Figure 2.3 of the *Field Manual*.

Step 3: Considering the position in the landscape (e.g. higher or lower on hill slope, location on levee or in depression) as well as soil observations such as depth to bedrock, stones and gravel, rooting depth, pH, salinity, sodicity, identify the likely soil type and compare with the description of this soil type in the back of the *Field Manual*. Rooting depth is an important observation because it indicates the limits of root exploration in the soil caused by limiting constraints, regardless of the type or combination of constraints.

Step 4: Most APSoils in the area have been classified using the soil type classification in the *Field Manual*. In addition to this source of reference, Table 1 provides a means to identify likely APSoil profiles for several the soil types in the area. Work is in progress to extend this list. Where a soil type does not have a matching APSoil, use the PAWC range from the *Field Manual* as a starting point for selection of possible APSoils.

Step 5: Use observations on rooting depth that will reflect any subsoil constraints to adjust the PAWC. In this preliminary approach pending refinement, the PAWC should be adjusted by using the rooting depth observations if available, or failing this, a reasoned estimate of root depth in the soil. The reasoned approach may draw on past cropping performance of the soil, or observations made in similar soils. The adjustment takes into consideration the crop root architecture, which is likely to diminish in density in response to the type of response; a chemical constraint (e.g. pH, salinity) is likely to progressively strengthen with depth and cause roots to peter out, so the adjustment to the "bucket" should be non-linear with depth. For example, for a saline-constrained soil where roots are observed to 100 cm, and the *Field Manual* indicates a PAWC of 200 mm for 150 cm (maximum depth) non-constrained profile, the adjusted PAWC would not be a 30% (100 versus 150 cm) but rather 50% of the full potential, i.e. 100 mm PAWC. For a depth-constrained profile where the roots meet an abrupt stop (e.g. at bedrock), the adjustment should subtract the proportion of 'missing' subsoil depth given indicatively in the *Field Manual* for the soil. For soil containing stones or gravels, yet the profile depth matches the *Field Manual*, the PAWC adjustment should account for the proportion of stones and gravels.

The above provides a *first* estimate of PAWC. It is likely to require further refinement over time as yield predictions based on the PAWC are compared with achieved yields.

The project has undertaken sampling along five transects in the Central Darling Downs to evaluate the above approach. Below we present two of the transects to illustrate the steps above. The transect figures show the sites projected on the survey slope, the LRA boundaries, whether salinity or sodicity were measured in the soil, course (>2 mm) fragments, indicative PAWC range for the LRA (from *Field Manual*), and the APSoil PAWC (wheat) if co-located with the site. In line with Step 3, the soil analyses, and site and landscape observations enabled each site along the transect to be matched to a soil type from the *Field Manual* and the PAWC adjusted if the data dictated. One site in each transect was located as close to an existing APSoil site to reference the PAWC.

Transect 4 (Figure 6) is 20 km long and in the southern part of the Central Darling Downs. It traverses LRA 8a "Poplar Box Walloons" formed on fine grained Walloon sandstone and has a gently sloping relief featuring undulating rises and low hills. The major soils are self-mulching, black cracking clays. This LRA gently transitions to LRA 2b "Older Alluvial Plains" on older, broad level plains of mixed basaltic and sandstone alluvium. Major soils for LRA 2b are grey cracking clays. The transect finishes at the base of the hillslope with LRA 1a, which is formed on recent, broad alluvial plains, again of mixed basaltic and sandstone origins. Common soils include black and grey cracking clays or texture

Table 1. Selected soils from the Central Darling Downs and possible APSoil profile candidates

Soil Type[1]	**LRAs[2]**	**PAWC range (mm)[3]**	**APSoil profiles**
Black Vertosol Anchorfield	1a, 1b, 2a	> 250	6, 7 (observed in 1a)
Grey Vertosol Cecilvale	1a, 1b, 2a, 2b, 2c, 3a,	200-250	17, 115 (observed in 1a) 10 (observed in 5a)
Black Vertosol Condamine	1a, 1b, 3a	150-200	8 (observed in 1a)
Black Vertosol Mywybilla	1a, 2a, 2b, 2c,	>250	1 (observed in 2a)
Black Vertosol Waco	1a, 2a, 2b, 2c, 7a, 7c	> 250	3, 1012, 14, 16 (observed in 2a) 30 (observed in 7a)
Brown Vertosol Millmerran	2d, 3a, 4a,	100-150	74 (observed in 3a)
Brown Sodosol Downfall	1a, 2b, 2d, 3a, 9a, 11,	100-150	69 (observed in 3a)
Grey Vertosol Kupunn	5a, 5b	200-250	9, 19, 20 (observed in 5a)
Grey Vertosol Moola	6a, 6b, 6c,	100-150	73 (observed in 6b, Mungbean only)
Grey Sodosol Walker	6a, 6c	100-150	72 (observed in 6b, Mungbean only)
Brown Sodosol Diamondy	6b	50-100	88 (observed in 6b)

