GUNNEDAH
NEW SOUTH WALES
TUESDAY 24TH JULY 2018

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

grdc.com.au

Contents

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

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

® Registered trademark

Yield gaps - how much yield potential is left behind by better growers on the Liverpool Plains and why? Identifying areas to capture lost yield and profit

Zvi Hochman[1], Airong Zheng[2], Marta Monjardino[3], Heidi Horan[1], David Gobbett[3], Franz Waldner[1]

[1] CSIRO Agriculture & Food, St Lucia, Qld
[2] CSIRO Land and Water, Dutton Park Qld
[3] CSIRO Agriculture and Food, Glen Osmond, SA

Key words

Yield gap, wheat, management, biophysical factors, farm attributes, farmer attributes

GRDC code

CSA00055

Take home messages

- Average wheat yields between 2000 and 2014 for the Liverpool Plains (2.6 t/ha) are 2.3 t/ha below the water-limited yield potential for dryland wheat. On average, this is costing growers $575/ha
- A national survey of 232 growers included 45 respondents from the Liverpool Plains. Of the 45 Liverpool Plains respondents, only 3 fell into the lower half of the national relative yield group, confirming the high standing of growers from the Liverpool Plains.
- At Quirindi, applying 45 kg N/ha resulted in a 36% yield gap. Failure to control weeds during the summer fallow could account for up to 14% yield loss and low seedling density for a 9% yield loss. Even at 90 kg N/ha a 14% yield gap remains.
- An emerging practice of sowing early (26 April) with a late maturing variety and flexible N fertiliser application is expected to have the potential to increase the yield frontier by 19%.
- This emerging best practice has the potential to increase financial returns in the Liverpool Plains from about $1260/ha to about $1930/ha. While proven in other regions, this emerging practice defies local convention and deserves to be investigated in local fields by growers, consultants and researchers.

Introduction

It is well known that Australia's growers are among the best in the world and that Liverpool Plains growers are among the best in Australia. So why is the yield gap in the Liverpool Plains sub-region 47% of the yield potential? Between 2000 and 2014 average annual wheat yield (Ya) was 2.6 t/ha while the water–limited yield potential (Yw) was 4.9 t/ha. This means that there is a yield gap of 2.3 t/ha or $575 per ha (@250 $/t) that is not realised (www.yieldgapaustralia.com.au).

We ask why such a substantial yield gap exists and why some growers achieve their yield potential while others do not. We examined this in three different ways:

1. A grower survey that investigated how farms with large yield gaps differ from farms with low yield gaps by relating yield gaps to grower characteristics, farm characteristics and farm management practices.

2. A simulation study that examined the impact of sub-optimal management practices at 50 weather stations spanning the Australian grain zone.
3. An economic (risk-adjusted profit) analysis that explored the results from the simulation study.

Grower survey

The survey aimed to comprehensively examine farm management practices as well as farm and farmer characteristics that may contribute to the wheat yield gaps in Australia. Using the GRDC customer relation database we conducted telephone interviews of 232 wheat producers from 14 contrasting local areas (SA2s; roughly equivalent to a shire) in the Australian grain zone (Figure 1).

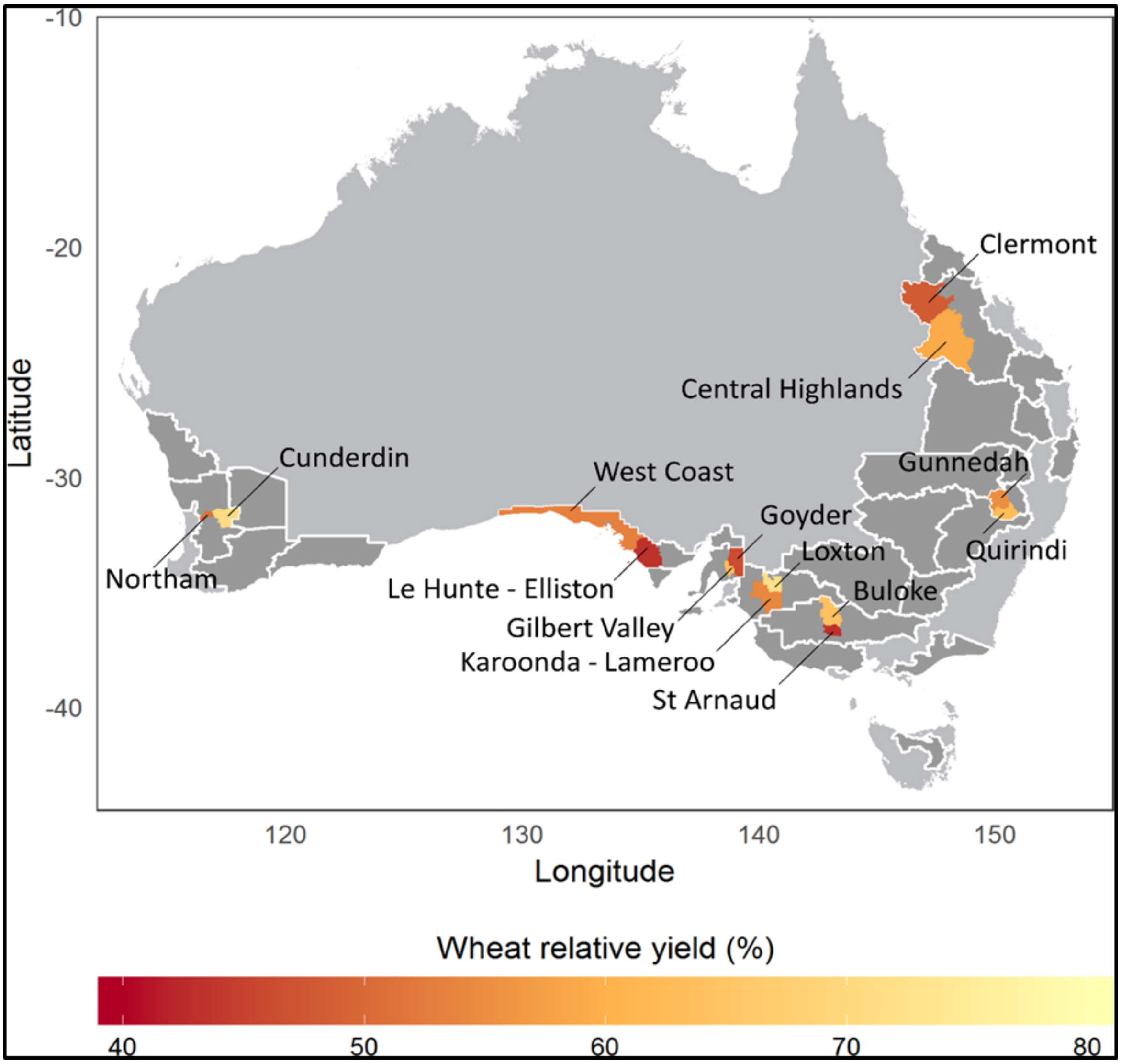


Figure 1. Locations of surveyed local statistical areas (SA2s) with contrasting average relative yields. The relative yield of wheat (% of water-limited yield potential) is indicated by the red-yellow colour gradient. The white borders shows the GRDC sub-regions of the Australian grain zone

The average participants' age was 51 years old (SD = 11, ranging from 20 to 89 years in age), with an average of 31 years (SD = 13) of experience in growing crops. Among the participants, there were only 10 female producers (4%). Seventeen participants (7%) identified as corporate farms while the rest identified as family farms. Thirty three participants (14%) owned or managed other farms in locations more than 50 km apart. The average cropping land area was 2,149 hectares (SD = 2,073).

The total area cropped by participants was 0.5 million hectares, or about 2% of Australia's cropped area.

Each farm's yield gap was calculated by comparing their reported wheat yield in 2016 against the water-limited yield potential, simulated under best management practices for their three dominant soil types, using weather data from all stations in their postcode. All farms were ranked according to their relative yields (Y% = 100 X Ya/Yw). The median relative yield was 64% and this value was used as a cut-off for dividing the respondents into two equal sized groups: the high relative yield (=small yield gap) group (mean Y% = 96%; SD = 20%) and the low relative yield (= large yield gap) group (mean Y% = 47%; SD = 12%). Hence, an average yield gap of 49% exists between these two groups. All survey responses were analysed to determine if there were significant differences in how the high and low relative yield groups responded.

The results revealed significant differences between farms with smaller yield gaps and those with greater yield gaps in relation to farming management, farm characteristics, and grower characteristics. Australian farms with smaller yield gaps (high relative yield) are more likely to be smaller holdings (high relative yield: Mean = 1886 ha, SD = 1993 vs low relative yield: Mean = 2395 ha, SD = 2127; p = .061), growing less wheat (high relative yield: Mean = 743 ha, SD = 880 vs low relative yield: M = 1171 ha, SD = 1111.2; p = .001) on more favourable soil types. These growers are more likely to apply considerably more N fertiliser to their wheat crop (Table 1), to grow a greater variety of crops, to soil-test a greater proportion of their fields, to have less area affected by herbicide-resistant weeds, and to be early adopters of new technology. They are less likely to grow wheat following either cereal crops or a pasture (Table 1). They are more likely to use and trust a fee-for-service agronomist, and to have a university education.

Table 1. Preceding crops before wheat crop and average nitrogen applied

	% of farms		**Nitrogen application**	
	High relative yield group (%)	**Low relative yield group (%)**	**High relative yield group M (SD) (kg N/ha)**	**Low relative yield group M (SD) (kg N/ha)**
A cereal crop	37***	65***	79 (51)*	57 (42)*
A canola crop	44	48	116 (146)**	58 (45)**
A pulse crop	62	53	75 (61)***	42 (34)***
A pasture phase	22***	44***	64 (58)**	30 (33)**

Note. The asterisk symbol indicates the statistical significance level of the differences between high and low relative yield groups, * $p < .05$, ** $p < .01$, *** $p < .001$.

Farms from the Liverpool Plains sub-region (Gunnedah and Quirindi SA2s) were massively over-represented in the high relative yields group with only 3 of the 45 respondents falling into the low relative yield (high yield gap) group. However, the large gap between highest and lowest yields reported for 2016 in the Liverpool Plains sub-region indicate that a significant yield gap still exists.

Simulation study

We conducted a simulation study on the impact of sub-optimal management practices at 50 weather stations that span the whole grain zone (Figure 2). A benchmark "best management practice" was defined by: zero tillage with clean fallows and stubble retained; a non-limiting supply of nitrogen to the crop; sowing at 150 plants/m² was activated between 26 April and 15 July when there were 30 mm of plant available water (PAW) and a 15 mm cumulative rain event occurred over any 3 consecutive days. Table 2 shows the average national impact, relative to water-limited yield potential (Yw), of selected sub-optimal management practices.

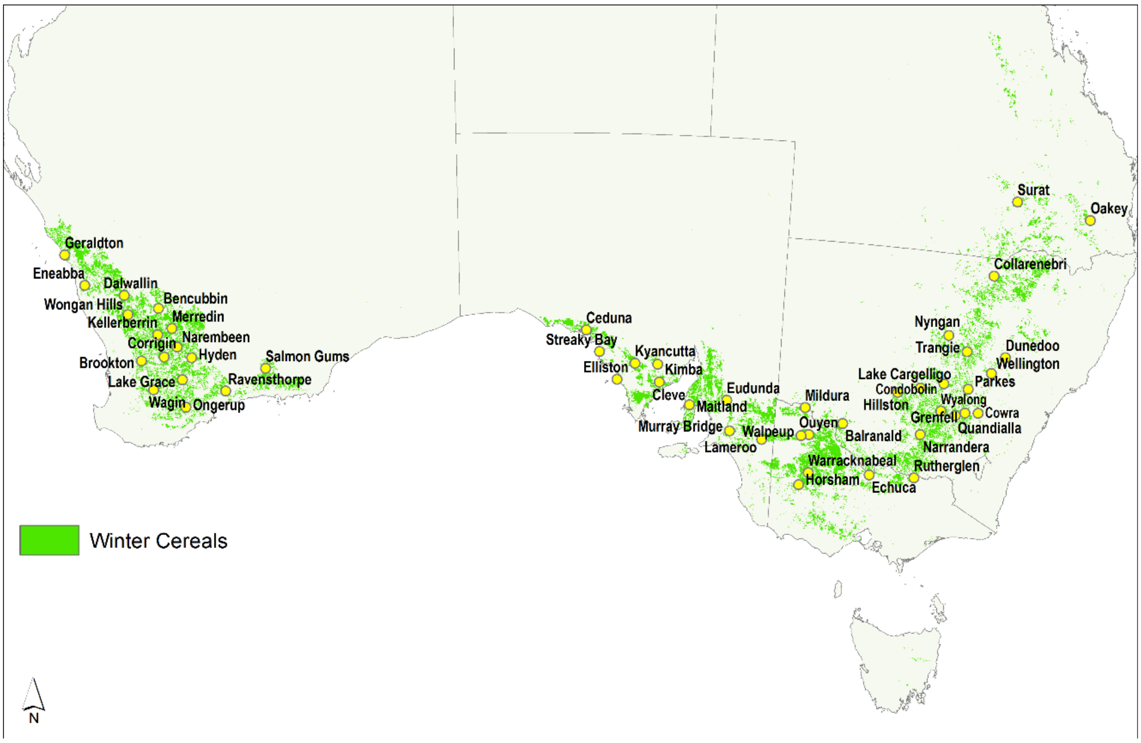


Figure 2. Fifty high quality weather stations and their distribution in Australia's cropping zone

Nationally, the average rate of N applied to grain crops is 45 kg N/ha (Angus and Grace, 2017). This one practice is sufficient to account for a 40% yield gap. Even at double that rate, a 23% yield gap remains. Frost and heat stress accounted for yield losses of between 16% and 25% of Yw depending on the function used (two versions of the Bell et al., 2015 function were used due to uncertainty about the function's parameters). Failure to control weeds during the summer fallow could account for up to a 26% yield loss; delayed sowing accounted for a 7% yield loss and low seedling density for an 8% yield loss. Any grower who is still practising conventional tillage could be missing out on 33% of their yield potential. Other factors that contribute to the yield gap, not included in simulations, include biotic stresses such as plant diseases, insects and other pests, in-crop weeds and extreme weather events (e.g. floods, strong winds and hail).

Since none of the 50 stations of Figure 2 were located in the Liverpool Plains, we repeated this analysis for Quirindi which had a 15 year average Yw of 5.1 t/ha. The impact of sub-optimal practices at this site were of a similar order to the national results with 45 kg N/ha accounting for a 36% yield gap. Even at 90 kg N/ha a 14% yield gap remains. Frost and heat stress accounted for yield losses of between 19% and 33% of Yw, depending on the function used. Failure to control weeds during the summer fallow could account for up to 14% yield loss and low seedling density for a 9% yield loss.

Despite the practice of late sowing in the Liverpool Plains, we found that the ideal sowing date was 26 April with a late maturing cultivar. This "emergent Yw" treatment, with a 15 year average yield of 6.0 t/ha, had a 19% advantage over Yw and should be considered as the new yield frontier. While frost and heat stress reduce the yield potential of both Yw and the new simulated yield frontier, the advantage of the new treatment is slightly enhanced when frost and heat stress are taken into account. The advantage of early sowing combined with later maturing (slower developing) varieties is consistent with recently published field and simulation work for sites from Dubbo south to Victoria, and west to SA and WA (Flohr et al., 2017) but will require flexible additional application of N fertiliser to meet N requirements of 6-9 t/ha crops when seasonal conditions are right (e.g. 2016).

Table 2. Impacts of management factors (treatments 2-7) and of frost and heat stress (treatments 9 & 10) on water-limited yield potential (Yw).

Treatment number	Treatment	Mean (t/ha)	SD (t/ha)	CV (%)	Y% (%)
1	Yw (water-limited yield)	4.28	0.92	21	100
2	Seedling density (50 plants/m^2)	3.78	1.10	29	88
3	Late sowing (2 week delay)	3.97	1.04	26	93
4	Summer weeds	3.18	1.17	37	74
5	Conventional tillage	2.86	1.08	38	67
6	N fertiliser (45 kg N/ha)	2.57	0.44	17	60
7	N Fertilizer (90 kg N/ha)	3.30	0.96	29	77
9	Frost and Heat	3.15	1.00	32	74
10	Frost and Heat 2 (moderate impact)	3.60	0.95	26	84

Risk-adjusted profit

Growers generally do not seek to maximise yield but rather to maximise their profit. However, growers are also generally averse to risk, meaning that profits should be adjusted for yield and price risk via a measure of certainty equivalent. The certainty equivalent represents the smallest amount of certain money a farmer is willing to receive to forgo an uncertain profit, and can be calculated as the difference between average profit and a risk premium (e.g. Hardaker et al., 2004; Monjardino et al., 2015). When typical costs were built in to allow profit and risk-adjusted profit to be calculated for a risk-neutral and a moderate risk-averse context, respectively (Figure 3), we found that, despite the higher costs, both maximum profit and maximum risk-adjusted profit were achieved by the emergent Yw treatment.

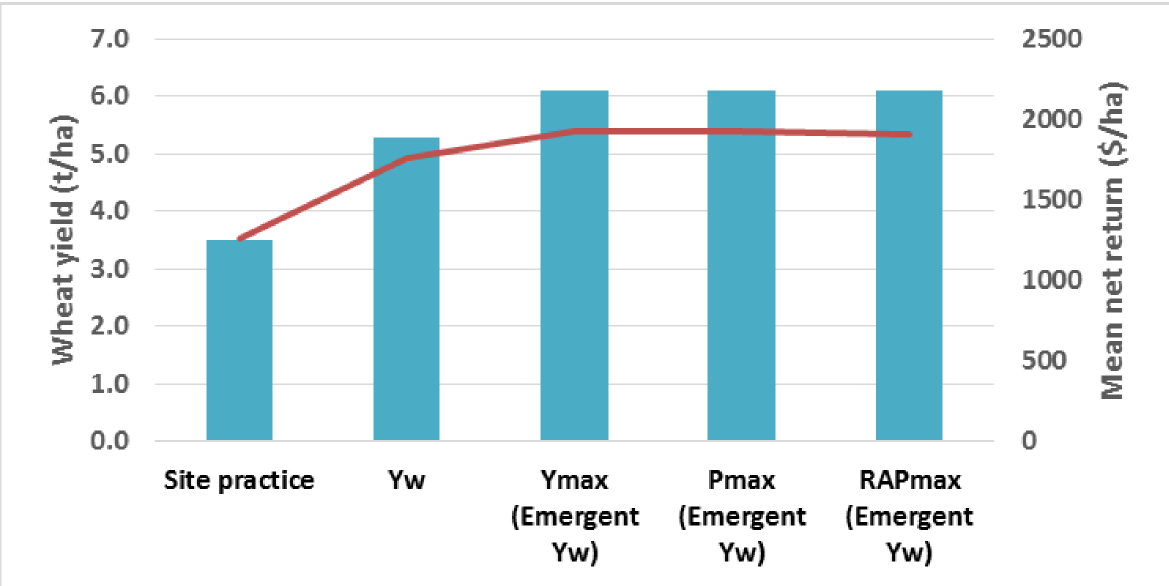


Figure 3. Wheat yield (t/ha) (blue bars) and net returns ($/ha) (red line) achieved by average site practice, water-limited yield potential (Yw) and yield-maximizing (Ymax), profit-maximizing (Pmax) and risk-adjusted profit maximizing (RAPmax) practices that are all emergent Yw treatments at a high yielding site (Dunedoo, NSW).

Conclusions

While wheat growers in the Liverpool Plains are among the most efficient in Australia, there is still room for closing the yield gap by adopting non-limiting N fertiliser practices and controlling fallow weeds.