[1] from local soil classification in the *Field Manual*; [2] as a main soil type; 3 from *Field Manual*

contrast bleached sands or loams over brown or black clays. The four sites in the transect are 4a (LRA 8a), 4b and 4c (LRA 2b) and 4d (LRA 1a).

The soils associated with each of the LRAs that were crossed are presented in the table in the Appendix, which also shows the site match to soil type. Site 4a is an Elphinstone soil on slopes (2-6%) of gently undulating plains and rises and consists of deep (100-150 cm) self-mulching black cracking clay that grades to brownish and yellowish and is formed on fine grained sandstone. At depth it can be highly sodic and saline and the PAWC is moderate (100-150 mm). Site 4b matches the Waco soil on gently sloping to flat alluvial plains. This soil comprises deep to very deep (100-180 cm), fine, self-mulching, dark cracking clay becoming browner at depth and formed on basaltic alluvium. It may be sodic and saline at depth. The unconstrained PAWC is very high (>250 mm). Lower in the landscape, site 4c is a Mywybilla soil on gently sloping to flat alluvial plains. The PAWC may be very high (>250 mm). This site is near APSoil # 4, which has a PAWC recorded as 281 mm and consistent with the *Field Manual*. Finally, 4d matches the Waco soil (gently sloping to flat alluvial plains), and with a very high PAWC (>250 mm). Roots were seen over the full length of all four profiles, meaning that none were constrained and so likely to reflect the PAWCs allocated to each soil in the *Field Manual*.

Transect 11 is 12 km long (Figure 7) and in the northern part of Central Darling Downs on the south-facing range. It firstly traverses LRA 7a, “Basaltic Uplands”, which comprises undulating rises and rolling low hills. The major soils of the LRA include grey-brown and brown clays or clay loams. Lower in the landscape it cuts across LRA 2a of “Older Alluvial Plains” and occupies broad level plains of basaltic alluvium. The major soils include black, self-mulching cracking clays. The transect then moves into LRA 1a, “Recent Alluvial Plains”. The LRA is also featured in Transect 4 and is part of the same valley system, so, again, is formed on recent, broad alluvial plains of mixed basaltic and sandstone origins. Common soils include black and grey cracking clays or texture contrast bleached sands or loams over brown or black clays. The four sites in the transect are 11a (LRA 7a), 11b (LRA 2a), 11c and 11d in LRA 1a.

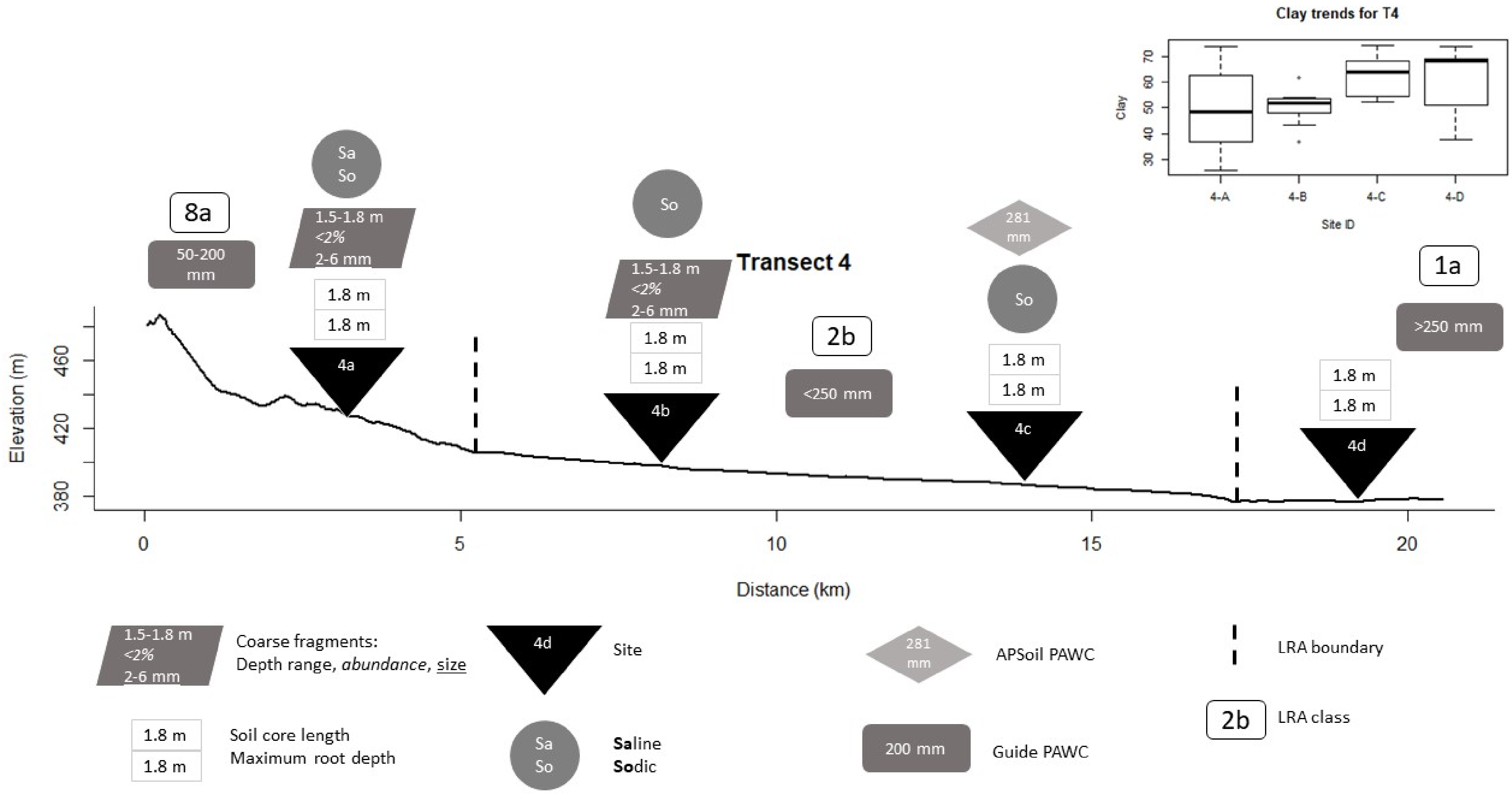

Clay trends for T4
Clay
Site ID
4-A
4-B
4-C
4-D
Transect 4
8a
50-200 mm
Sa
So
1.5-1.8 m
<2%
2-6 mm
1.8 m
1.8 m
4a
4b
4c
4d
2b
<250 mm
281 mm
1a
>250 mm
Elevation (m)
Distance (km)
Coarse fragments:
Depth range, abundance, size
Site
APSoil PAWC
LRA boundary
Soil core length
Maximum root depth
Saline
Sodic
200 mm
Guide PAWC
LRA class

Figure 6. Transect 4 sites positioned on terrain with accompanying LRA boundaries, coarse fragments, profile and root depth, saline and sodic conditions, APSoil PAWC and clay %