Simulation analysis suggests that, contrary to current practice, early sowing with slow maturing varieties has the potential to lift the production frontier by 19% and significantly improve risk-adjusted profitability. This finding needs to be fully evaluated in local field experiments.

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. We gratefully acknowledge the expert advice provided by Jan Edwards and Alan Umbers of GRDC as well as by Pam Watson, CEO of Down To Earth Research who conducted the interviews. We wish to thank Dr Jeremy Whish who reviewed an earlier draft of this paper.

References

Angus, J.F., Grace, P.R., 2017. Nitrogen balance in Australia and nitrogen use efficiency on Australian farms. Soil Res. 55, 435-450.

Bell, L.W., Lilley, J.M., Hunt, J.R., Kirkegaard, J.A., 2015. Optimising grain yield and grazing potential of crops across Australia's high-rainfall zone: a simulation analysis. 1. Wheat. Crop & Pasture Science 66, 332-348.

Flohr, B.M., Hunt, J.R., Kirkegaard J.A., Evans J.R., 2017. Water and temperature stress define the optimal flowering period for wheat in south-eastern Australia. Field Crops Res. 209, 108-119.

Hardaker, B.J., Huirne, R.B.M., Anderson, J.R., Lien, G., 2004. Coping with Risk in Agriculture, second ed. CABI Publishing, Oxford.

Monjardino, M., McBeath, T., Ouzman, J., Llewellyn, R., Jones, B., 2015. Farmer risk-aversion limits closure of yield and profit gaps: A study of nitrogen management in the southern Australian wheatbelt. Agric. Sys. 137, 108-118.

Contact details

Zvi Hochman
CSIRO Agriculture and Food
Ph: 07 3214 2234
Email: zvi.hochman@csiro.au

Farming systems – Spring Ridge, northern NSW

Andrew Verrell[1], Lindsay Bell[2] and David Lawrence[3]

[1]NSW DPI, Tamworth, NSW; [2]CSIRO, Toowoomba Qld; [3]QDAF, Toowoomba, Qld

Key words

Farming systems, cropping, water use, pathogens, economics, Spring Ridge

GRDC code

DAQ00192

Take home messages

- To date, differences between systems in total grain production for three crop years is small with values ranging from 11,084 kg/ha (high legume system) to 8,573 kg/ha (high crop intensity).
- Commodity prices between systems has driven gross margins, not yield, with the low crop intensity system (wheatxxcotton) $2,739 $GM/ha outperforming the high nutrition (wheatxchickpeaxwheat + 200 kgN/ha) system, $2,011 $GM/ha.
- WUE is a useful metric i.e. $ GM/mm water used (rain + change in soil water) to determine farming system benefits and derive profitable crop sequencing. To date, the low crop intensity system has returned $1.66 $GM/mm compared to the high nutrition system $1.30 GM/mm.
- Vx., vx, cxm vChanges in pathogen loadings are small across all systems, to date. The Spring Ridge site has no *Pratylenchus thornei* and below threshold levels of *Pratylenchus neglectus*. Common root rot and crown rot levels were not detectable at the onset of the experiment and have only risen slightly due to non-host crops being grown in the systems.

Introduction

While advances in agronomy and the performance of individual crops have helped grain growers to maintain their profitability, current farming systems are underperforming; with only 30% of the crop sequences in the northern grains region achieving 75% of their water limited yield potential (Hochman *et al*. 2014). Growers are facing challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Changes will be needed to meet these challenges and to maintain the productivity and profitability of our farming systems.

The Queensland Department of Agriculture and Fisheries (QDAF), CSIRO and the New South Wales Department of Primary Industries (NSW DPI) are collaborating to conduct an extensive field-based farming systems research program. This program is focused on developing farming systems to better use the available rainfall to increase productivity and profitability.

The generic systems

The northern farming systems projects are investigating how several modifications to farming systems will impact on the performance of the cropping system as a whole over several crops in the sequence. This involves assessing various aspects of these systems including water use efficiency, nutrient balance and nutrient use efficiency, changes in pathogen and weed populations and changes in soil health.

The key system modifications we are examining involve changes to:

- **Crop intensity** – ie. the proportion of time that crops are growing which impacts on the proportion of rainfall transpired by crops and unproductive water losses. This is being altered by changing soil water thresholds that trigger planting opportunities. High crop intensity systems have a lower soil water threshold (crop planted on 30% full profile); moderate intensity systems have a moderate soil water threshold of 50% full profile, and low intensity systems require a profile > 80% full before a crop is sown and higher value crops are used when possible.
- **Increased legume frequency** – crop choice aims to have every second crop as a legume across the crop sequence, with the aim of reducing fertiliser N inputs required.
- **Increased crop diversity** – crop choice aims to achieve 50% of crops resistant to root lesion nematodes (preferably 2 in a row) and crops with similar in-crop herbicide mode of action can't follow each other. The aim is to test systems where the mix and sequence of crops are altered to manage soil-borne pathogens and weeds in the cropping system.
- **Nutrient supply strategy** – by increasing the fertiliser budget to achieve 90% of yield potential for that crop compared with a 50% of yield potential with the aim of boosting background soil fertility, increasing N cycling and maximising yields in favourable years.

This range of system modifications are being tested across 7 locations; Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red & grey soils). The core experimental site, located near Pampas on the eastern Darling Downs, aims to explore the interactions amongst these various modifications to the cropping systems across a range of crop sequences that occur across the northern grains region. The core site is comparing 34 different system treatments.

The Spring Ridge Site - "Nowley"

The Spring Ridge farming area lies in the northern end of the southern region of the Liverpool Plains. Rainfall distribution and variability is shown in Table 1. This southern region has the highest summer rainfall, with relatively high winter rainfall, of any area in north eastern NSW. The Plains is one of the safest dryland cropping areas in the region with summer cropping typically a major component in the system. This is possible due to consistency of summer and winter rainfall, coupled with a large proportion of high water holding capacity vertosols.

Table 1. The, 90, 50 and 10 percentile rainfall and variability indexes (VI) for summer and winter rainfall (mm) and the summer/winter ratio for rainfall for northern and southern Liverpool Plains

	Summer rainfall				Winter rainfall				
Region	90 %	50 %	10 %	VI	90 %	50 %	10 %	VI	Summer/Winter ratio
Northern	564	411	288	0.67	395	261	153	0.93	1.57
Southern	595	435	295	0.69	377	240	145	0.97	1.81

Due to the low variability and high summer rainfall this area has a diverse cropping system with a range of summer and winter crops able to be grown, making this one of the most productive cropping areas in Australia. Zero tillage systems based on control traffic platforms dominate this region.

'Nowley' is owned by The University of Sydney and is located 21km north west of Spring Ridge on predominantly sloping black vertosol country with a plant available water capacity (PAWC) > 200 mm. The site has been cropped for over a hundred years and is representative of a large proportion of the Liverpool Plains. The site was in fallow out of a sorghum crop at the commencement of the trial and was planted to wheat across the entire site in 2015 to set a common starting point. The site is subject to major weed pressure but has no other biotic stresses of note.

Cropping systems

Six systems were identified as priorities through consultation with farmers and advisers in northern NSW;

1. Baseline - The baseline system was designed to represent a standard cropping system for the majority of the northern NSW cropping areas, which is desired to be kept relatively consistent across farming systems locations. Planting trigger will be 50% of full profile. The area has both winter and summer crop with a diverse range of cropping options. At present the baseline system consists of wheat/fallow/sorghum/double cropped chickpea/ wheat/chickpea/.
2. Higher nitrogen supply - This system is a duplicate of the crop sequence for the baseline system which is designed to examine the economics and system performance of high nitrogen fertiliser inputs. Fertilising will be targeting a higher yield (90% of seasonal yield potential for nitrogen).
3. High crop intensity – the trigger for planting will be soil moisture at 30% of full profile. This mirrors current cropping system sequencing on the Liverpool Plains and is based around a standard crop sequence of; wheat/fallow/sorghum/double cropped chickpea.
4. Higher crop diversity - This system is investigating alternative crop options to help manage and reduce nematode populations, disease and herbicide resistance. The profitability of these alternative systems will be critical. A wider range of 'profitable' crops may enable growers to maintain soil health and sustainability as the age of their cropping lands increase. Crop options considered for this system include: wheat, durum, barley, chickpeas, field pea, fababean, canola, mustard, sorghum, maize, sunflowers, mungbeans and cotton.
5. Higher legume - The high legume system is focused on soil fertility and reducing the amount of nitrogen input required through fertiliser. It is required that one in every two crops is a legume and the suite of crops available for this treatment is: wheat, durum, barley, chickpeas, faba beans, fieldpeas and mungbeans. Crops will be planted at an average moisture trigger (50% full soil moisture profile).
6. Lower crop intensity - This lower intensity system is designed to plant at a lower frequency when the profile is >80% full. High value crops are targeted and the crops included are, wheat, barley, chickpea, sorghum and cotton.

Crop sequencing at Spring Ridge

In 2015 wheat was planted across all systems after a 12 month fallow out of sorghum. All treatments had 50 kg/ha of Granulock® Zn and 100 kg/ha of nitrogen as urea applied at sowing. Yield data suggested that the site was uniform. Crop sequences for the various systems in the following 3 years are shown in Table 2.

In 2016, systems started to become more diverse with crop choice mainly consisting of a range of winter pulse crops (chickpea, faba bean and field peas). The high crop intensity system followed the Liverpool Plains commercial practice and was fallowed through to sorghum in 2016/17.

The 2017 season was one of the most demanding and difficult winter growing seasons on record with an unprecedented frost incidence.

Luckily, the 2016 crops were mainly composed of pulse residue and not large amounts of cereal straw as this would have exacerbated the radiant frost incidence. A reasonable summer fallow rainfall in 2016/17 ensured there was adequate soil moisture reserves coming in to a very dry winter 2017 crop period (see Table 3).

Table 2. Cropping sequence for the six farming systems at Spring Ridge, 2015-2017

	2015		2016		2017	
System	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**
Baseline	Wheat		Chickpea		Wheat	
High nutrient supply	Wheat		Chickpea		Wheat	
High crop intensity	Wheat		Fallow	Sorghum	Chickpea	
Crop diversity	Wheat		Field peas		Wheat	
High legume	Wheat		Faba bean		Wheat	
Low intensity	Wheat		Fallow		Fallow	Cotton

Table 3. Summer and winter rainfall for Nowley, 2015-2017

	Rainfall (mm)		
Period	**2015**	**2016**	**2017**
Preceding summer	265	200	408
Winter	190	349	80

In 2017 wheat was planted across most systems following a range of winter pulses in 2016, except the high intensity system which was double cropped to chickpea after a 2016/17 sorghum crop.

All treatments had 50 kg/ha of Granulock® Zn and 100 kg of nitrogen as urea applied at sowing while the high nutrient system had an additional 100 kg N/ha applied as urea at the late tillering stage.

Crop system yields at Spring Ridge

The cumulative grain (or grain + lint) yields (Figure 1) are quite similar for the five main systems with 2,500 kg/ha separating highest yield(high legume @ 11,084 kg/ha) from fifth highest (high crop intensity @ 8,573 kg/ha). The major yield differences in these systems emanated from the 2016 winter crop choices, with chickpea (baseline @ 3063 kg/ha and high nutrient @ 3329 kg/ha) yielding lower than field pea (3631 kg/ha) and faba beans (4256 kg/ha) in the crop diversity and high legume systems, respectively. The high intensity system was fallowed in 2016 into sorghum (2978 kg/ha) and then double cropped into a late chickpea crop (1981 kg/ha) in 2017. The low intensity system was cropped to cotton in the 2017/18 summer season and this yield value represents seed + lint (2078 kg/ha).

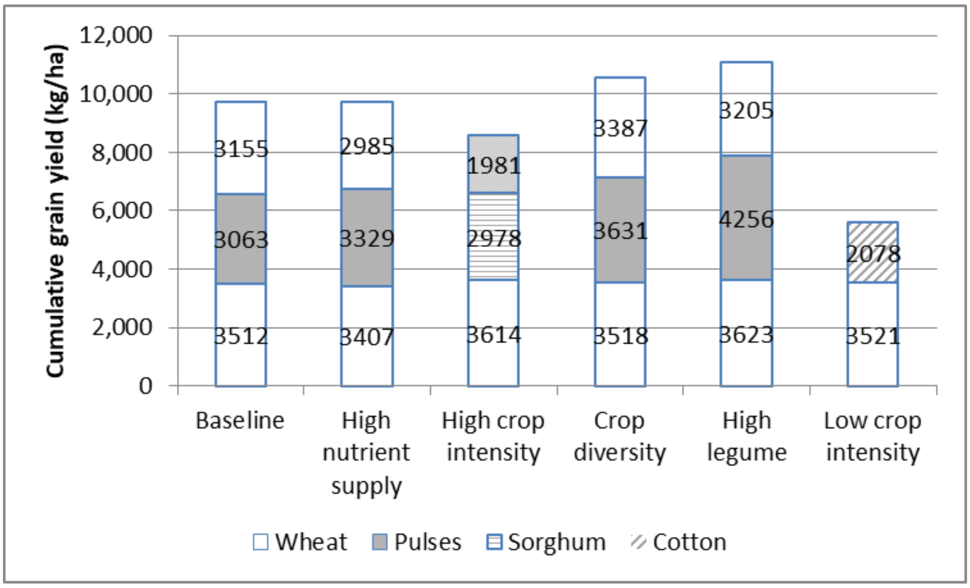


Figure 1. Cumulative grain (or grain + lint) yield of the Spring Ridge systems (kg/ha)

Crop systems economics at Spring Ridge

Gross margins ($/ha) have been calculated for each crop within the six systems. Table 4 contains the grain pricing used in these calculations based on median prices over the past ten years.

Table 4 Ten (10) year median port prices, less $40/t cartage costs, for selected crops

Crop	$/t	*Crop*	$/t
Barley	218	Mungbean	667
Canola	503	Oat	400
Chickpea	504	Pasture Grass	150
Cotton	1090	Pasture Legume	150
Durum	269	Sorghum	221
Fababean	382	Sunflower	700
Fieldpea	350	Vetch	150
Maize	281	Wheat	269

After the first three growing seasons of the farming systems experiment at Nowley, the low crop intensity system (2 crops in 3 years) has the greatest cumulative gross margin with $2739/ha (Figure 2). This is entirely due to the high value cotton crop that produced around 4 bales/ha in the 2017/18 summer crop season. The other five systems are comparable to one another with the high legume system (wheat/faba bean/wheat) returning $2252/ha and the high intensity (wheat/sorghum/double crop chickpea) returning $2198/ha. The next best is the baseline system ($2184/ha), followed by crop diversity ($2022/ha) and high nutrition systems ($2011/ha), which are comparable to each other.

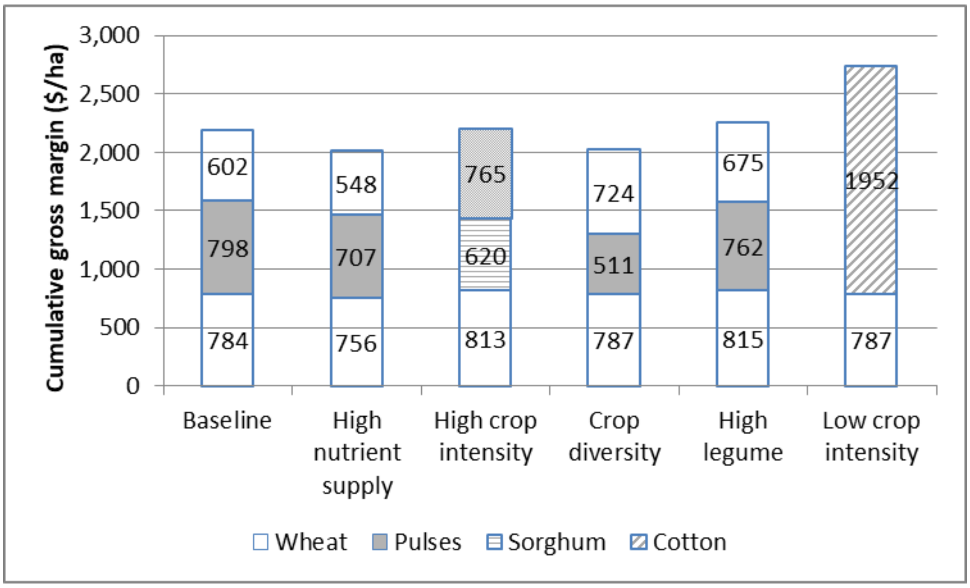


Figure 2. Cumulative grain gross margin ($/ha) of the Spring Ridge systems excluding fallow costs

In terms of wheat following pulses; wheat following chickpea had the lowest returns ($602/ha and $548/ha) compared to wheat following faba bean ($675/ha) and field pea ($724/ha).

Crop system water-use-efficiency at Spring Ridge

While crop water use efficiency (kg grain/mm crop water use) is a useful metric to compare performance of individual crops, it fails to account for the efficiency of soil water accumulation in the previous fallow, or legacy effects after a particular crop either in the form of residual soil water at harvest, or impact on subsequent fallow efficiency. Hence, to account for the efficiency of the farming system over time, we have calculated system water-use efficiency for the various systems over the first 3 years of this experiment. We define system water use efficiency as the $ gross margin return per mm of water used (i.e. rainfall + change in soil water). Gross margin over the whole crop sequence was calculated from the sum of yield multiplied by the 10-year average price for each crop, minus variable costs (fertiliser, seed, herbicides, and operations) accumulated over the whole crop sequence (Figure 3).

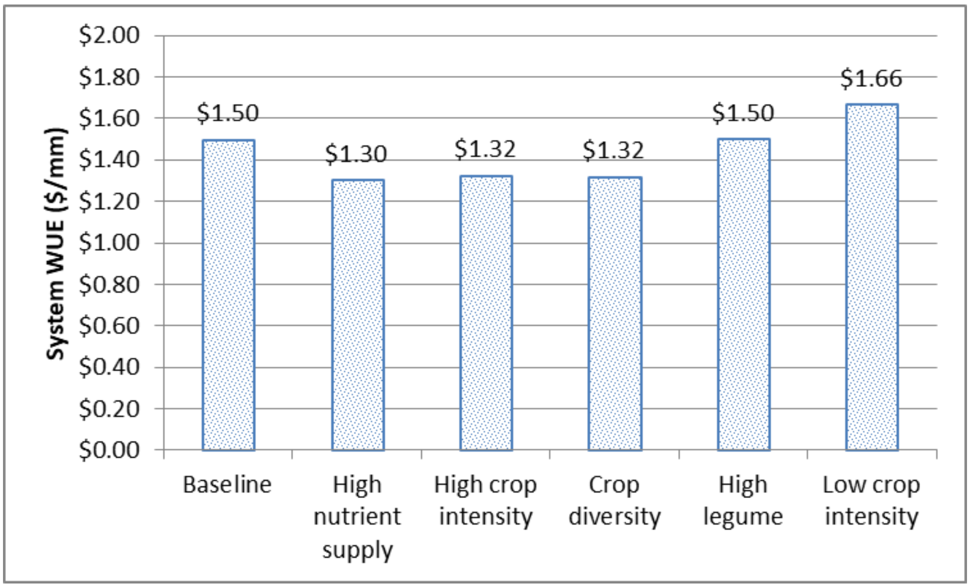


Figure 3. System water use efficiency ($ gross margin/mm water used) for the period from March 2015 to Dec 2017/March 2018 for different crop sequences modified to increase or decrease crop intensity, increase legume frequency and/or crop diversity. Note the low intensity system has been calculated thru to March 2018 at the conclusion of the cotton crop while the other systems are thru to the end of the 2017 winter season.