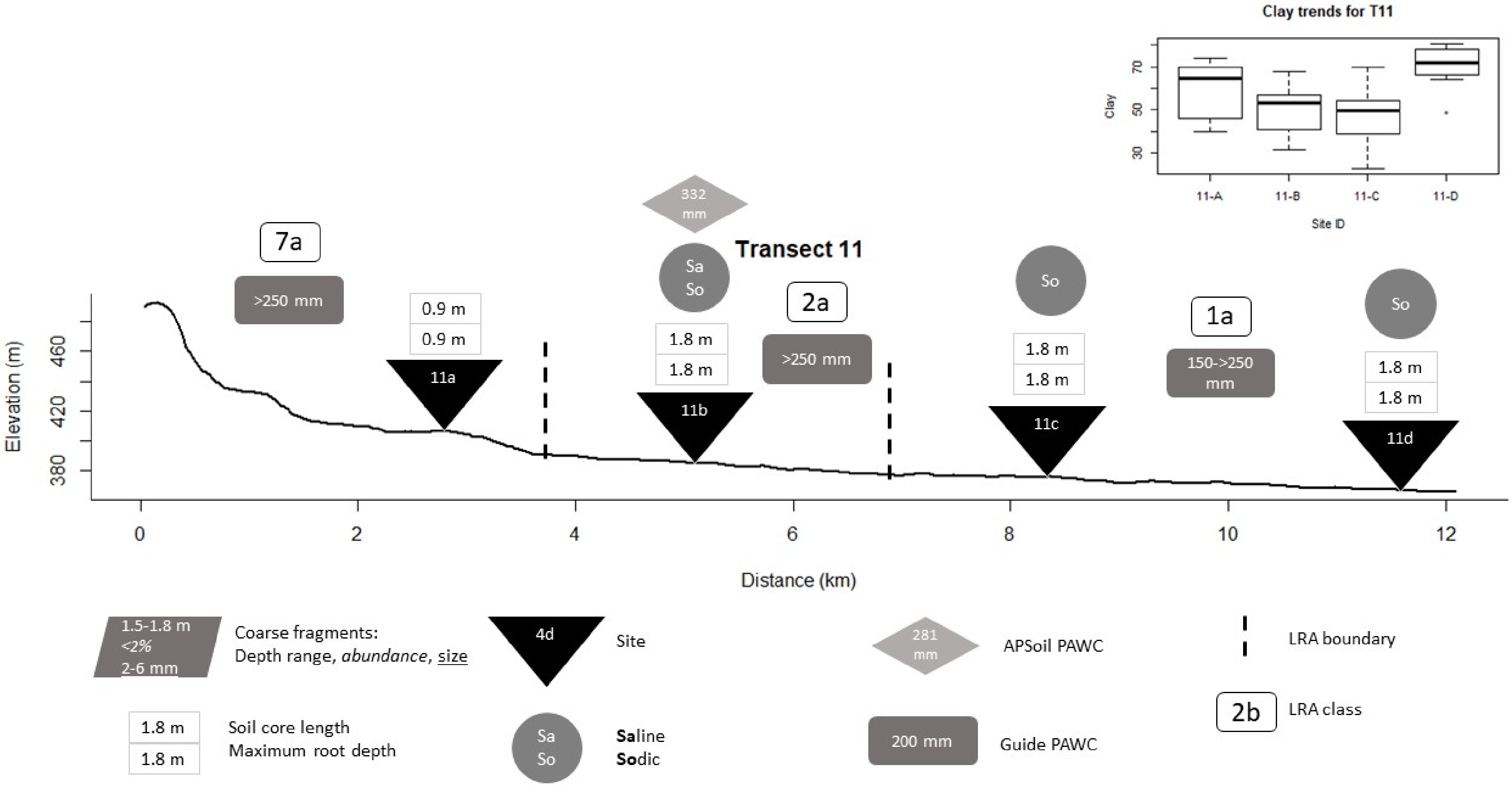

Clay trends for T11
Clay
Site ID
11-A
11-B
11-C
11-D
Transect 11
7a
>250 mm
0.9 m
0.9 m
11a
332 mm
Sa So
1.8 m
1.8 m
11b
2a
>250 mm
So
1.8 m
1.8 m
11c
1a
150->250 mm
So
1.8 m
1.8 m
11d
Elevation (m)
Distance (km)
1.5-1.8 m
<2%
2-6 mm
Coarse fragments:
Depth range, *abundance*, size
4d
Site
281 mm
APSoil PAWC
LRA boundary
2b
LRA class
1.8 m
1.8 m
Soil core length
Maximum root depth
Sa So
Saline
Sodic
200 mm
Guide PAWC

Figure 7. Transect 11 sites positioned on terrain with accompanying LRA boundaries, coarse fragments, profile and root depth, saline and sodic conditions, APSoil PAWC and clay %

The soils associated with the LRAs covered by transect 11 are presented in the Appendix. Site 11a is a Burton soil on long gentle slopes and broad flat basalt ridges and features moderately deep to deep (75-150 cm) non-cracking red-brown to red clay. The PAWC is moderate (100-150 mm), and given the observed soil depth was 90 cm, the PAWC is likely to be ~110 mm after adjustment. Site 11b is a Waco soil on gently sloping to flat alluvial plains. This soil is deep to very deep (100-180 cm), fine, self-mulching, dark cracking clay becoming browner at depth and formed on basaltic alluvium, and may be sodic and saline at depth. PAWC from the *Field Manual* is very high (>250 mm) and consistent with the APSoil PAWC near the site (# 11; 332 mm). Roots were seen all the way through the soil. Sites 11c and 11d match the Anchorfield soil on gently sloping to flat alluvial plains. This is a self-mulching, dark clay becoming grey, yellow or brown at depth. The soil may be sodic and moderately to highly saline at depth and the unconstrained PAWC can be very high (>250 mm). Roots were noted throughout both soil profiles so the PAWC at the site was not constrained.

Conclusions

Plant Available Water Capacity (PAWC) is an important soil parameter that assists dryland growers in particular to plan and manage their crops. PAWC data for over 1100 Australian soils are freely available to growers through the APSoil database, Google Earth or SoilMapp for iPad. However, not every soil is covered so that most growers need to use the resources available to match their soil to APSoil. These resources include soil and land mapping and reports that can lead the farmer to make a strong match. This paper illustrates one such approach being tested in the Central Darling Downs that applies a knowledge of the soils in the landscape, how they were formed and their distributions. Once the match between the soil of interest and the PAWC from APSoil or other resources has been made, the PAWC for the soil of interest can be adjusted based on the depth of roots observed in the soil profile, which is an indicator of depth to PAWC constraining factors, if any.

Work is currently underway to develop and evaluate digital soil maps. These are maps that predict soil properties on a 90 m x 90 m grid (http://www.clw.csiro.au/aclep/soilandlandscapegrid/). This provides the opportunity to map within LRA unit variability, but this is still research in progress.

Resources

Queensland soils and others

LRA (and other) mapping available through the Queensland Globe: https://qldglobe.information.qld.gov.au/ (Select 'Add Layers', then choose 'Land resource area mapping' under 'Geoscientific information' and zoom into the area of interest)

LRA manuals from: https://publications.qld.gov.au/dataset?q=land+managament+manual

APSoil, PAWC characterisation protocols

The APSoil database is freely available here: http://www.apsim.info/Products/APSoil.aspx includes link to Google Earth file)

GRDC PAWC booklet: GRDC PAWC booklet: https://grdc.com.au/resources-and-publications/all-publications/publications/2013/05/grdc-booklet-plantavailablewater

Soil Matters book: http://www.apsim.info/Portals/0/APSoil/SoilMatters/pdf/Default.htm

SoilMapp: for Apple iPad devices, see www.csiro.au/soilmapp and links to Apple App Store

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers throughout the Central Darling Downs - especially those allowing entry on their land the generous spend time with us in discussion. Our thanks also go for the good discussions we have had with Drs Andrew Biggs and Mark Silburn from the Queensland Government Department of Natural Resources and Mines.

References

Biggs, A.J.W., Coutts, A.J., Harris, P.S. (Eds.), (1999) Central Darling Downs Land Management Manual - Soil Chemical Data Book, DNRQ990102. Government of Queensland, Coorparoo, Qld, 107 pp.

Dalgliesh, N. and Foale, M.A., (1998) Soil Matters: Monitoring Soil Water and Nutrients in Dryland Farming. CSIRO Tropical Agriculture, Agricultural Production Systems Research Unit, Toowoomba, Qld.

Harris, P.S., Biggs, A.J.W., Coutts, A.J. (Eds.), (1999a) Central Darling Downs Land Management Manual - Field Manual, DNRQ990102. Government of Queensland, Coorparoo, Qld, 191 pp.

Harris, P.S., Biggs, A.J.W., Stone, B.J., Crane, L.N., Douglas (Eds.), (1999b) Central Darling Downs Land Management Manual - Resource Information Book, DNRQ990102. Government of Queensland, Coorparoo, Qld, 321 pp.

Contact details

Mark Thomas
CSIRO Agriculture and Food
Waite Road, Urrbrae, SA 5064
Ph: 08 8303 8471
Email: mark.thomas@csiro.au

Appendix

Table 2. Transect 4 Land Resource Areas and component soils (descriptions adapted from the Field Manual; Harris et al. 1999a).