Only small differences have been observed between the systems, with WUE of between $1.30 and $1.66/mm The high nutrient supply (WheatxChickpeaxWheat), high crop intensity (WheatxxSorghum/double crop chickpea) and crop diversity (WheatxField peaxWheat) systems have all shown lower WUE returns of around $1.30/mm. Adding extra nitrogen, as a split application, into the high nutrition system in a low rainfall season (2017) resulted in a -$0.20 decline in the return on water compared to the baseline system (WheatxChickpeaxWheat).

Inserting faba beans into the system (high legume) has yielded equivalent WUE values to the baseline cropping system while growing a high value dryland cotton crop (low crop intensity) on a full profile of soil moisture has resulted in the best WUE ($1.66/mm) return to date.

Pathogens of the cropping systems at Spring Ridge

The entire site was sampled in early 2015 to examine the background pathogen status via soil DNA probing. When sampled, the site had been fallowed out of a sorghum crop and was to be planted to wheat.

Two DNA probes are taken each year; March and then in November-December. Table 5 compares the pre-sow DNA values in 2015 to the values at the end of the 2017 winter season for selected pathogens. The data presented in table 5 is for soil samples taken in the crop row, so represent primary points of infection.

Table 5. DNA soil sample values for selected pathogens before first wheat crop (2015) and at harvest 2017

System	*P.thornei*		*P.neglectus*		*Yellow leaf spot*		*Bipolaris*		*Fusarium*	
	#/g	*#/g*	*#/g*	*#/g*	*copies/g*	*copies/g*	*pg/g*	*pg/g*	*pg/g*	*pg/g*
	Pre-sow 2015	Harvest 2017	Pre-sow 2015	Harvest 2017	Pre-sow 2015	Harvest 2017	Pre-sow 2015	Harvest 2017	Pre-sow 2015	Harvest 2017
Baseline	0.00	0.00	0.24	0.42	0.00	7.95	0.00	2.66	0.63	7.40
High nutrient supply	0.00	0.05	0.09	1.06	0.00	62.74	0.00	0.84	0.65	3.40
High crop intensity	0.00	0.01	0.06	0.22	0.00	0.13	0.00	0.39	1.32	0.97
Crop diversity	0.00	0.00	0.11	0.00	0.00	2.97	0.00	2.37	0.25	14.02
High legume frequency	0.00	0.00	0.12	0.22	0.00	0.27	0.00	0.82	1.43	4.46
Low crop intensity	0.00	0.00	0.26	0.00	0.00	0.87	0.00	0.64	0.90	2.35

#/g = number per gram of soil, pg/g = picograms/g soil

The difference in values in 2015, for individual pathogens across the systems, represents site variability as none of these different cropping systems had been invoked at the time of background sampling. There were virtually no nematodes at this site except for trace levels of *Pratylenchus neglectus* and no *Pratylenchus thornei*. P. *thornei* levels have not really changed in 3 seasons while *P. neglectus* have risen slightly in systems where chickpeas have been grown, but these values are extremely low. Nematode levels would need to reach > 2 nematodes per gram of soil to be considered damaging. These values need to be compared to the low crop intensity system which has been under long fallow, prior to cotton in 2017/18 summer period, where *P. neglectus* is at undetectable levels.

Sorghum, cotton and field peas present a low risk to nematode build up while chickpea, faba bean and bread wheat can present a medium to high risk. The biggest variations occur within chickpea and wheat varieties regarding nematode increases. PBA HatTrick⍦ is one of the least susceptible chickpea varieties (used at this site) while the wheat varieties Spitfire and EGA Gregory⍦ are both susceptible in terms of resistance to the nematodes as well as being moderately tolerant.

Yellow leaf spot (YLS) has come back into the zero tillage site and spiked sharply in the high nutrient system where 200 kg/N/ha was applied to EGA Gregory⍦ wheat as a split application in 2017. Both *Bipolaris* and *Fusarium* levels have risen over the three seasons but are again quite low with minor variance between systems. Spitfire and EGA Gregory⍦ are the only two wheat varieties to be sown across the site and both are susceptible to YLS, *Bipolaris and Fusarium* infection.

References

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

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 also like to thank, specifically, our co-operator and host at 'Nowley', The University of Sydney who have assisted us in implementing this experiment. We must also thank Michael Nowland for his management of the experimental site along with Mat Grinter and Peter Sanson for technical assistance in the field and laboratory.

Contact details

Andrew Verrell
NSW DPI Tamworth
Mb: 0429 422 150
Email: andrew.verrell@dpi.nsw.gov.au

® Registered Trademark

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

Farming systems site report – Narrabri, northwest NSW

Jon Baird and Gerard Lonergan, NSW Department of Primary Industries

Key words

Northern farming systems, water limited yield potential, nematodes

GRDC code

DAQ00192

Take home messages

- The baseline, high nutrients, high intensity and high legume systems resulted in the highest grain production at Narrabri. With differences in gross margins of the four systems due to the grain value of the crop choice in 2016. High intensity (wheat-canola-wheat) had highest gross margin, baseline and high nutrient (wheat-chickpea-wheat) the second and third highest gross margin and the high legume system (wheat-faba bean-wheat) the lowest gross margin of the top four systems.
- The baseline, high nutrients, high legumes and high intensity systems had the greatest crop water use efficiency in 2016 and in return the highest system gross margin per mm of rainfall. The low intensity system (which contained a summer cotton crop) had lower water use efficiency than the high diversity but greater system gross margin per mm due to the value of the summer crop in the low intensity system and frost damaged 2017 canola crop in the high diversity system.
- *Pratylenchus thornei* numbers were higher after a chickpea crop compared to faba bean and field pea in 2016, while canola and cotton reduced *P. thornei* numbers in the same season. The higher *P. thornei* numbers after the 2016 chickpea crop have continued through to December 2017 (post the 2017 wheat crop).
- There was no difference in wheat yield (2017) following chickpea, faba bean or canola grown in 2016.

Project background

While advances in agronomy and the performance of individual crops have helped grain growers to maintain their profitability, current farming systems are underperforming; with only 30% of the crop sequences in the northern grains region achieving 75% of their water limited yield potential.

Growers are facing challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Changes will be needed to meet these challenges and to maintain the productivity and profitability of our farming systems. Consequently, The Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and CSIRO are conducting an extensive field-based farming systems research program, focused on developing farming systems to better use the available rainfall to increase productivity and profitability, with the question;

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

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

Research began with local growers and agronomists in 2014 to identify the key limitations, consequences and economic drivers of farming systems in the northern region; to assess farming systems and crop sequences that can meet the emerging challenges; and to develop the systems with the most potential for use across the northern region.

Experiments were established at seven locations; a large factorial experiment managed by CSIRO at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres by DAF and NSW DPI (Table 1). Several of these systems are represented at every site to allow major insights across the northern region, while the site specific systems will provide insights for local conditions.

The following report details the systems being studied in Narrabri how they are implemented locally and the results after the first three years. Data and system performance indicators have been developed to compare performance across sites.

Table 1. Summary of the regional farming systems being studied at each location in the northern farming systems initiative

System	**Regional sites**					
	Emerald	Billa Billa	Mungindi	Spring Ridge	Narrabri	Trangie x2 (Red & Grey)
Baseline – represents a typical zero tillage farming system	*	*	*	*	*	*
Higher nutrient supply – as for the 'baseline' system but with fertilisers for 100% phosphorus replacement and nitrogen targeted at 90% of the yield potential each season	*	*	*	*	*	*
Higher legume - 50% of the crops are sown to legumes	*	*	*	*	*	*
Higher crop diversity – a wider range of crops are introduced to manage nematodes, diseases and herbicide resistance		*	*	*	*	*
Higher crop intensity – a lower soil moisture threshold is used to increase the number of crops per decade	*	*		*	*	*
Lower crop intensity – crops are only planted when there is a near full profile of soil moisture to ensure individual crops are higher yielding and more profitable		*	*	*	*	*
Grass pasture rotations – pasture rotations are used to manage soil fertility. One treatment has no additional nitrogen fertiliser, while the other has 100 kg N/ha/year to boost grass production		Grass (+/-N)				
Higher soil fertility (higher nutrient supply plus organic matter) - as in the high nutrient system but with compost/manure added	*	*				
Integrated weed management (incl. tillage) – this system is included at Emerald where crops, sowing rates, row spacings and 'strategic tillage' are included to manage weeds and herbicide resistance	*					

Narrabri farming system research site

The Narrabri farming system research site is located on the University of Sydney research farm - "Llara" (-30.263321, 149.860037). "Llara" is representative of the dryland farming operations throughout north-west NSW. The soils are predominately chocolate vertosols and have a plant available water capacity of 190 mm to a depth of 120 cm. The site has a long history of high productivity and has been under a controlled traffic system for many years. The first season of the farming system project was winter 2015, where wheat was grown across all systems to ensure the site had a consistent starting base.

Traditionally, the dryland farming systems grown in the Narrabri region are winter cereal dominated, with summer crops such as sorghum or dryland cotton planted on an opportunity basis. In recent years there has been a push by growers to bring summer crops into a routine cropping rotation due to the greater crop gross margin returns and to utilise summer rainfall. Another benefit of growing summer crops is the increase of cropping diversity that may reduce the amount of soil borne disease (e.g. crown rot) that have caused great productivity loss in the area.

Figure 1. Narrabri farming systems site – 20 September 2017

Cropping sequence at the Narrabri farming systems site

Wheat was planted in the winter of 2015 across all systems to establish a consistent base allowing various crops to be planted in the 2016 cropping year. Early rain provided good establishment and early plant vigour, but a dry finish to the 2015 winter meant yield was quite low (2.1 t/ha) and grain size was small.

The 2016 winter saw chickpeas planted as the industry standard baseline and also as a high nutrient system. The industry standard was in line with local grain growers who planted above average hectares of chickpeas to take advantage of the higher chickpea grain price. Field peas and faba beans were planted in the greater diversity and higher legume systems respectively, while canola was planted in the high intensity system. The low intensity system was kept as winter fallow and initially planned for long fallow through to summer 2017/18, but high rainfall during the winter of 2016 filled the soil profile and thus the system was planted to cotton in November 2016 (Figure 2).

In autumn 2017 all the systems, except for the low intensity system which was following a summer cotton crop, had good soil moisture levels that triggered crop plantings during the optimum window for the specific crops (canola planted on 19th of April and wheat planted on 11th May). This saw the baseline, high nutrients, high crop intensity and high legume systems return to cereal plantings. The greater diversity system was planted to canola following the 2016 field peas. To prevent soil degradation, barley was planted as the cover crop in the low intensity system but sprayed out prior to booting. The 2017 winter crops received considerably less in-crop rainfall compared to the 2016 winter crops (184 mm verses 450 mm) and unfortunately a number of heavy frosts occurred during August/September which greatly impacted the 2017 canola yield.

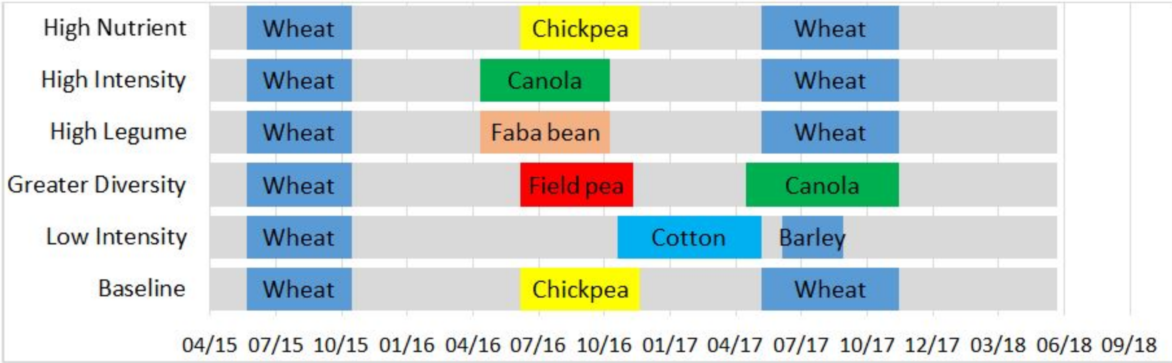


Figure 2. Cropping sequence and fallow length of the six farming systems at Narrabri

Grain / lint yield

The cumulative yield of the six systems (Figure 3) highlight the similar productivity of the baseline, high nutrients, high legume and high intensity systems (9.3, 9.1, 9.3, and 9 t/ha respectively). As stated before, the baseline and high nutrient system followed similar cropping sequences (Wh-Ch-Wh), while the high legume contained faba beans (Wh-Fb-Wh) and the high intensity had canola (Wh-Can-Wh) during the 2016 winter. These four systems produced significantly more total grain (or grain + lint) than both the greater diversity and low intensity systems (5.95 and 3.4 t/ha respectively). These lower yielding systems received unfavourable growing conditions during 2017. The low intensity system, which had cotton in the 2016/17 summer, received large yield penalties due to the extreme heat during the important boll development stage. While the 2017 canola crop (greater diversity system) received a number of frosts during late August/ early September (during the flowering/ pod fill stage) that devastated final yield.

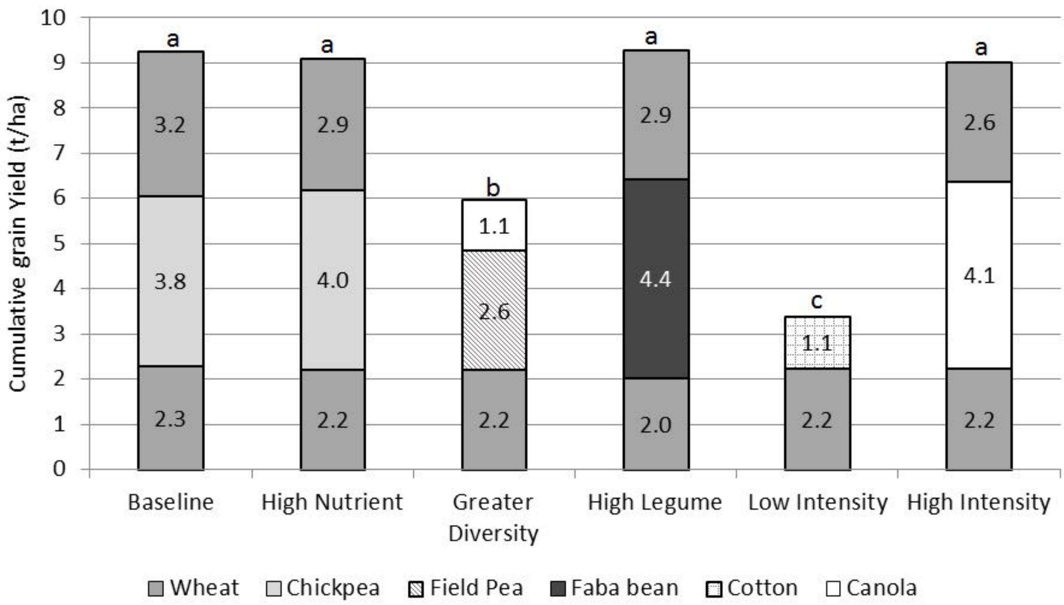


Figure 3. Cumulative grain yields of the six systems at the Narrabri farming systems trial. Labels a, b, c denotes significance groups, l.s.d.=1.2, P<0.001.

System economics

After the first three growing seasons of the farming systems trial at Narrabri, the high intensity system has the greatest cumulative gross margin with $2407/ha or $802/ha/yr (Figure 4). The baseline system had similar system gross margin with $2339/ha, while the high nutrient system was

$133/ha less than the baseline system due to the extra cost of the higher applied fertiliser rate. The high legume system had the next highest gross margin with $2165/ha. The difference in gross margins of the top four systems is primarily driven by the grain value of the crops planted in 2016. Of the crops grown in 2016, chickpea (baseline and high nutrients) and canola (high intensity) had the highest grain value ($504/t and $503/t respectively), followed by faba bean (high legume - $382/t). It is noted that grain prices used for the farming system project's gross margin analysis are 10 year median grain prices (Brisbane port) less transport costs ($40/t) across all northern farming system sites. This was to ensure there is no confusion between biophysical characterisations of each site and changes in transportation/market costs between sites.

The low crop intensity system which grew two crops in the three seasons (one less than the other farming systems) had the second lowest gross margin at Narrabri with $1232/ha. While the greater diversity system resulted in the lowest gross margin of the six Narrabri farming systems ($858/ha).

These results highlight the impact of the harsh growing conditions during the summer of 2016/2017 and the winter of 2017. The cotton crop (low intensity system) had a gross margin of $843/ha, the second lowest returning crop for the 2016 planting season. While the greater diversity system had the two lowest retuning crops, field peas ($320/ha - 2016) and canola ($158/ha - 2017).

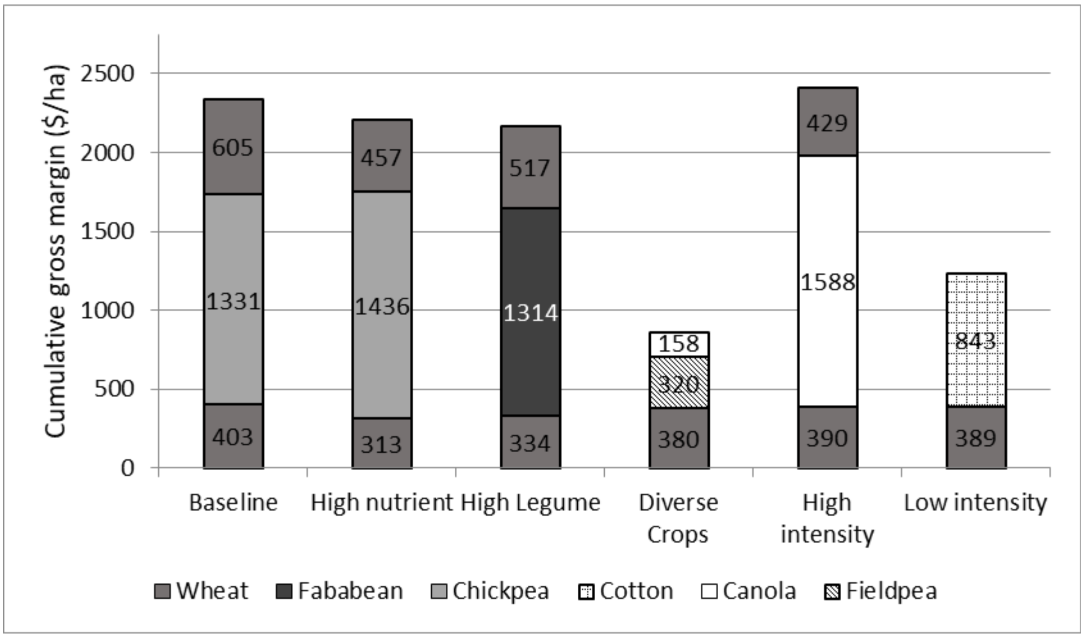


Figure 4. Cumulative gross margins of the six farming systems at Narrabri (includes crop and fallow costs). Grain values used for gross margin analysis are 10 year median prices at port, minus transport costs. Prices used at Narrabri include: wheat - $269/t, faba bean – 382/t, canola - $503/t, chickpea - $504/t, field pea - $350/t and cotton - $1090/t (includes lint and seed).

Water use efficiency

The low intensity system (with the two harvested crops from the three seasons) had the lowest fallow efficiency (the proportion of rainfall available to the next crop) and lowest crop water use efficiency (kg yield/mm crop water use) in 2016 (cotton – 2 kg /mm) (Figure 5). Conversely the high intensity system resulted in the highest fallow efficiency to date (61% 2015/16 summer fallow). Although there were five different crops planted in 2016, all systems resulted in similar crop water use efficiency in 2016, except the low intensity system (cotton). The impact of the 2017 frost damage on the greater diversity system (canola) is highlighted by the crop's water use efficiency of 4.5 kg/mm (which is the lowest efficiency rating for crops harvested in 2017), compared to the high intensity canola crop (2016) which had 7 kg/mm water use efficiency.

From the cropping sequences at Narrabri, we are able to compare the water use efficiency of wheat grown from two different seasons in the same system. The water use efficiency for both the baseline and the high legume systems were 4.5 and 5 kg/mm higher in 2017 compared to 2015, even though there was similar in crop rainfall for both the seasons (approx. 180 mm). A difference of the two seasons is that the 2017 crop was planted with an extra 35 mm of plant available water compared to the 2015 wheat crop and yield for both systems were 0.9 t/ha greater in 2017 compared to 2015.

Baseline, high nutrient, high legume and high intensity systems all had similar system water use efficiency (system gross margin per mm of rainfall). These four systems are had greater efficiency than the low intensity and greater diversity systems. The greater diversity system had the lowest system water use efficiency ($0.57 ha/mm) due to the poor gross margin of its 2016 field pea crop and the frost impacted 2017 canola crop. The long fallow periods in the low intensity system did reduce the system efficiency ($0.84 ha/mm), but it must be noted that the system had the highest plant available moisture (> 40 mm) than the other five systems at the completion of the 2017 cropping season (15/12/2017).

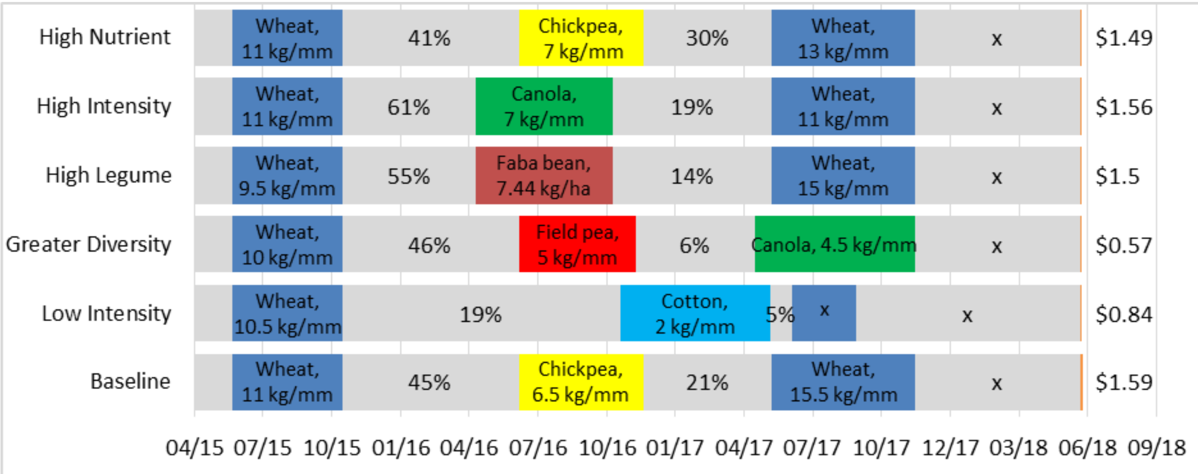


Figure 5. Crop water use efficiency, fallow efficiency and system gross margin per mm of rainfall for the six Narrabri farming systems up to the harvest of the last crop. Coloured bars represent crop choice and water use efficiency; grey bars contain the fallow efficiency or the proportion of rainfall available to the next crop.

Soil pathogens

Of the 18 soil pathogens tested pre and post every crop within the farming system project at Narrabri, *Pratylenchus thornei* results have shown a strong system related trend during the first three seasons. Crop choice during the 2016 season had the biggest impact on *P. thornei* numbers, with chickpeas (PBA HatTrick ⓓ) grown in the baseline and high nutrient systems increasing *P. thornei* numbers by up to 5 times the pre-sown number. The other legumes planted in 2016 (field pea - PBA Ouraⓓ (greater diversity) and faba bean – PBA Wardaⓓ (high legumes)) also increased *P. thornei* numbers but not to the extent of the chickpeas. The cotton (Sicot 748B3F) and canola (44Y89) in the low and high intensity systems respectively decreased the number of *P. thornei* in the soil during the 2016 winter. Although *P. thornei* did increase to moderate levels in 2016 within the baseline and high nutrient systems, no yield impact was recorded as chickpea yield equalled 3.8 t/ha for the baseline and 4 t/ha for the high nutrient system.

While *P. thornei* numbers across all six systems did reduce during the 2016/17 summer fallow, *P. thornei* numbers in both the baseline and high nutrient systems increased slightly during the 2017 winter wheat crop (Longreach Lancerⓓ). As a result both these systems had more than three times the *P. thornei* numbers than the other four farming systems at the end of 2017. Conversely the other four farming systems continued to reduce *P. thornei* numbers during 2017 and had approx. 1.2 nematodes/g soil (Figure 6) at the end of 2017. To date the higher nematode numbers in the baseline and high nutrient systems have not impacted yield as there is no difference in yield from the 2017 wheat planted in the baseline, high nutrients systems with the high legume and high intensity systems (all systems were planted to the same wheat variety in 2017 - Longreach Lancerⓓ). These results complement industry guidelines as Longreach Lancerⓓ is rated as moderately susceptible in terms of increasing *P. thornei* numbers (NSW DPI winter crop variety sowing guide 2018). However Lancerⓓ is tolerant-moderately tolerant to *P. thornei,* therefore moderate levels of *P. thornei* are not expected to cause any yield impact.

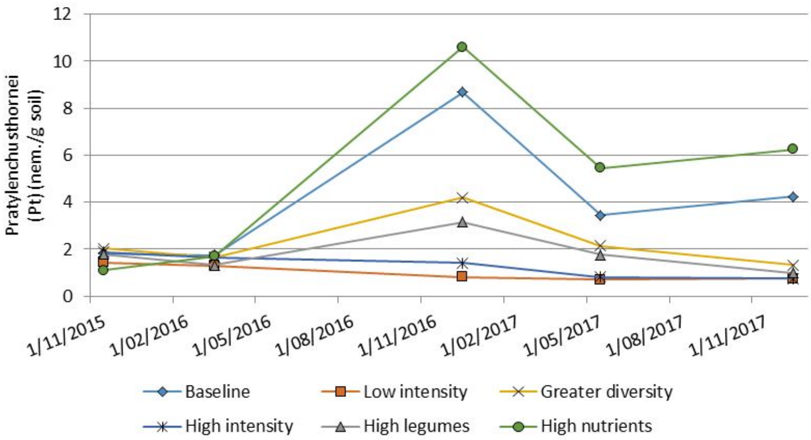


Figure 6. *Pratylenchus thornei* at the Narrabri farming system site

Conclusion

From the first three seasons at the Narrabri farming systems research site, the crop choice of the 2016 winter had the biggest impact on system gross margins and productivity, with the wheat-chickpea-wheat sequence and wheat-canola-wheat resulting in high grain yield and the highest gross margins. This result is due to the 2016 winter crops being significantly higher yielding than both the 2015 and 2017 winter seasons and the grain value of chickpea and canola in 2016 resulted in higher gross margins for the baseline and high intensity systems compared to the other four farming systems at Narrabri.

Although the sequence within the baseline and high nutrients systems have resulted in high grain production and system gross margins, the two-crop rotation does not reflect well for best management practice in the area. Of particular concern are long term implications on crop disease and nematode numbers (in particular *Pratylenchus thornei*). Future crop selections for the baseline and high nutrient systems will need to take into account the varieties' susceptibility to *Pratylenchus thornei.*

Acknowledgements

The research undertaken as part of this project (DAQ00190) 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 must also acknowledge the assistance provided by staff at the University of Sydney research farm – 'Llara'.

Contact details

Jon Baird
NSW Department of Primary Industries
21888 Kamilaroi Highway, Narrabri 2390
Ph: 02 67991520 Email: jon.baird@dpi.nsw.gov.au

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

Water extraction, water-use and subsequent fallow water accumulation in summer crops

Lindsay Bell[1], Andrew Erbacher[2]

[1] CSIRO Agriculture and Food
[2]Department of Agriculture and Fisheries, Queensland

Key words

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

GRDC code

CSA 00050, DAQ 00192

Take home messages

- Consider both soil water extraction as well as subsequent fallow accumulation when considering different summer crop options.
- Cotton and maize had higher water use than sorghum, but less efficient fallows.
- Mungbean water use and soil water extraction is often lower than summer cereal crops, but differences are often diminished after the subsequent fallow.
- Differences in soil water extraction under different sorghum configurations are small and seasonal, but impacts on subsequent fallow efficiency could be significant.

Introduction

The efficiency that soil water accumulates during fallows and crops ability to extract that water and convert into yield is a key driver of farming system productivity and profitability. While a large amount of work has been done on winter crops in farming systems, significantly less information is available on the relative water extraction of different summer crops and their impact on subsequent fallow water accumulation. Some previous work was conducted in the western farming systems projects and in Central Queensland that examined the impact of different sorghum crop configurations on water extraction and fallow accumulation. The current GRDC-funded farming systems projects have also gathered useful information on the soil water dynamics during and after different summer crop options in the farming system. This paper aims to provide an update on some of this information and improve understanding of how crop choice and management might influence residual soil water at the end of the crop and accumulation during a subsequent fallow.

Differences in crop water extraction between summer crops

Amongst the various summer crops grown across farming systems research sites, there are 3 cases where there are opportunities to draw comparisons of soil water dynamics during and after summer crops of different types.

Core farming systems site 2016/17

At the farming systems experiment at Pampas in 2016/17 a range of summer crops (maize, sorghum and cotton) were sown in the same season, with similar crop history and starting soil water (220 mm plant available water) (see Table 1). This allows a useful comparison of the extent of soil water extraction between these crops under the same conditions and the soil water accumulation during the subsequent fallow. Mungbean was also sown, but later in the same summer season.

In this season 136 mm of rain fell after soil sampling at the end of August and before sowing maize, sorghum and cotton on 5 October. Hence, the soil profile was full at sowing for each of these crops. Similarly, 265 mm of rain, replenished the soil profile to > 200 mm before Mungbean sowing on 10 Jan 17. Hence, all crops began with a full soil profile.

Soil sampling post-harvest in all these crops revealed only small differences in soil water – ranging from 130 mm in mungbean to 175 mm in sorghum. Effective crop water use over this period, after estimated soil evaporation was subtracted, was similar in maize and cotton, about 30 mm lower in sorghum and about 80 mm lower in mungbean. Despite relatively high crop water use, mungbean and maize yields (1.4 and 3.4 t/ha respectively) resulted in much lower returns per mm of crop water use ($ 0.70-0.80/mm) compared to cotton (4.1 bales/ha) and sorghum (6.8 t/ha) which produced higher returns per mm of crop water use ($ 1.80-2.00/mm).

A dry winter followed these crops with little soil water accumulating. Soil water status after sorghum and maize was maintained, while this declined after cotton and mungbean – presumably due to lower ground cover following these crops. Hence, at the start of the next summer cropping season, soil water was 20 mm lower after cotton than it was after maize, and this was significantly lower than after sorghum (35 mm). Over the whole annual sequence (from 30 Aug 16 to 20 Sept 17), including the crops water extraction and subsequent fallow accumulation, the relative change in soil water was 20 mm less for maize than cotton, 50 mm higher for sorghum than cotton and 65mm higher for mungbean than cotton.

Table 1. Comparison of soil water extraction, crop water use efficiencies and subsequent fallow soil water status between summer crop options sown at the core farming systems experiment, Pampas during the summer of 2016/17

		Sorghum	Maize	Cotton	Mungbean
Crop water availability and use					
Plant available water (PAW) pre-sowing (30 Aug 16)		**220**	**221**	**223**	**117**
Plant available water (PAW) post harvest (1 May 17)		**175†**	**148**	**141**	**130**
In crop Rainfall – 740 mm	Pre-sowing to sowing	136	136	136	265
	Sowing - maturity	287	337	347	280
	Maturity to post-harvest	317	267	257	9
Effective crop water use (30 Aug 16 – 1 May 17)[A]		**495**	**523**	**532**	**437**
Crop water use efficiency (WUE) (kg product/mm water use)		**13.7**	**6.1**	**1.7**	**2.8**
Crop WUE ($/mm water use)		**2.02**	**0.74**	**1.82**	**0.83**
Fallow water accumulation					
Fallow rainfall (1 May – 20 Sept 17)		78			
PAW at end of subsequent fallow (20 Sep 17)		**180†**	**146**	**127**	**92**
Net change in soil water (30 Aug 16 to 20 Sept 17)		**-40**	**-75**	**-96**	**-25**

† - Calculated from soil samples taken earlier; [A] – Total rainfall + soil water extraction – APSIM predicted soil evaporation (290 mm)

Price assumptions used in calculations were 10 year median port prices less $40/t cartage costs. These were $221/t for sorghum, $667/t for mungbean, $281/t for maize and $1090/t for cotton ($537/bale plus seed).

Core farming systems site 2017/18

In the subsequent summer cropping season, data from the core experimental site at Pampas allowed for comparisons of soil water extraction and crop water use between sorghum (solid plant 1 m row spacing, 60,000 plants/ha), high density sorghum (solid plant 0.5 m row spacing, 90, 000 plants/ha) and mungbean (see Table 2). The crops compared here had a common crop history (following maize in 2016), and soil nutrient status was also similar. This showed little difference in soil water extraction between these different crops, but effective crop water use was estimated to be 20 mm less in mungbean than sorghum in the same summer. Interestingly there was no difference in sorghum crop water extraction, or crop water use efficiency between the standard or high density configurations.

Table 2. Comparison of soil water extraction, crop water use efficiencies and subsequent fallow soil water status between summer crop options sown at the Core Farming Systems experiment, Pampas during the summer of 2017/18.

		Sorghum	Sorghum (high density)	Mungbean
Plant available water (PAW) (20 Sept 2017)		166	156	152
PAW post harvest (26 Mar 2018)		**58**	**40**	**42**
Change in soil water		**-108**	**-116**	**-110**
In crop Rainfall – 362 mm	Pre-sowing to sowing	125	125	169
	Sowing - maturity	140	140	96
	Maturity to post-harvest	97	97	97
Effective crop water use (20 Sep 17 – 26 Mar 18)[A]		**269**	**266**	**245**
Crop water use efficiency (WUE) (kg product/mm water use)		**18.9**	**18.5**	**4.2**
Crop WUE ($/mm water use)		**2.62**	**2.86**	**1.75**

[A] – Total rainfall + soil water extraction – APSIM predicted soil evaporation (200-220 mm)

Price assumptions used in calculations were 10 year median port prices less $40/t cartage costs. These were $221/t for sorghum and $667/t for mungbean.

Billa Billa farming systems site 2016/17

Two separate comparisons of summer crops are possible at the Billa Billa Farming systems site in summer 2016/17 (Table 3). The first, between spring sown sorghum crops with different starting soil waters (after a long-fallow after wheat, and after a short-fallow following mungbean). Both sorghum crops finished with similar post-harvest soil water status, despite nearly 100 mm difference in starting soil water. The sorghum crop with the higher availability of water yielded significantly more and ended with a much higher crop grain WUE than the crop starting with more marginal soil water. This translated into double the gross margin return per mm.

The second comparison can be made between sorghum and mungbean crops sown in January following a pulse crop the previous winter. Both crops started with a similar soil water status, but soil water was about 100 mm lower following the sorghum crop compared to the mungbean crop in July after harvest. This was largely driven by the difference in maturity timing between the crops, with the sorghum crop having access to an additional 115 mm of in-crop rain that fell after the mungbean crop was mature. So in the case of the mungbean crop, this 115mm would have added to finishing soil PAW levels. Despite these differences in post-harvest soil water at July 2017, differences in soil water were negated at the end of the subsequent fallow (in March 2018); with soil water similar at this time. Over the whole annual cycle, there was only a marginal difference in the change in soil water, with sorghum extracting more soil water than mungbean but higher subsequent fallow efficiency after sorghum made up for this difference.

Table 3. Comparison of soil water extraction, crop water use efficiencies and subsequent fallow soil water status between summer crop options sown at the Billa Billa farming systems experiment during the summer of 2016/17

		Date	Comparison 1		Date	Comparison 2	
			Sorghum (long-fallow)	Sorghum (short-fallow)		Sorghum	Mungbean
Plant available water (mm)	Pre-sowing	1 Sep 16	**237**	**142**	13 Oct 16	181	181
	Post-harvest	31 Jan 17	51	44	12 July 17	**78**	**188**
Change in soil water (mm)			**-186**	**-98**		**-103**	**+9**
Rainfall	Pre-sow to sowing		149	149		71	71
	Sowing - maturity		128	128		329	177
	Maturity – post-harvest		12	12		0	115
Total rainfall pre-sow to post-harvest			289	289		401	401
Estimated soil evaporation			195			274	
Effective Crop water use (mm)[A]			**326**	**238**		**432**	**320**
Crop water use efficiency (WUE) (kg product/mm water use)			**4.6**	**3.69**		**3.71**	**1.58**
Crop WUE ($/mm water use)			**1.45**	**0.77**		**0.74**	**0.39**
Post-fallow plant available water (20 Mar 18)			**223**[†]			**196**	**172**
Net change in soil water to 20 Sep 17			**-14**			**+15**	**-9**

[†] - calculated from soil samples taken earlier; [A] – Total rainfall + soil water extraction – APSIM predicted soil evaporation
Price assumptions used in calculations were 10 year median port prices less $40/t cartage costs. These were $221/t for sorghum and $667/t for mungbean.

Impact of sorghum configuration on crop water extraction and water accumulation

Little contemporary work has examined the effects that different sorghum crop configurations, such as solid planting, single skip or double skip, have on crop water use, crop water-use-efficiency and subsequent fallow accumulation. The information presented here is from research conducted previously by others.

In the study of Routley et al 2003 (Table 4), few differences in soil water change and crop water use were statistically significant due to high site variability. However, at 3 of the 4 experimental locations double-skip sorghum crops extracted 20-40 mm less soil water than solid plant. Single skip sorghum was intermediate in soil water extraction and crop water use, with around 10 mm less soil water extraction but these small differences are hard to assess experimentally. Interestingly in these data sets, the high rainfall year at Croppa Creek (> 400 mm in-crop rain) showed a significant yield penalty and lower crop WUE under the double skip configuration compared to single skip or solid plant. In contrast in the low rainfall season at Bungunya (165 mm in-crop rain), the single-skip and double-skip crops yielded similarly to solid plant crops but due to lower soil water extraction had higher crop WUE. Analysis over a wider range of environments and seasons has shown that double-skip or single-skip row sorghum crops only outperform solid-plant sorghum in dry growing seasons or when soil water at sowing is marginal (e.g. <60% full profile) (Whish et al. 2005).

Other locations have also shown marginal differences in total crop water use and soil water extraction between different sorghum row configurations. Results in 10 experiments Nebraska in the USA show no significant difference in total crop water use or extraction between solid, single-skip or double skip configurations (Abunyewa et al. 2011)

Table 4. Effect of sorghum configuration on soil water change, crop water use, yield and crop water-use efficiency over 4 seasons and locations

Site & year (in-crop rain)	Sorghum configuration	Change in soil water (mm)	Crop water use (mm)	Yield (t/ha)	WUE (kg/ha/mm)
Croppa Creek 2000/01	Solid (1 m)	+59	350	5.53	15.8
	Single skip	+71	338	5.60	16.7
(409 mm)	Double skip	+82	327	4.54	13.9
Billa Billa, 2000/01	Solid (1 m)	+13	311	2.91	9.4
(324 mm)	Single skip	+23	301	2.63	8.7
	Double skip	+19	305	2.85	9.4
Bungunya 2001	Solid (1 m)	-126	291	2.62	9.0
(165 mm)	Single skip	-112	277	2.74	9.9
	Double skip	-87	252	2.63	10.5
Billa Billa 2001/02	Solid (1 m)	+17	236	2.57	10.9
(253 mm)	Double skip	-2	255	2.81	11.0

Source: Routley, R., Broad, I., McLean, G., Whish, J., and Hammer, G. (2003). The effect of row configuration on yield reliability in grain sorghum: I. Yield, water use efficiency and soil water extraction. Proceedings of the Eleventh Australian Agronomy Conference, Geelong, Jan 2003.