LRA	**Site**	**Soil type** d = dominant s = subdominant	**Setting**	**Description**	**PAWC**
LRA 8a "Poplar Box Walloons" on fine grained Walloon sandstone	4a	Elphinstone (d)	slopes (2-6%) of gently undulating plains and rises	deep (100-150 cm) self-mulching black cracking clay that grades to brownish and yellowish and formed on fine grained sandstone. At depth it can be highly sodic and saline	moderate (100-150 mm)
		Talgai (s)	slopes (3-6% and hilltops and dissected low sandstone hills	black or grey cracking clay with brown clay subsoils, sodic and moderately saline at depth	moderate (100-150 mm)
		Charlton (s)	mid to upper slopes on basalt rises and low hills	coarse self-mulching black cracking clay on basalts	moderate (100-150 mm)
		Purrawunda (s)	mid to lower slopes (4-8%) of basalt rises and low hills, and on broad basalt crests	fine self-mulching, brown black cracking clay on basalt	moderate (100-150 mm)
		Toolburra (s)	gently undulating to undulating broad sandstone ridges	moderately deep to deep, red-brown cracking light clay	moderately high (150-200 mm)
		Kenmiur (s)	steep slopes and scarps and crests of flat-topped and rounded low hills, including basalt	very shallow gravelly or stony brown loam or clay loam	very low PAWC (<50 mm)
		Walker (d)	upper slopes of undulating sandstone rises	moderately deep to deep texture contrast soil with a dark brown to grey-brown loam sandy loam to clay loam over dark brown to dark grey-brown clay; highly sodic and saline at depth	moderate (100-150 mm)

LRA	Site	Soil type d = dominant s = subdominant	Setting	Description	PAWC
LRA 2b "Older Alluvial Plains" on older, broad level plains of mixed basaltic and sandstone alluvium		Cecilvale (d)	elevated plains of mixed alluvium	deep crusting, grey cracking clay. It may be strongly sodic, becoming strongly saline at depth	high (200-250 mm)
	(4c)	Mywybilla (s)	gently sloping to flat alluvial plains	deep to very deep self-mulching dark clay with a subsoil that is black or very dark grey grading to light brownish grey heavy clay. It can be sodic and moderately saline at depth	very high (>250 mm)
	(4b)	Waco (s)	gently sloping to flat alluvial plains	deep to very deep (100-180 cm), fine, self-mulching, dark cracking clay becoming browner at depth and formed on basaltic alluvium, may be sodic and saline at depth	very high (>250 mm)
		Downfall (s)	flat plains and very gently sloping (<1%) valley floors of mixed alluvium	found on the back plain and is a hardsetting loam over brown clay on sandstone becoming, and increasingly sodic and saline at depth	moderate (100-150 mm)
		Oakley (s)	flat plains, very gently sloping valley floors (<2%)	thin reddish brown hardsetting loamy surface, and red-brown clay subsoils of mixed origin. Can be moderately saline	moderate (100-150 mm)
LRA 1a "Recent Alluvial Plains" on broad level plains of mixed basaltic and sandstone alluvium		Condamine (d)	along active river floodplains, terraces and stream banks	deep to very deep (80-100 cm) coarse self-mulching black cracking clay. The soil may be sodic and highly saline at depth	moderately high (150-200 mm)
		Mywybilla (d)	gently sloping to flat alluvial plains	deep to very deep self-mulching dark clay with a subsoil that is black or very dark grey grading to light brownish grey heavy clay. It can be sodic and moderately saline at depth	very high (>250 mm)
		Anchorfield (d)	gently sloping to flat	a self-mulching, dark clay becoming grey, yellow or	very high (>250

LRA	Site	Soil type d = dominant s = subdominant	Setting	Description	PAWC
			alluvial plains	brown at depth. The soil may be sodic and moderately to highly saline at depth	mm)
		Haslemere (d)	slight rises on the Condomine River floodplain	deep texture contrast soil with thin (<20 cm) bleached sandy loam to clay loam surface over black clay subsoils, on alluvia of mixed origin. It can be highly saline	low (50-100 mm)
	4d	Waco (s)	gently sloping to flat alluvial plains	deep to very deep (100-180 cm), fine, self-mulching, dark cracking clay becoming browner at depth and formed on basaltic alluvium, may be sodic and saline at depth	very high (>250 mm)
		Cecilvale (s)	elevated plains of mixed alluvium	deep crusting, grey cracking clay. It may be strongly sodic, becoming strongly saline at depth	high (200-250 mm)
		Downfall (s)	flat plains and very gently sloping (<1%) valley floors of mixed alluvium	found on the back plain and is a hardsetting loam over brown clay on sandstone becoming, and increasingly sodic and saline at depth	moderate (100-150 mm)
		Combidiban (s)	low sandy banks in flat to gently undulating alluvial plains	a deep texture contrast soil with yellow, grey or brown sandy clay subsoils. Located on low sandy banks on alluvial plains and is sodic at depth	small (<50 mm)

Table 3. Transect 11 Land Resource Areas and component soils (descriptions adapted from the Field Manual; Harris et al. 1999a).