The impact of the different row configurations on subsequent fallow water accumulation is also a critical factor to consider. It is expected that narrower rows with more even ground cover should improve soil water infiltration during a fallow after sorghum, while wide-row crops would be less efficient at accumulating water. However, there is little information on this currently. An experiment in Emerald conducted in 2006 (Table 5), showed that sorghum sown on narrow rows (0.5 m) had higher average ground cover at the end of the subsequent long fallow and had accumulated about 20 mm more soil water compared to sorghum on wide rows of 2.0 m. Other differences were not significant but intermediate row spacings accumulated soil water between these two extremes.

Further examination of the impact of narrow row (0.5 m) and higher density sorghum crops on subsequent fallow water accumulation is expected in the coming 12 months from farming systems experiments.

Table 5. Effects of sorghum row spacing on ground cover at the end of the subsequent fallow and fallow water accumulation.

Sorghum row spacing (m)	Average ground cover at end of fallow (%)	Fallow water accumulation (29 Mar 05-26 Apr 06)
0.5	22	101
1.0	19	88
1.5	14	86
2.0	14	78

Source: Routley R, Lynch B, Conway M (2006) the effect of sorghum row spacing on fallow cover distribution and soil water accumulation in Central Queensland. In Proceedings of the 13th ASA Conference, 10-14 September 2006, Perth, Western Australia.

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. Particular thanks and recognition must go to Richard Routley for reminding me of the past work on sorghum configuration effects on water extraction and fallow efficiency presented here.

References

Abunyewa A, Ferguson RB, Wortmann CS, Lyon DJ, Mason SC, Irmak S, Klein RN (2011) Grain sorghum water use with skip-row configuration in the Central Great Plains of the USA. *African Journal of Agricultural Research* 6 (23), 5328-5338.

Routley R, Lynch B, Conway M (2006) the effect of sorghum row spacing on fallow cover distribution and soil water accumulation in Central Queensland. In Proceedings of the 13th ASA Conference, 10-14 September 2006, Perth, Western Australia.

Routley, R., Broad, I., McLean, G., Whish, J., and Hammer, G. (2003). The effect of row configuration on yield reliability in grain sorghum: I. Yield, water use efficiency and soil water extraction. Proceedings of the Eleventh Australian Agronomy Conference, Geelong, Jan 2003.

Whish J, Butler G, Castor M, Cawthray S, Broad I, Carberry P, Hammer G, McLean G, Routley R, Yeates S (2005) Modelling effects of row configuration on sorghum yield reliability in north-eastern Australia. *Australian Journal of Agricultural Research* **56**, 11-23.

Contact details

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

Soil water – methods to predict plant available water capacity (PAWC) using soil-landscape associations

Kirsten Verburg[1], Uta Stockmann[1], Brett Cocks[2], Bill Manning[4], Jenet Austin[5], Mark Glover[1], Mark Thomas[3], John Gallant[5]

CSIRO Agriculture and Food, [1]Canberra ACT, [2]Toowoomba Qld, and [3]Adelaide SA
[4]North West Local Land Services, Gunnedah NSW
[5] CSIRO Land and Water, Canberra ACT

Key words

Plant Available Water Capacity (PAWC), soil water, APSoil, eSPADE, soil survey, Crop Lower Limit (CLL), subsoil constraints, soil-landscape, yield forecasting, APSIM

GRDC code

CSP00210

Take home messages

- Plant available water (PAW) is a key determinant of potential yield in dryland agriculture. Obtaining a measurement or estimate of PAW can, therefore, inform crop management decisions relating to time of sowing, crop type or the level of fertiliser inputs.
- Estimating PAW, whether through soil coring, use of a soil water monitoring device or a push probe, requires knowledge of the plant available water capacity (PAWC) of a soil. PAWC characterisations for 26 soils in the Liverpool Plains are publicly available in the APSoil database, which can be viewed in Google Earth and in the SoilMapp application for iPad.
- PAWC for wheat within the Liverpool Plains range from 115 to 300 mm. PAWC for other crops may be similar (e.g. sorghum, cotton) or less (e.g. chickpea, mungbean). Variation in the observed PAWC can be linked to parent material, texture and subsoil constraints, with subsoil salinity responsible for the largest reductions in PAWC.
- Similarity in soil properties is key when extrapolating from these PAWC characterisation sites to a location of interest – the nearest characterisation is not necessarily the appropriate one.
- Conceptual models of relationships between soil properties, parent material and position in the landscape can assist with extrapolation and prediction of PAWC. This information is increasingly becoming available on-line, including soil-landscape and soil and land resources mapping of the Liverpool Plains on eSPADE.
- Digital maps of predicted soil properties at 90 or 100 m resolution are also being developed and can assist with identifying areas where the risk of subsoil salinity reducing PAWC needs to be considered.
- Work is currently underway to test and refine the PAWC prediction processes and make them more user-friendly.
- In the meantime, exploring the soil differences on your farm using these tools and the provided PAWC information may explain differences in performance between or within paddocks, help adjust yield expectations and inform management decisions.

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 1000 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).

A number of 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 information 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 requires matching of 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 deposited. This is often related to landscape position. Information on soil-landscape associations, therefore, provides 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 on PAWC. It discusses how soil-landscape associations can be used to inform extrapolation from existing PAWC sites and assist with prediction of PAWC, illustrated by examples from the Liverpool Plains.

Plant available water capacity (PAWC)

To characterise a soil's PAWC, or '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 water content

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.

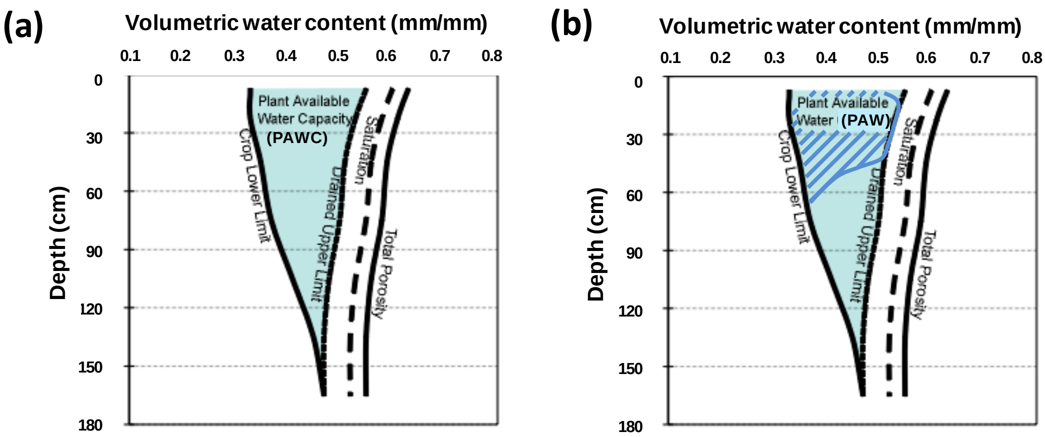


Figure 1. (a) The plant available water capacity (PAWC) is the total amount of water that each soil type can store and release to different crops and is defined by its drained upper limit (DUL) and its crop specific crop lower limit (CLL); (b) plant available water (PAW) represents the volume of water 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 crop lower limit.

Plant available water (PAW)

Plant available water is the difference between the crop lower limit (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 in order to quantitatively report soil water content).

An approximate estimate of PAW can be obtained from knowledge of the plant available water capacity (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 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 (see e.g. Routley 2010, Whish 2014, Dalgliesh 2014 and Fritsch and Wylie 2015).

Field Measurement of PAWC

Field measurement of drained upper limit (DUL), crop lower limit (CLL) and bulk density (BD) are described in detail in the GRDC PAWC Booklet '[Estimating plant available water capacity]' (see Resources section). Briefly, to determine the drained upper limit 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 crop lower limit 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.

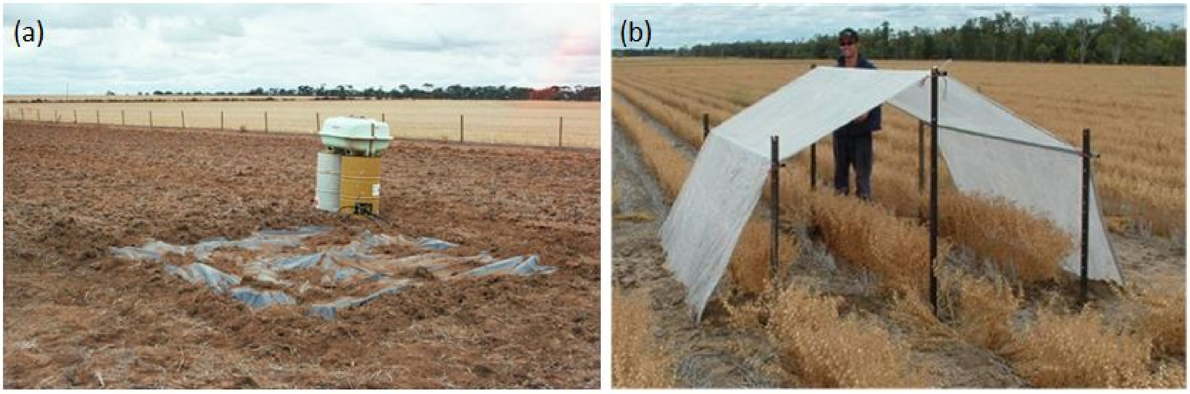


Figure 2. (a) Wetting up for drained upper limit (DUL) determination and (b) rainout shelter used for crop lower limit (CLL) determination.

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 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 drained upper limit (DUL) or crop lower limit (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.

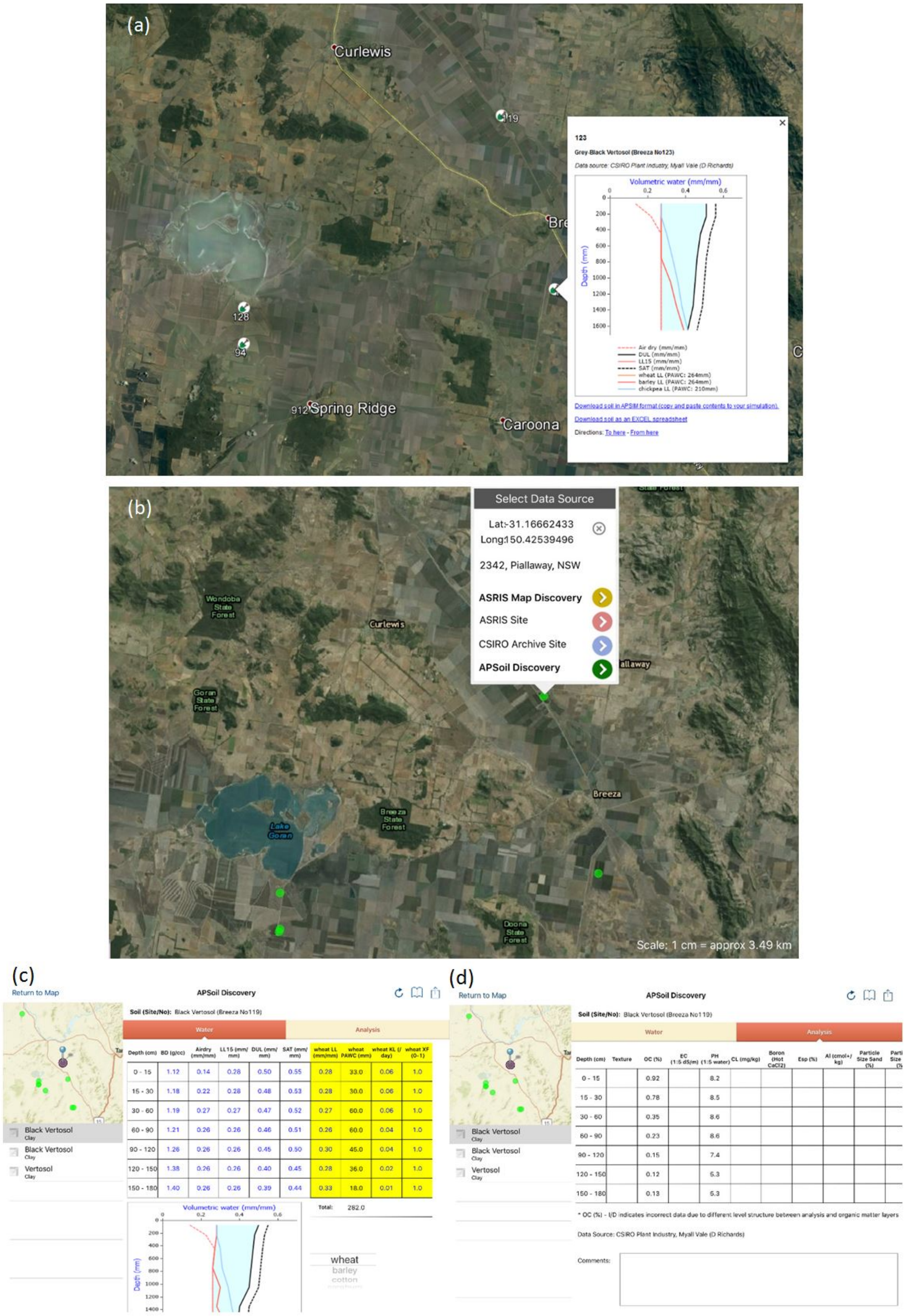


Figure 3. Access to geo-referenced soil PAWC characterisations of the APSoil database via (a) Google Earth and (b) SoilMapp; (c, d) APSoil discovery screens in SoilMapp.

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 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 more tightly held water. This affects the amount of water a soil can hold against drainage (drained upper limit - DUL) as well as how much of the water can be extracted by the crop (crop lower limit - 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, sodicity, toxicity from aluminium or boron and extremely high density subsoil may limit root exploration, sometimes reducing the PAWC bucket significantly.

The crop lower limit 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 crop lower limit for a single crop. The crop lower limit for wheat, barley and oats are often considered the same and that of canola can be found to be similar as well, but care needs to be taken with such extrapolations 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, a pdf of which is available for free online (see Resources section).

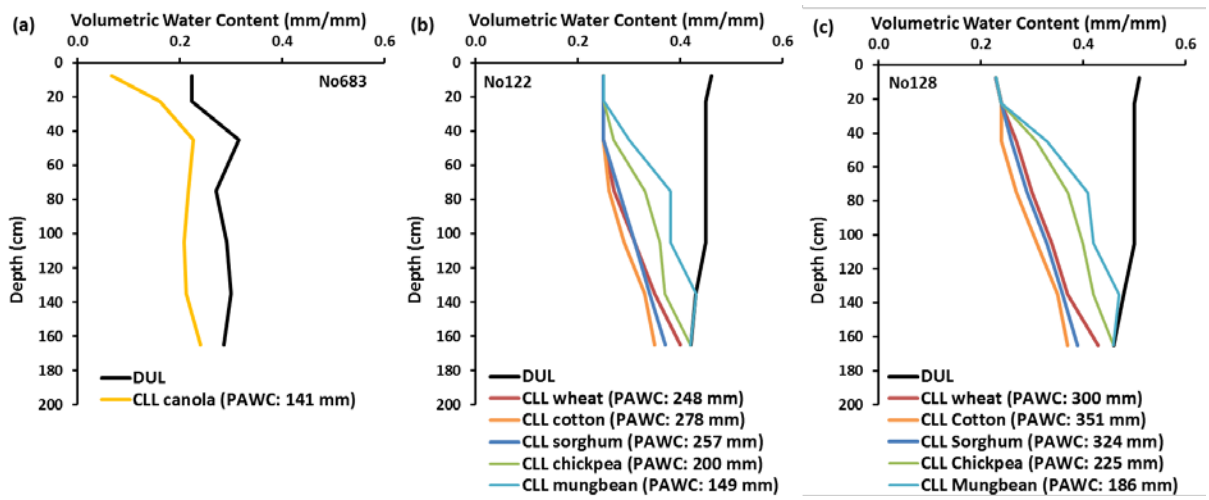


Figure 4. Select soil PAWC characterisations from Trangie and the Liverpool Plains.
(a) Sandy clay loam (APSoil No683) near Trangie NSW. Alluvial sediment formed on a meander plain of the Macquarie River more than 150,000 years ago. There is a higher proportion of sand, particularly in the surface of this soil which causes the lower PAWC.
(b) Vertosol on quaternary basaltic alluvium of Coxs Creek in the Liverpool Plains near Boggabri NSW (APSoil No122). Due to the high clay content the soil has a large PAWC, but its size depends on crop type.
(c) Vertosol on footslopes in Jurassic basalts and associated alluvium south of Goran Lake NSW (APSoil No128) has a large PAWC bucket exhibiting similar crop type effects. The mineralogy of the soil contributes to the very large PAWC.

Liverpool Plains soils and their landscape context

Within the Liverpool Plains cropping is practiced mainly on the heavy shrink-swell soils (Vertosols) of the plains and footslopes of basaltic origin. The high clay content of these soils means that many of the soils have relatively large PAWC of 200-350 mm. There are some subtle differences in response to clay mineralogy (related to parent material composition) and texture (e.g. inclusion of sand or fine gravel), which explain the variation within that range. Larger variation in PAWC within the Liverpool Plains is, however, caused by subsoil constraints, in particular subsoil salinity. These can limit root water uptake quite dramatically and can reduce PAWC by as much as 50%.

A report published last year (Verburg et al. 2017) describes fifteen new PAWC characterisations in the Liverpool Plains that were undertaken in recent years. These have enhanced the coverage of different soil types within the Liverpool Plains considerably. The location of new and existing PAWC characterisations in the Liverpool Plains is shown in Figure 5, along with some of the key PAWC profiles.

Extrapolating from these PAWC characterisations to predict PAWC at a location of interest 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. In many landscapes, including the Liverpool Plains, the soil properties are tightly linked to a soil's parent material, development and position in the landscape and these same aspects underpin the many soil and land resource surveys that have been carried out over the years and that are increasingly becoming available on-line. This suggests that we can draw on this information to assist with PAWC prediction.

The report by Verburg et al. (2017) examined to what extent we may be able to generalise from the PAWC characterisations within the Liverpool Plains by drawing on the available soil-landscape information. This information grouped soils derived from similar parent material and/or in similar landscape position. It allowed some tentative hypotheses to be developed, which will be tested further in the current GRDC project 'Methods to predict plant available water capacity (PAWC)'.

For example, the Black Vertosols situated on the mid to lower, gentle and long footslopes of the Liverpool Ranges are likely to have a PAWC of 250-300 mm for the deeper rooting crops like wheat, sorghum and cotton (see e.g. APSoil No 1168 in Figure 5j which had similar PAWC as APSoil No 1167, 867, 868). Subsoil salinity may reduce the PAWC for Grey Vertosols at the footslope-plain junction where drainage can be impeded. Soils on the footslopes in Jurassic basalts and associated alluvium (e.g. APSoil No 94, 127, 128 south of Goran Lake) appear to have a higher PAWC due to the different mineralogy (Jurassic Garrawilla volcanics; see e.g. APSoil No 128 in Figure 5k), provided the rooting depth of the crop is not limited by soil depth (higher landscape positions) or subsoil constraints (lower landscape positions).

The PAWC characterisation No 1174 near Kelvin NSW is in an alluvial fan landscape of slightly different parent material. Its mineralogy and/or slightly coarser texture likely contribute to the slightly lower PAWC (~ 240 mm to 1.8 m; see Figure 5d).

In the broad alluvial plains of the Coxs' Creek and the Mooki River, Vertosols without subsoil constraints/salinity often achieve a PAWC of 250-300 mm (see e.g. Figure 5a (No 1171), Figure 5c (No 122), Figure 5e (No 119) and Figure 5i (No 1306)). Other similar PAWC characterisations include APSoil No 1172, 123 and 1309. Subsoil salinity can, however, dramatically reduce this PAWC, see e.g. Figure 5b (No 1170) and Figure 5h (No 1307). In the upper reaches of the Mooki River where the alluvial plains are constricted between low sandstone hills, saline water tables are generally higher, reducing the PAWC slightly compared to the broader plains further north (e.g. Figure 5g (No 869)).

Alluvial plains in which the materials were deposited under more variable conditions, may have coarser texture (throughout the soil or in particular layers) reflecting periods of higher energy deposition. The higher concentration of sand will reduce the PAWC slightly (e.g. Figure 5f (No 1166)).

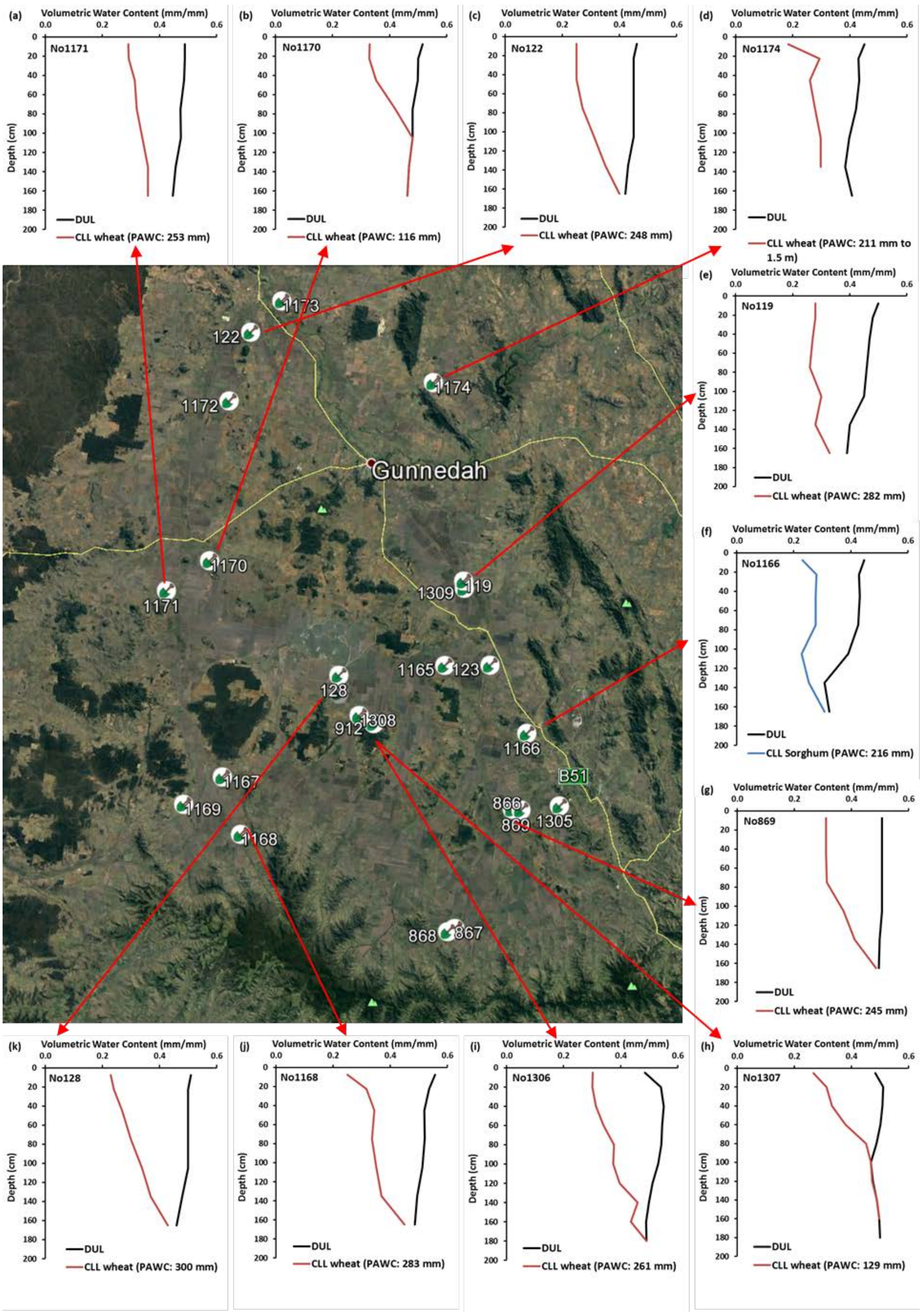


Figure 5. Select wheat and sorghum PAWC characterisations (to 1.8 m) from the Liverpool Plains.

Using information on soil-landscape associations

The information on soil-landscape mapping in the Liverpool Plains can be accessed through the eSPADE tool (see Resources section), which delineates the soil-landscape units and provides a description and typical soil profiles for each unit (see Figure 6).

APSoil No 128 (Figure 4c, Figure 5k) falls within this soil-landscape unit and soils are expected to have large PAWC, except where soil depth limits crop rooting (upper slopes) or where rooting is constrained by subsoil salinity (lower slopes towards Lake Goran).

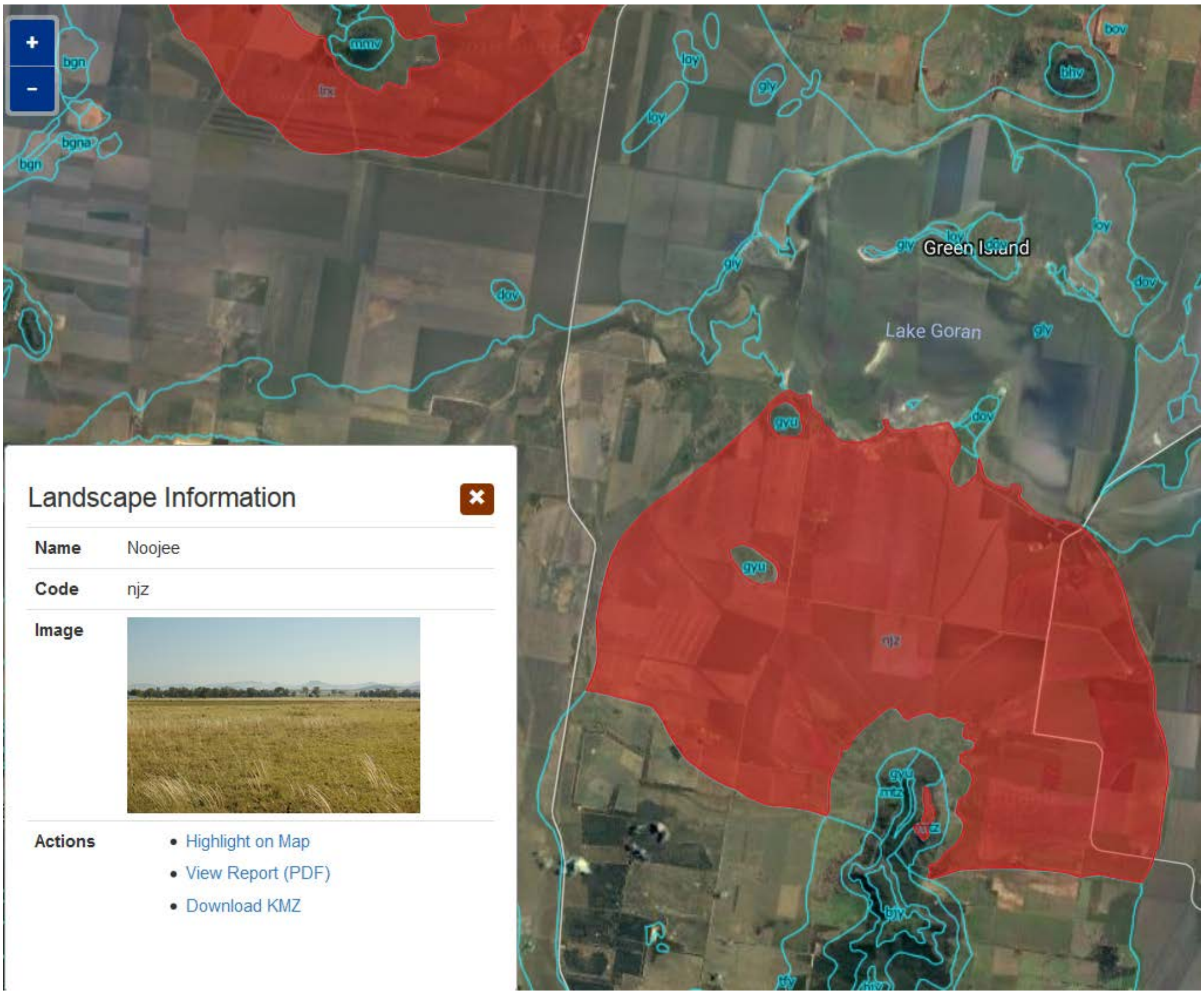


Figure 6. Example of soil-landscape mapping available for the Liverpool Plains through eSPADE. Mapping unit description is available through a pdf report.

Another resource that may prove useful in the future but is still undergoing testing for its use in predicting PAWC profiles, is digital soil mapping. The Soil and Landscape Grid of Australia (see Resources section) provides predictions of soil properties for 6 different layers (e.g. clay%, sand%, organic carbon %, pH) and landscape attributes (e.g. slope) at a spatial resolution of 90 m x 90 m. eSPADE provides a similar resource of modelled soil attributes (0-30 and 30-100 cm depth). These property maps could be used to predict PAWC directly.

The eSPADE tool also includes predictions of electrical conductivity (EC), which is an important indicator for subsoil salinity. This can be used to identify areas where the risk of subsoil salinity reducing PAWC may be higher. In Figure 7 the EC prediction highlights known areas where subsoil salinity can occur west and south east of Lake Goran. It is important to note, however, that these are

predicted properties based on modelling of data obtained in soil surveys. It is important that the predictions are verified on the ground, e.g. through soil analysis of soil cores or electromagnetic (EM) mapping. Subsoil salinity can vary dramatically over short distances – the two PAWC characterisations located north of Spring Ridge NSW with contrasting PAWC due to subsoil salinity (Figure 5h and 5i) were only 2 km apart.

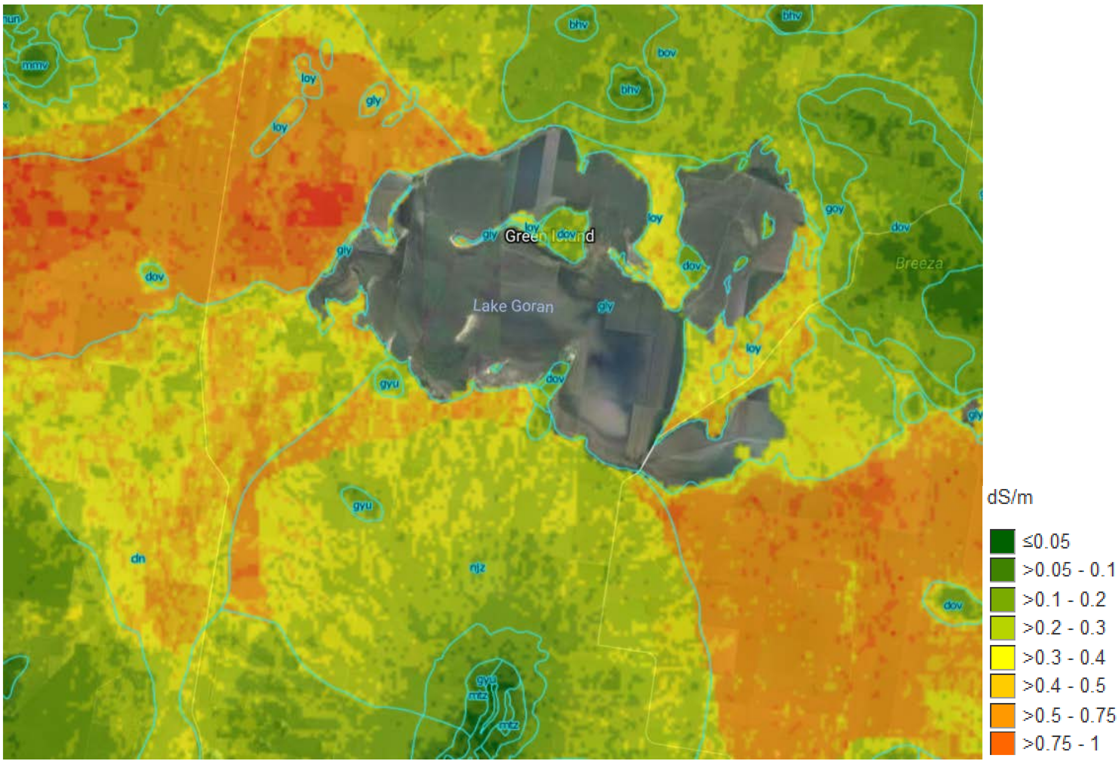


Figure 7. Example of *predicted* soil properties available for the Liverpool Plains through eSPADE: EC for 30-100 cm layer.

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. We also gratefully acknowledge the contributions of CSIRO colleagues and many collaborators and farmers to the field PAWC characterisations. In the Liverpool Plains these included Dick Richards and Michael Bange (CSIRO, Narrabri), George Trumann (LLS), Graeme Schwenke (DPI), consultants Pete McKenzie and Jim Hunt, and local growers. The information on PAWC presented in this paper heavily draws on the work over many years by Neal Dalgliesh (CSIRO). Discussions with him and others, including with those involved with soil-landscape mapping in NSW (Neil McKenzie, Rob Banks, Brian Murphy and Neroli Brennan) were invaluable for the development of concepts and ideas presented in this paper.

Resources

APSoil database: http://www.apsim.info/Products/APSoil.aspx (includes link to Google Earth file)

SoilMapp (soil maps, soil characterisation, archive and APSoil sites): Apple iPad app available from App store; documentation: https://confluence.csiro.au/display/soilmappdoc/SoilMapp+Home

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

Soil and Landscape Grid of Australia: http://www.clw.csiro.au/aclep/soillandscapegrid/

eSPADE v2.0 (soil-landscape and land systems mapping and reports, reports on soil characterisation sites from various surveys): http://www.environment.nsw.gov.au/eSpade2Webapp

Yield Prophet®: http://www.yieldprophet.com.au

Yield Prophet Lite: http://www.yieldprophet.com.au/yplite/

SoilWaterApp: Apple iPad app for estimating soil water during fallow and crops

References

Dalgliesh N (2014) Practical processes for better soil water management. GRDC Update paper. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/02/Practical-processes-for-better-soil-water-management

Fritsch S, Wylie P (2015) Managing the yield gap to achieve your yield potential on the western Downs. GRDC Update paper. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/07/Managing-the-yield-gap-to-achieve-your-yield-potential-on-the-western-Downs

Routley R (2010) Water use efficiency – Optimizing farming systems performance and balancing fallow length and sowing decisions. GRDC Update paper. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2010/09/water-use-efficiency-optimizing-farming-systems-performance-and-balancing-fallow-length-and-sowing-decisions

Verburg K, Cocks B, Manning B, Truman G, Schwenke GD (2017) APSoil plant available water capacity (PAWC) characterisation of select Liverpool Plain soils and their landscape context, CSIRO, Canberra. https://www.apsim.info/Products/APSoil.aspx

Verburg K, Thomas M, Austin J, Glover M, Stockmann U (2018) GRDC Northern Region scoping study: Available soil information to support prediction of PAWC. CSIRO, Australia. https://www.apsim.info/Products/APSoil.aspx

Whish J (2014) Sorghum yield risk vs starting soil moisture. GRDC Update paper. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/08/Sorghum-yield-risk-vs-starting-soil-moisture

Contact details

Dr Kirsten Verburg
CSIRO Agriculture and Food
GPO Box 1700, Canberra ACT 2601
Ph: (02) 6246 5954
Email: kirsten.verburg@csiro.au

® Registered trademark

Reserve phosphorus (P) and potassium (K) availability and release in northern region soils; effects of flooding and fertiliser bands

Chris Guppy[1], Phil Moody[2] and Matt Tighe[1]

[1]University of New England; [2]Department of Environment and Science, Queensland

Key words

Fertiliser bands, flooding, potassium, phosphorus, soil tests

GRDC code

UNE00022; UQ00078

Take home messages

- Blends of muriate of potash with ammonium phosphates and calcium phosphates may initially decrease soil solution phosphorus (P) particularly under wide row spacings at rates normally put down in deep bands.
- Potassium (K) application may best be done separately (spatially) to P and nitrogen (N) applications to limit formation of less soluble reaction products.
- Extended incubation of fertiliser bands suggests that compounds continue to drop out of soil solution with time and thus may not readily become plant available. Soil testing is ongoing to determine if this risk is high.
- Extended flooding mobilises reserve P and K minerals if soil carbon levels are high, mainly through acidification of alkaline soils and reduction of iron (Fe) and manganese (Mn) compounds releasing the bound P.

Introduction

Declining soil fertility in the northern grains region has resulted in novel fertiliser application strategies and an awareness of the changes in phosphorus (P) and potassium (K) availability needed to increase grain production and optimise fertiliser recovery. Large reserves of P and K may exist in these soils and we have limited understanding of how to quantify them and how long they may remain to replenish existing available P and K sources. This brief paper updates growers and advisers on recent results related to fertiliser bands and flooding effects on the release and availability of P and K to the soil solution, and hence to plants.

Method

Fertiliser bands

The effect of mixing fertiliser in bands was tested on 4 soils with differing properties from the northern grains region. The four soils were: soil 1: Ferrosol (0-10cm); soil 2: upland Vertosol (0-10cm); soil 3: grey Vertosol (10-30 cm); soil 4: Kandosol (10-30 cm). Fertiliser rates equivalent to those occurring in the field (g fertiliser/m crop row @ 1m row spacing) were converted to (mg fertiliser/g soil) and incubated at field capacity for 10 days.

Fertiliser forms were applied to supply the following nutrient rates: N (nitrogen) 100kg/ha; P (phosphorus) 40kg/ha; K (potassium) 100kg/ha; and S (sulfur) 30kg/ha.

Treatments were:

1. MAP (mono-ammonium phosphate) @ 40 kg P/ha (not balanced for N)
2. MAP (as above) + KCl (potassium chloride)
3. DAP (di-ammonium phosphate) @ 40 kg P/ha (not balanced for N)
4. DAP (as above) + KCl (potassium chloride)
5. TSP (Triple Superphosphate) @ 40 kg P/ha (balanced for N)
6. TSP (as above) + KCl (potassium chloride)

After 10 days and 30 days, a 1:1 saturated paste was created with dried soil (25 g dried soil/25 mL deionised water water) and allowed to equilibrate for 16 hours before centrifugation and analysis of the soil solution pH and solution P concentration.

Flooding

Effects of flooding on P and K pools of 12 northern grains region soils were tested in two independent experiments carefully designed to maintain anaerobic conditions throughout. The first experiment used 4 soils and sampled over time to determine how long to incubate soils before they had reduced enough to see the effects of flooding on soil chemistry. Reduced soils (those with an Eh <100mV) have lost all of their free oxygen, and other oxidised species are used to accept electrons as carbon compounds are reduced. A further 8 soils, to increase the range of northern grains region soils examined were then flooded for 30 days prior to analysis.