LRA	Site	Soil type d = dominant s = subdominant	Setting	Description	PAWC
LRA 7a, “Basaltic Uplands” on undulating rises and rolling low hills		Craigmore (d)	mid to lower slopes of basalt rises and hills	deep to very deep (100-180 cm) self-mulching cracking clay with distinct red-brown subsoil	very high (>250 mm)
		Irving (d)	mid to lower slopes of low basalt hills	deep to very deep (100-180 cm) fine self-mulching cracking clay with brown or reddish brown subsoils o	very high (>250 mm)
		Charlton (d)	mid to upper slopes on basalt rises and low hills	coarse self-mulching black cracking clay	moderate (100-150 mm)
		Purrawunda (d)	mid to lower slopes (4-8%) of basalt rises and low hills, and on broad basalt crests	fine self-mulching, brown black cracking clay	moderate (100-150 mm)
		Kenmiur (d)	steep slopes and scarps and crests of flat-topped and rounded low hills, including basalt	very shallow gravelly or stony brown loam or clay loam	very low PAWC (<50 mm)
		Beauaraba (s)	upper slopes on low basalt hills and crests	very shallow, very dark cracking clay	low (<50 mm)
		Aubigny (s)	gently undulating low basalt hills and rises	shallow to moderately deep (30-70 cm), non-cracking reddish brown clay	low (<50 mm)
		Southbrook (s)	upper slopes, benches and flat-topped ridges of basalt rises and low hills	moderately deep (50-100 cm) non-cracking clay on basalt	moderate (50-150 mm)
		Mallard (s)	upper slopes and broad flat basalt ridges	very shallow to shallow (20-40 cm) brown to grey-brown clay loam over brown and red clay	low (<50 mm)
	11a	Burton (s)	long gentle slopes and	moderately deep to deep (75-150 cm) non-cracking red-	moderate (100-

LRA	Site	Soil type d = dominant s = subdominant	Setting	Description	PAWC
			broad flat basalt ridges	brown to red clay	150 mm
		Aberdeen (s)	in marginal areas between dark cracking clays and red soils	moderately deep to deep (50-130 cm) reddish brown coarsely structure clay	very high (>250 mm)
		Yargullen (s)	lower slopes, valley floors and alluvial fans from basalt	moderately deep (50-130 cm) black heavy clay	low (50-100 mm)
2a "Older Alluvial Plains" on broad level plains of basaltic alluvium	11b	Waco (d)	gently sloping to flat alluvial plains	deep to very deep (100-180 cm), fine, self-mulching, dark cracking clay becoming browner at depth and formed on basaltic alluvium, may be sodic and saline at depth	very high (>250 mm)
		Anchorfield (s)	gently sloping to flat alluvial plains	a self-mulching, dark clay becoming grey, yellow or brown at depth. The soil may be sodic and moderately to highly saline at depth	very high (>250 mm)
		Mywybilla (s)	gently sloping to flat alluvial plains	deep to very deep self-mulching dark clay with a subsoil that is black or very dark grey grading to light brownish grey heavy clay. It can be sodic and moderately saline at depth	very high (>250 mm)
		Cecilvale (s)	elevated plains of mixed alluvium	deep crusting, grey cracking clay. It may be strongly sodic, becoming strongly saline at depth	high (200-250 mm)
		Yargullen (s)	lower slopes and valley floors	moderately deep black heavy clay with fine to moderate granular surface of soft white carbonate. Strong alkalinity.	low (50-100 mm)
LRA 1a "Recent Alluvial Plains" on broad level plains of mixed basaltic and sandstone alluvium		Condamine (d)	along active river floodplains, terraces and stream banks	deep to very deep (80-100 cm) coarse self-mulching black cracking clay. The soil may be sodic and highly saline at depth	moderately high (150-200 mm)
		Mywybilla (d)	gently sloping to flat	deep to very deep self-mulching dark clay with a subsoil	very high (>250