Soils were simply maintained at field capacity prior to extraction (aerated), or flooded permanently and spiked with sugar to ensure soil carbon was high enough to use all of the oxygen and reduce the soils (anaerobic). $CaCl_2$- P and K, exchangeable K, Colwell- and BSES-P and tetra-phenyl borate extractable K (TBK), along with pH, Eh and electrical conductivity (EC) were then measured.

Results

Fertiliser bands

The effects of fertiliser form on soil solution pH and P concentration are shown in Figure 1. In all soils addition of KCl decreased soil pH and solution P concentration perhaps because of the increased ionic strength in the soil solution.

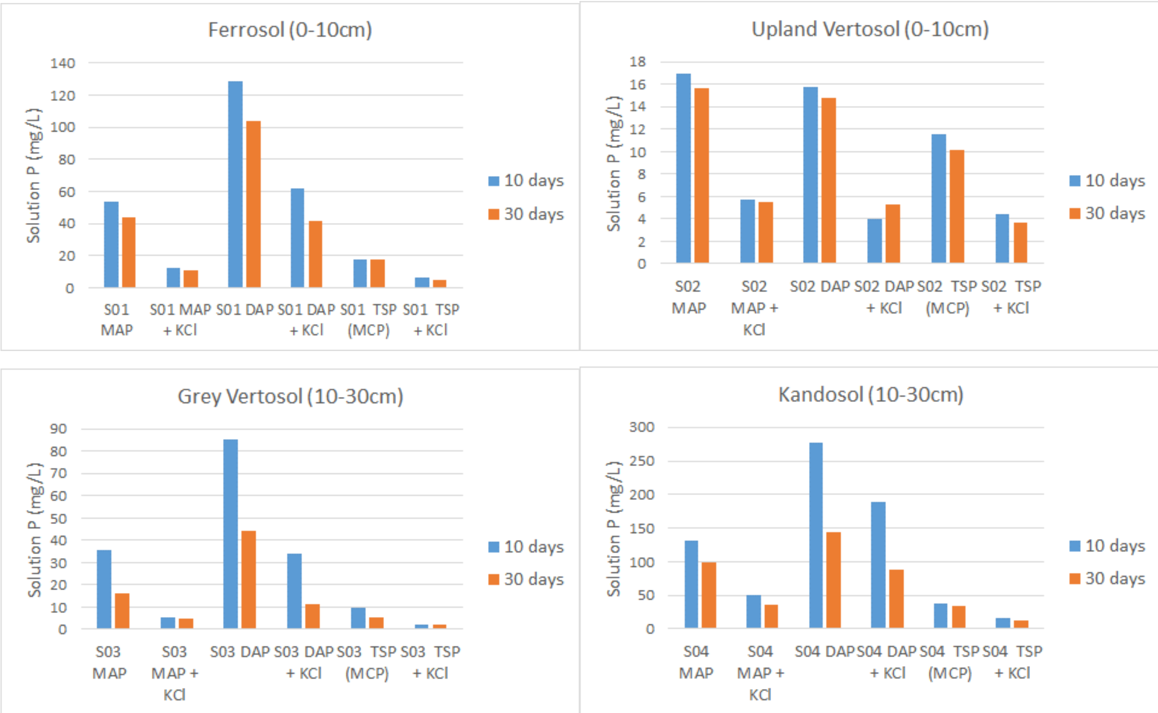


Figure 1. Effect of fertiliser form on soil solution pH and P concentration in fertiliser bands after 10 and 30 days incubation at field capacity for four soils from the northern grains region. Treatments in order from left to right are MAP, MAP and KCl, DAP, DAP and KCl, TSP, and TSP and KCl.

In soils 1, 3 and 4, solution P concentrations declined in the order: DAP>MAP>TSP; for soil 2, solution P concentrations were DAP=MAP>TSP. The addition of KCl to all P forms decreased solution P concentration in all soils.

The addition of KCl to any P source reduced soil pH. The pH is lower because the ionic strength (saltiness) is much higher, and H^+ ions are displaced from the soil surface. As the pH is lower, the likelihood that the loss of P from soil solution is due to the formation of calcium phosphates is less likely. This has been suggested by researchers in the past, as the high K^+ addition, displaces Ca^{2+}, raising the solution Ca and P concentrations to levels that may result in formation of calcium phosphates relative to the simple P additions alone. We are investigating if the lower soil pH associated with MAP relative to DAP when combined with KCl may have promoted the formation of potassium taranakites (potassium aluminium phosphates) or potentially struvites (magnesium ammonium phosphates). This may explain the lower solution P concentration observed in both soils with MAP+KCl than with DAP+KCl.

Over time the loss of P from solution following the addition of K did not reverse, and P availability decreased further as P reacted with soil surfaces within the band. Further work is needed to see what available P soil tests indicate about the effect of K addition to fertiliser bands is over time.

Flooding

pH & Eh

The pH of flooded soils were 0.3–0.7 unit lower than when aerated, when starting pH was alkaline. Acidic soils increased in pH upon flooding (Figure 2). All soils were anaerobic after 30 days flooding with Eh values ranging from -90 to -134 mV. These results are as expected when soil is flooded. Soils tend toward a pH of 7, and, if adequate carbon is present for microbial activity, flooded soils will have lower oxidation. The tendency for pH to rise in acidic flooded soils occurs because H^+ is consumed as oxidised compounds are reduced (NO_3, Mn oxide, Fe oxide, etc), releasing hydroxide (OH^-) and raising pH. In alkaline soils, the increase in respired CO_2 dominates. This dissolves in the water at higher concentrations, producing carbonic acids that lower the pH. Most flooded soils then end up with a pH between 6.7-7.2.

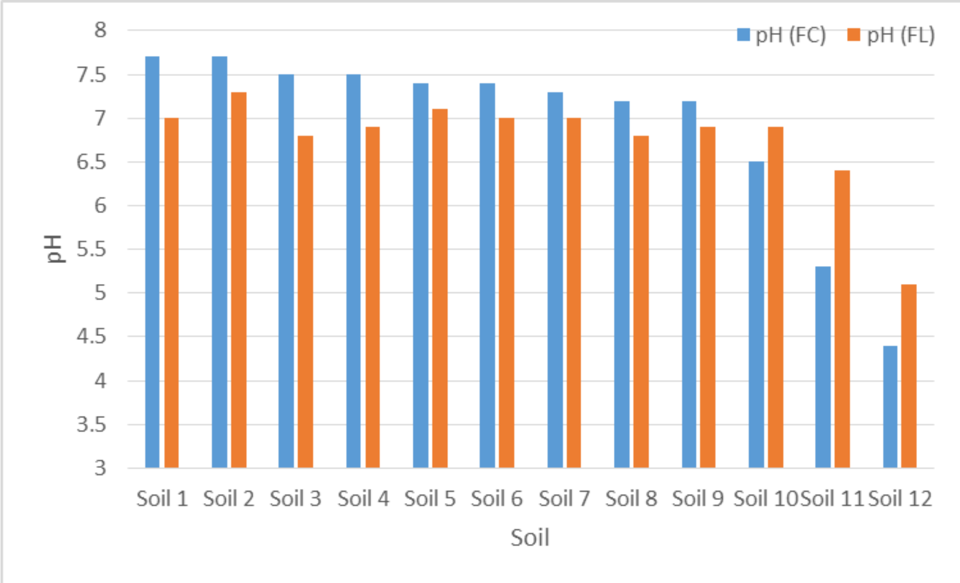


Figure 2. Effect of flooding (FL) on pH of 12 soils from the northern grains region after 30 days incubation. Values presented in order of decreasing starting pH measured at field capacity (FC)

Soil solution P and K ($CaCl_2$ extractable P/K)

Calcium chloride extractable P increased by 2–10 fold in most soils when flooded for 30 days (Table 1). Whilst solution P concentrations were typically low (1-4 mg P/kg), an increase in solution P concentration after flooding is likely, because the Fe (iron) oxide surfaces to which P is strongly attracted will dissolve; releasing the P. Flooding increased the $CaCl_2$–K in all studied soils by a factor of 3 (Table 1). Solution extractable K was 10-50% of exchangeable K in the range of soils tested. Part of the increase in solution K may be associated with dilution of the soils when flooded, but also related to cation exchange with soluble Fe^{2+}.

Table 1. Percentage (%) change in extracted P and K values for the 8 soils investigated in Experiment 2 incubated for a full 4 weeks under flooded conditions. Soils are ordered from alkaline to acid starting pH at field capacity and responses are the average of three replicates.

	$CaCl_2$ P	$CaCl_2$ K	Exchangeable K	BSES P	BSES K	Colwell P	TBK
Soil 1	339	31*	-16	33	5	-11	3
Soil 2	279	94*	-8	-2	-2	7	-7*
Soil 4	157*	89*	-3	-62*	-6	33*	-10*
Soil 7	71	94*	3	38*	6	47*	-19*
Soil 9	1149*	61*	-7*	298*	20	152*	-36*
Soil 10	405	137*	2	-6	0	41*	-2
Soil 11	142	101*	8	1	-3	-7	15
Soil 12	-13	167*	41*	274*	22*	30*	10

* Indicates significant increase or decrease in extractable concentration of P or K.

Note that some changes, though larger than other significant effects were not different, as the variation between replicates was higher in those soils.

Exchangeable K and Colwell P

Eight of the twelve experimental soils in this study showed a significant increase ($\geq$ 15%) in Colwell P when flooded (Table 1, Fig. 3). The increase in Colwell P of flooded soils in Experiment 1, (except in soil 4), was only observed at the second and final sampling, 15 and 30 days after flooding indicating that at least 2 weeks flooding is needed to reduce the soils and release the P (Figure 3). Increased Colwell-P values are expected on flooding due to reduced fixation to oxidic soil colloids that dissolve, releasing the P to the soil solution.

Exchangeable K did not change in response to 30 days of inundation in most soils. As exchangeable K measurements usually include solution K measurements, the redistribution of K upon flooding resulted in no change. Other studies have observed slightly reduced exchangeable K because the permanent charge is lower when the Fe is reduced. We did not observe that in our study.

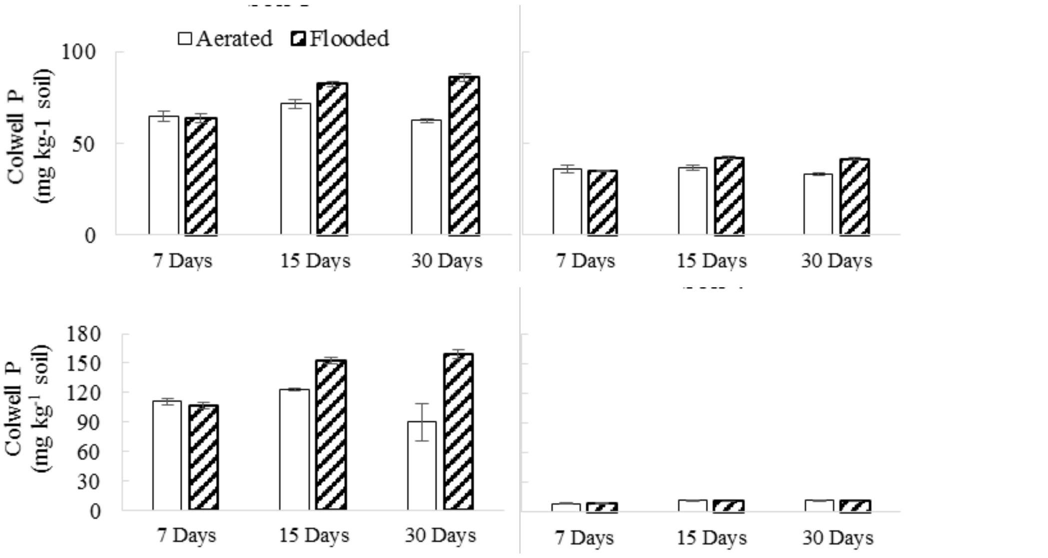


Figure 3. Bicarbonate extractable P (Colwell P) of 4 soils in Experiment 1 of the flooding experiments. Open bars represent field capacity condition (aerated) and hatched bars represent flooded condition (anaerobic) over 7, 15 and 30 days of incubation. Values are the means of 3 replicates with standard error bars.

BSES–P, BSES–K and TBK

BSES-P was not consistently affected by flooding. This was slightly unexpected, as previous work has demonstrated that acidification of solution does mobilise Ca phosphate sources, and flooding soil should lower solution P concentrations and encourage minerals to dissolve. Over time, we expect that this will happen, and at least some of the soils did have higher BSES-P and Colwell-P values following flooding.

BSES-K is not a routine soil test, and was correlated with exchangeable K (R^2 = 0.7) but not with TBK (R^2 = 0.4). BSES-K ranged between 25 and 60% of the values extracted by TBK. BSES-K was not affected by flooding soils. Higher solution K in 4 soils after flooding was accompanied by lower TBK and lower pH compared to the aerated ones. This may be associated with dissolution of some of K minerals in soils, e.g. micas and feldspars, in response to increasing acidification.

Conclusions

Band applied fertilisers have effects on soil solution pH, and solution P, Ca, Mg and K concentrations. In general, KCl addition with MAP, DAP and TSP lowers solution P concentration relative to the single P form added alone.

Irrespective of the bioavailability of the reaction products, the effect of KCl decreasing solution P concentration when applied with any P form will decrease the diffusion rate of P away from the fertiliser band, thereby reducing P supply rate to crop roots relative to the P form applied alone.

When soils are flooded, the main driver of change in P and K release is the shift in pH associated with redox changes in the soil. Alkaline soils fall in pH, and hence P and K minerals may dissolve. Acid soils increase in pH, and hence have a smaller effect on reserve P and K release. Practically, flood events do mobilise P and K, however the amount mobilised and the forms the minerals re-precipitate in upon oxidation following flooding are yet to be determined.

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. Result presented arose from GRDC funded projects UNE00022 and UQ00078.

Contact details

Chris Guppy
University of New England
Agronomy and Soil Science, UNE, Armidale, NSW 2351
Ph: 02 6773 3567
Fx: 02 6773 3238
Email: cguppy@une.edu.au

Irrigation water quality – Soil impacts over time? What constitutes poor quality? What can be managed? When is it better to not irrigate at all?

Chris Guppy, UNE

Contact details

Chris Guppy
University of New England
Agronomy and Soil Science, UNE, Armidale, NSW 2351
Ph: 02 6773 3567
Fx: 02 6773 3238
Email: cguppy@une.edu.au

Notes

Investigating the impact of rain-fed cotton on grain production in northern farming systems

Jon Baird[1], Gerard Lonergan[1], Lindsay Bell[2]

[1]NSW Department of Primary Industries, Narrabri, NSW
[2]CSIRO, Toowoomba, QLD

Key words

Northern farming systems, summer cropping, double cropping

GRDC code

DAQ00192

Take home messages

- Long fallow with good ground cover is paramount for preparing to establish a summer crop.
- November has the greatest probability of adequate planting conditions for summer crops in Northern grains regions.
- Chickpeas provided the best crop choice for double cropping in 2017 post the dryland cotton crop at Narrabri, due to high crop gross margins and its greater ability to extract soil moisture compared to wheat.
- Cultivating after dryland cotton crop did reduce cotton volunteers and ratoons by >100 plants/ha, but yield of the following chickpea crop was reduced by 42% in 2017.

Cotton's fit in a dry-land farming system

Rain fed cotton production is an integral part of dryland farming systems in the northern grain regions of NSW, and southern Queensland. New cultivars with greater lint yield potential, high commodity prices and improved moisture management with the uptake of minimum-till farming have resulted in greater areas of farming land purposely kept for growing dryland cotton. As a result, questions are being raised about the sustainability of growers committing to growing a long-season summer crop in an unpredictable rainfall climate, and its impact on their farming system.

Issues for growing cotton in a dryland farming system include: How to sequence back into grain crops? What crop to grow after the cotton crop? Does cultivation of the cotton ratoons impact yield potential, and if so for how long? If cultivation does not occur, what is the impact of ratoon and volunteer cotton control?

Issues such as planting moisture opportunity, gross margins, rainfall efficiency and the impact on crop sequencing are investigated by the GRDC-funded farming systems projects. In collaboration with the Queensland Department of Agriculture and Fisheries (DAF), CSIRO and the NSW Department of Primary Industries (NSW DPI), the farming systems program is focused on developing systems to better use available rainfall to increase productivity and profitability. We present results from 2 sources here that investigate the options for transitioning from a cotton crop back to a grain crop and the legacy impacts on subsequent crops in a dryland farming system.

Summer planting opportunities for dryland cotton

One of the major decisions growers have when sequencing a cotton crop is the probability of receiving ideal planting conditions. APSIM modelling was used to predict the probability for ideal planting conditions (i.e. 30 mm of rain over 3 days and plant available water > 100 mm) for two northern NSW sites (Spring Ridge and Narrabri) (1a) and south east Qld (Pampas)(1b). Simulations outputs were taken from simulations of crop sequences involving a summer crop following either a winter cereal or chickpea in the previous year (i.e. Wheat – chickpea - wheat - long fallow, or wheat - chickpea – long fallow). All simulations assumed no-till, full stubble retention, with optimum fallow weed management.

All three regions follow a similar trend, although Pampas achieves planting probabilities earlier than both Narrabri and Spring Ridge. The probability of planting summer crop at Narrabri is not as strong during the month of October compared to the other two sites. The models indicate that in approximately 25-30% of years there is a probability of meeting these sowing conditions in October, which is the optimum planting month for cotton in northern NSW (Cotton Seed Distributers, 2013). Importantly this shows that at both Breeza and Narrabri there is only a 65% probability of summer planting conditions occurring by the 15th December, meaning growers may miss out on ideal planting in 3 out of 10 years. On the eastern Darling Downs the simulations predict an extra 10% chance with 75% probability of planting before mid-December.

1(a) 1(b)

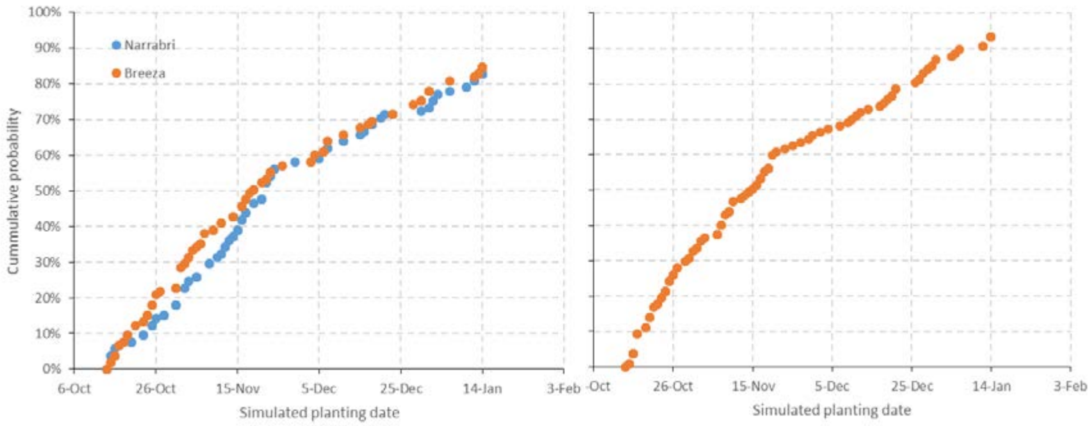


Figure 1. Summer planting opportunity for (a) northern NSW (Narrabri and Breeza) and (b) Pampas, Qld. Where conditions met >30 mm of rain over three days and >100 mm of PAW following a long-fallow after a winter cereal in the previous year (assuming no-till, full stubble retention and optimal fallow weed management).