LRA	Site	Soil type d = dominant s = subdominant	Setting	Description	PAWC
			alluvial plains	that is black or very dark grey grading to light brownish grey heavy clay. It can be sodic and moderately saline at depth	mm)
	11c, 11d	Anchorfield (d)	gently sloping to flat alluvial plains	self-mulching, dark clay becoming grey, yellow or brown at depth. The soil may be sodic and moderately to highly saline at depth	very high (>250 mm)
		Haslemere (d)	slight rises on the Condomine River floodplain	deep texture contrast soil with thin (<20 cm) bleached sandy loam to clay loam surface over black clay subsoils, on alluvia of mixed origin. It can be highly saline	low (50-100 mm)
		Waco (s)	gently sloping to flat alluvial plains	deep to very deep (100-180 cm), fine, self-mulching, dark cracking clay becoming browner at depth and formed on basaltic alluvium, may be sodic and saline at depth	very high (>250 mm)
		Cecilvale (s)	elevated plains of mixed alluvium	deep crusting, grey cracking clay. It may be strongly sodic, becoming strongly saline at depth	high (200-250 mm)
		Downfall (s)	flat plains and very gently sloping (<1%) valley floors of mixed alluvium	found on the back plain and is a hardsetting loam over brown clay on sandstone becoming, and increasingly sodic and saline at depth	moderate (100-150 mm)
		Combidiban (s)	low sandy banks in flat to gently undulating alluvial plains	a deep texture contrast soil with yellow, grey or brown sandy clay subsoils. Located on low sandy banks on alluvial plains and is sodic at depth	small (<50 mm)

KEY CONTACTS

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

NORTHERN REGION

TOOWOOMBA
214 Herries Street
TOOWOOMBA, QLD 4350

P:+61 7 4571 4800
northern@grdc.com.au

OPERATIONS GROUP

SENIOR REGIONAL MANAGER
Gillian Meppem
Gillian.Meppem@grdc.com.au
M: +61 4 0927 9328

CONTRACT ADMINISTRATOR AND PANEL SUPPORT
Tegan Slade
Tegan.Slade@grdc.com.au
M: +61 4 2728 9783

CONTRACT AND TEAM ADMINISTRATOR
Brianna Robins
Brianna.Robins@grdc.com.au
P: +61 7 4571 4800

APPLIED RESEARCH AND DEVELOPMENT GROUP

SENIOR MANAGER CROP PROTECTION (NATIONAL)
Emma Colson
Emma.Colson@grdc.com.au
M: +61 4 5595 8283

SENIOR MANAGER AGRONOMY, SOILS, NUTRITION AND FARMING SYSTEMS (NATIONAL)
Michael Bange
Michael.Bange@grdc.com.au
M: +61 4 4876 6881

MANAGER AGRONOMY, SOILS, NUTRITION AND FARMING SYSTEMS
Kaara Klepper
Kaara.Klepper@grdc.com.au
M: +61 4 7774 2926

MANAGER AGRONOMY, SOILS, NUTRITION AND FARMING SYSTEMS
John Rochecouste
John.Rochecouste@grdc.com.au
M: +61 4 7774 2924

MANAGER CHEMICAL REGULATION (NATIONAL)
Gordon Cumming
Gordon.Cumming@grdc.com.au
M: +61 4 2863 7642

CROP PROTECTION MANAGER
Vicki Green
Vicki.Green@grdc.com.au
M: +61 4 2904 6007

CONTRACT ADMINISTRATOR
Linda McDougall
Linda.McDougall@grdc.com.au
M: +61 4 7283 2502

GENETICS AND ENABLING TECHNOLOGIES GROUP

NATIONAL VARIETY TRIALS OFFICER
Laurie Fitzgerald
Laurie.Fitzgerald@grdc.com.au
M: +61 4 5595 7712

GROWER EXTENSION AND COMMUNICATIONS GROUP

SENIOR MANAGER EXTENSION AND COMMUNICATION (NATIONAL)
Luke Gaynor
Luke.Gaynor@grdc.com.au
M: +61 4 3666 5367

GROWER RELATIONS MANAGER
Richard Holzknecht
Richard.Holzknecht@grdc.com.au
M: +61 4 0877 3865

GROWER RELATIONS MANAGER
Susan McDonnell
Susan.McDonnell@grdc.com.au
M: +61 4 3662 2649

COMMUNICATIONS MANAGER
Toni Somes
Toni.Somes@grdc.com.au
M: +61 4 3662 2645

BUSINESS AND COMMERCIAL GROUP

MANAGER COMMERCIALISATION
Chris Murphy
Chris.Murphy@grdc.com.au
M: +61 4 2277 2070