Post-cotton crop management implications

A grain systems trial was established to evaluate selected farming system options post a cotton crop at the University of Sydney Narrabri research farm "Llara". The study initiated by the NSW DPI northern cropping systems team, investigated various farming management treatments after growing dryland cotton, in particular grain production, soil nutrition, weed control, pathogen levels and system gross margins.

In total six treatments were developed consisting of three crop choices (wheat, chickpeas and a cover crop - barley), and three post cotton cultivation practices (full cultivation, plant line ripping and no till).

The tillage treatments post the cotton crop included:

- No till: No cultivation with following crops sown directly into cotton stubble with a no till planter. Only herbicides were used to control cotton regrowth or volunteers.
- Plant line ripping: Ripping tynes cultivated along the plant line of the cotton crop to a depth of 30cm. No cultivation occurred between the plant lines
- Full cultivation: Offset discs were used twice to ensure full disturbance.

Following a rain fed cotton crop grown in the 2016/17 summer, tillage events occurred approximately 1 month after cotton harvest and subsequent crops were planted on the 26th June with approximately 40% of plant available water capacity (PAWC).

Grain crop yields

After the 2016/17 dryland cotton crop, there was low residual soil moisture in the profile (77 mm of plant available moisture to a depth of 120 cm). The implementation of the cultivation treatments further reduced the plant available water in both the full cultivation and plant line cultivation treatments (Table 1). Along with below average in-crop rainfall during the winter of 2017, these factors combined resulted in low grain yields for both wheat and chickpea. The no till systems resulted in greater grain yield for both crops. The wheat no till treatment yielded 0.28 t/ha higher than the wheat plant line cultivated treatment, while the chickpea no till yielded 0.275 t/ha higher than the chickpea plant line cultivated treatment. This equated to a yield difference of 38% for wheat, and 42% for chickpeas. Crop choice also impacted final grain yield with the wheat no till treatment yielding 34% higher than the chickpea no till treatment (0.97 t/ha and 0.64 t/ha respectively).

Table 1. Plant available water (PAW) after cultivation implementation and subsequent grain yield and crop biomass of wheat or chickpea crops following cotton at Narrabri, NSW (2017)

Site	Crop	Cultivation	Pre crop PAW (mm)	Yield (t/ha)	Crop biomass (t/ha)
Narrabri	Wheat	No till	78	0.97	2.5
Narrabri	Wheat	Plant line cultivation	67	0.70	2.4
Narrabri	Wheat	Full cultivation	56	0.67	2.3
Narrabri	Chickpea	No till	74	0.64	2.1
Narrabri	Chickpea	Plant line cultivation	64	0.37	1.5
Narrabri	Cover crop - barley	No till	79	NA	2.7

Economic returns of crops

An important aspect of the study based at Narrabri was to evaluate the economics of implementing the various management treatments. Due to the low yields, only two treatments were profitable after the 2017 winter harvest – no till chickpeas and no till planted wheat (Figure 2). Although both treatments did receive an extra herbicide than the cultivated treatments, the yield advantage resulted in higher gross margins. While crop choice did impact gross margin, as no till chickpeas resulted in a higher income than the no till wheat ($132/ha and $44/ha respectively). The results show that both cultivation and crop choice had an impact on the gross margin for the grain crop following cotton. For growers considering the value of planting a strategic cover crop after a dryland cotton crop, the farming system's 2017 cover crop (barley) resulted in a cost of $100/ha. The cost includes planting cost, seed purchase and herbicide applications and fallow maintenance up to December 2017.

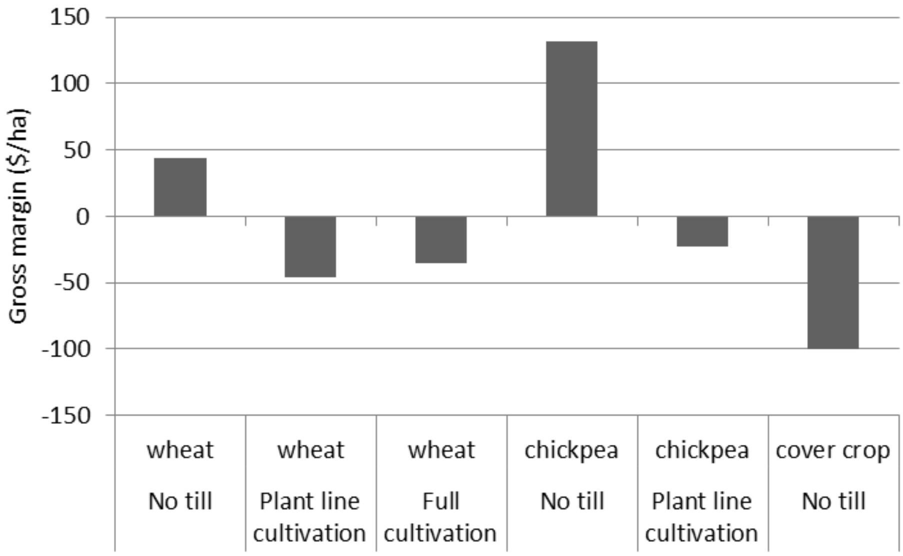


Figure 2. Crop gross margins post a dryland cotton crop from Narrabri, 2017. Grain values used for gross margin analysis are 10 year median prices at port, minus transport costs. Prices used at Narrabri include: wheat - $269/t and chickpea - $504/t

Crop water use efficiency (WUE)

After the 2016-17 rain fed cotton crop, there was 77 mm of plant available water (PAW) at the Narrabri farming systems site (equal to 42% of plant available water capacity (PAWC)). As expected, soil disturbance due to cultivation treatments led to a loss in soil water. The full cultivation reduced plant available water by 21 mm, while the plant line cultivation reduced plant available water by 12 mm. As a result the no till treatments had higher plant available water at planting. Subsequently, the no till chickpeas had the greatest crop water use for all the treatments planted in 2017 (189 mm, $p<0.05$). The impact of cultivation was highlighted by the three wheat treatments, with no till wheat using more moisture than plant line cultivated wheat, which in turn had higher crop water use than the fully cultivated wheat (178, 161 and 144 mm respectively).

While wheat had higher water use efficiency (kg grain/mm crop water use) than chickpea (4.6 and 3.4 respectively), a no till sowing operation resulted in higher water use efficiency than plant line cultivation for both crops (Table 2) ($p<0.001$).

Interestingly crop choice had an impact on the plant available water left in the profile after the 2017 winter crop harvest. There was an average of 57.8 mm plant available water for the wheat no-till and plant line cultivation treatments at harvest, while the chickpea averaged (for the same cultivation treatments) a lower amount of 42.5 mm. This result supports the theory that chickpeas can access more soil water than wheat. They were able to produce grain later in the season, while the wheat treatments were observed to have matured earlier due to moisture stress (Figure 3).

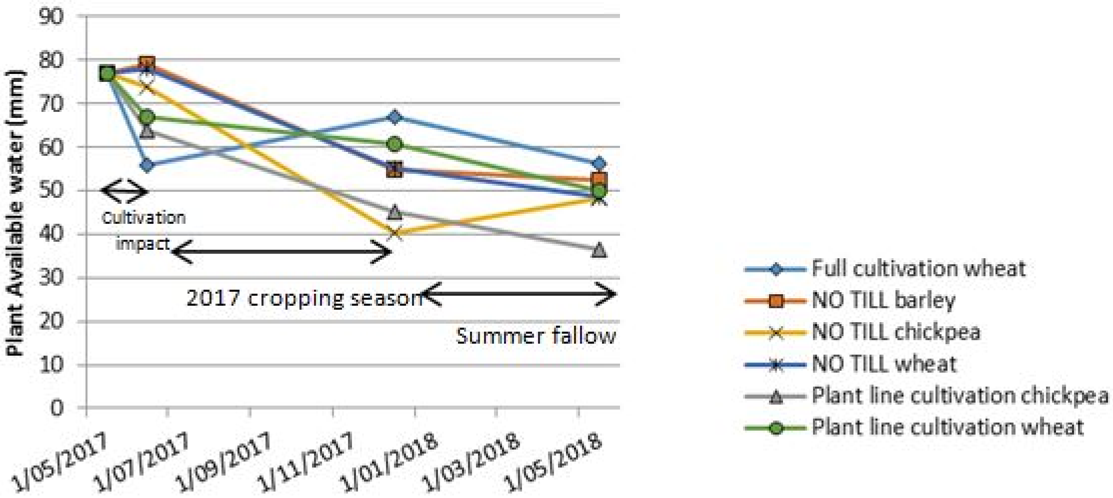


Figure 3. Plant available water, Narrabri 2017-18

Table 2. System water use efficiency, Narrabri 2017

Cultivation treatment	Crop	Crop water use (mm)	Water use efficiency (kg grain/mm/ha)
No till	Cover crop - barley	179	-
No till	Chickpea	189	3.4
No till	Wheat	178	5.5
Plant line cultivation	Chickpea	174	2.1
Plant line cultivation	Wheat	161	4.3
Full cultivation	Wheat	144	4.6
	l.s.d	31	2.4

Cotton regrowth and volunteer control

A major concern for growing rain fed cotton is the number of ratoon and volunteer cotton plants that occur after cotton harvest. Controlling ratoon and volunteers can be expensive and become hosts for pests and diseases. Weeds counts conducted 184 and 300 days after the harvest of the cotton crop show the longevity of the volunteers and ratoon plants. The application of the two cultivation treatments did reduce the number of cotton ratoons and volunteers, with the plant line cultivation having the greatest effect. While both the cultivation activities did incur an extra cost for the management systems, the higher number of ratoons and cotton volunteers resulted in extra herbicide applications for the no-till treatments.

It should be noted that there are no registered or consistently reliable herbicide options available for the control of cotton ratoon.

Table 3. Residual ratoon and volunteer cotton plant numbers (plants/ha) at Narrabri, at 184 and 300 days after cotton harvest

Cultivation	Crop	24/11/2017 184 (DAH)	19/03/2018 300 (DAH)
No till	Wheat	153	90
No till	Chickpea	103	11
No till	Cover crop	156	36
Plant line	Wheat	0	4
Plant line	Chickpea	3	1
Full cultivation	Wheat	26	33
	s.e	80	45

Crop yields following cotton compared to other crop sequences

Farming system trials at Narrabri and Pampas have provided opportunities to compare the yield of crops grown as a double crop after a summer crop, with the yield of crops grown after different previous crops in the cropping sequence. At both Narrabri and Pampas, cotton and sorghum crops were followed by a double crop of wheat. Here the yield of these wheat crops were compared with the yield of wheat crops grown after chickpeas followed by a summer fallow. As shown Table 4, a chickpea- fallow-wheat sequence clearly resulted in a higher yield at both the Pampas and Narrabri trial sites when compared to wheat yields following cotton or sorghum. The yield of the wheat crop following directly after cotton was 65% lower at Narrabri and 47% lower at Pampas compared to following chickpea. It must be noted that both Pampas and Narrabri received below average rainfall during the 2017 winter growing season, but the results show the large impact cotton has on the following crop's yield. At the Pampas site, it should also be noted the impact of a long season summer crop (cotton) compared to a shorter growing summer crop (sorghum). Wheat yield when double-cropped following sorghum yielded significantly higher than following cotton (1.75 and 1.06 t/ha respectively – Pampas 2017).

Table 4. Wheat yield at farming systems research sites Narrabri and Pampas in 2017 following cotton compared to other previous crop sequences.

Site	Previous crop	Crop	Pre-plant PAW (mm)	Wheat crop yield (t/ha)	Wheat crop biomass (t/ha)
Narrabri	Cotton	Wheat	78	0.97	2.5
Narrabri	Chickpea - fallow	Wheat	115	2.20	7.6
Pampas	Cotton	Wheat	146	1.06	3.38
Pampas	Chickpea - fallow	Wheat	188	2.01	6.73
Pampas	Sorghum	Wheat	181	1.75	5.58

The Pampas experiment also compared the impact of different summer crops (maize and cotton) on the pre-plant soil water and yield for subsequent summer crops (sorghum or mungbean) (Table 5). When cotton was the previous crop compared to maize, starting plant available water for the next summer crop was approximately 20 mm lower and yields of sorghum were reduced by 0.4 t/ha and yields of mungbean were reduced by 0.3 t/ha.

Table 5. Comparison of soil water pre-plant and subsequent grain yields of sorghum or mungbean crops following either cotton or maize the previous summer, Pampas 2017.

Previous crop history	Pre-plant PAW (mm) 01/09/2017	Sorghum yield (t/ha)[A]	Mungbean yield (t/ha)[B]
Maize – fallow	145	4.44	1.04
Cotton – fallow	127	4.04	0.73

[A] *cv.* Taurus, sown 3 Nov 17, soil N 150-180 kg/ha, 65 000 plants/ha
[B] cv. Jade, sown 8 Dec 17, 360 000 plants/ha

Conclusion

There are many challenges sequencing cotton in a dry land farming system. Firstly, growers need to evaluate the impact and risk of growing a long season summer crop in a variable climate with unreliable summer rainfall. Northern NSW and south-east Queensland do have high probability of adequate spring – summer planting conditions especially after a long fallow with good ground cover; however, the planting conditions may occur later than the ideal planting date for full lint yield potential.

The opportunity to plant a double crop after cotton in optimum conditions is limited; therefore, if growers do plant, the crop will benefit from capacity to tolerate moisture stress. At Narrabri, chickpeas stood out as the ideal second crop in a double cropping sequence, as they were able to extract a greater amount of soil moisture in a low moisture environment and also resulted in the greatest gross margin. Wheat and the cover crop (barley) did have greater biomass accumulation and did result in greater residual stubble cover, which may have a beneficial impact on future grain crops. While cultivating did have benefits such as reducing the cotton ratoons and volunteer numbers, the cost of the implementation on soil moisture caused significant yield reduction. If growers are able to defoliate their cotton within the regulated date, the ideal treatment is to leave the field in a no till situation. It is noted that there are no registered or reliable options for control of ratoon cotton with herbicides.

We have also found that the greater moisture extraction of cotton compared to other summer crop options can have legacy impacts that last > 12 months, resulting in lower grain yields compared to growing crops after other summer crop options. These negative impacts should be considered when evaluating the profitability of dryland cotton compared to other summer grain crop options (e.g. sorghum, maize).

References

Bell, L. et al (2015). "Improving northern farming systems performance". GRDC Update paper

Keating, B. A. et al (2003). "An overview of APSIM, a model designed for farming systems simulation". Europ. J. Agronomy 18: 21.

Cotton Seed Distributers. "A guide to dryland cotton". www.csd.net.au

Acknowledgements

The research undertaken as part of this project (DAQ00190 and CSA00050) 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 must also acknowledge the assistance provided by staff at the Pampas experimental site (Jack Mairs, Duncan Weir, John

Lawrence) and co-operators and hosts at 'Anchorfield' and 'Llara' who assist us implement this experiment in a variety of ways (too many to mention).

Contact details

Jon Baird
NSW Department of Primary Industries
21888 Kamilaroi Highway, Narrabri 2390
Ph: 02 6799 1520
Email: jon.baird@dpi.nsw.gov.au

Helicoverpa armigera resistance management in pulses, and recent research findings on Rutherglen bug

Melina Miles, Adam Quade, Trevor Volp, DAF Queensland

Key words

Helicoverpa armigera, resistance, chickpeas, mungbeans, soybeans, Rutherglen bug, canola

GRDC code

DAQ00196, UM00048 (NIRM)

Take home messages

1. The *H. armigera* resistance management strategy is designed to prolong the useful life of the newer chemistry currently available to pulse growers. Familiarise yourself with the strategy and the full range of options available for *Helicoverpa* control in chickpeas, mungbeans and soybeans. Consider what products you will use if a second spray is required in these crops.
2. Rutherglen bug adults are present in canola crops much earlier than was previously thought. Females are depositing eggs in the soil and leaf litter from early spring through to harvest. At this point, there is no obvious option for preventing the build-up of large populations of nymphs in canola stubble, but recent work is helping to understand how these populations develop.

The *Helicoverpa armigera* resistance management strategy (RMS)

This material has been extracted from the "Science behind the strategy" document available at https://ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies/

General rationale for the design of the strategy

Chickpeas and mungbeans are currently, and for the foreseeable future, the most valuable grains crops influenced by the RMS. Therefore, the resistance management strategy (RMS) is primarily focused on insecticide Modes of Action (MoA) rotation in these systems and is built around product windows for Altacor® and Steward® because:

1. Altacor® (chlorantraniliprole) is at risk from over-reliance in pulses, but resistance frequencies are currently low.
2. Steward® (indoxacarb) is at risk due to genetic predisposition (high level genetic dominance and metabolic mechanism) and pre-existing levels of resistance in NSW and QLD (with elevated levels in CQ during 2016-17). In addition, the use of indoxacarb in pulses may increase as generic products come on to the market.

There are two regions within the RMS, each with their own resistance management strategy designed to make the most effective products available when they are of greatest benefit, whilst minimising the risk of overuse:

1. Northern Grains Region: Belyando, Callide, Central Highlands & Dawson (Table 1)
2. Central Grains Region: Balonne, Bourke, Burnett, Darling Downs, Gwydir, Lachlan, Macintyre, Macquarie & Namoi (Table 2)

- The RMS provides windows-based recommendations common to these regions because *H. armigera* moths are highly mobile and have the capacity to move between these regions.

- No RMS is currently proposed for the Southern and Western grain regions (Victoria, South Australia and Western Australia) for winter crops. Biological indicators suggest that that the risk of *H. armigera* occurring in winter crops, at densities where control failures may occur, is presently considered low. *Helicoverpa* control in summer crops in these regions should use the Central Grains region RMS.

Use of broad-spectrum insecticides

The early use of synthetic pyrethroids (SPs) in winter pulses (August – early September) is adopted where the assumption is made that early infestations of *Helicoverpa* will be predominantly *H. punctigera* which are susceptible to SPs. Similarly, the use of carbamates to delay the application of Group 28 or Group 6 products, carries risks. If adopting this strategy, be aware of the following risks:

- Recent monitoring with pheromone traps has shown *H. armigera* to be present in all parts of the Northern Grains region from early August (www.thebeatsheet.com.au).
- Reduced efficacy of SPs and carbamates against *H. armigera* can be masked when treating very low population densities (< 3/sqm).
- If *H. armigera* are present, even at low levels in a population treated with SPs or carbamates, the treatment will select for further resistance. Whilst initial applications may be effective, later treatments may be significantly less effective.

Table 1. Grains resistance management strategy for *Helicoverpa armigera* across Australia. Best practice product windows and use restrictions to manage insecticide resistance in *H.armigera.* **Northern Region: Belyando, Central Highlands, Dawson and Callide.**

SELECTIVITY: Increasing ↑ / Decreasing ↓

Insecticide	June				July				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr				May			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Bacillus thuringiensis																																																
Helicoverpa viruses																																																
Paraffinic oil (Note 1)																																																
Chlorantraniliprole (Note 2, 3)																																																
Indoxacarb (Note 4)																																																
Spinetoram (Note 2, 4, 5)																																																
Emamectin benzoate (Note 2, 4, 5)																																																
Carbamates (Note 2, 4 6)																																																
Pyrethroids (Note 2, 4, 7)																																																

No restrictions	DO NOT USE during this period	No more than one application per crop per season	No more than two applications per crop per season

ADDITIONAL INFORMATION

Notes:

1. Some nC27 paraffinic spray oils can be used to suppress Helicoverpa populations and are best used as part of an IPM program.
2. Observe withholding periods (WHP). Products in this group have WHP 14 days or longer.
3. Maximum one spray of chlorantraniliprole alone or in mixtures per crop per season.
4. Refer to label for warning of insecticide risk to bee populations.
5. Maximum two consecutive sprays alone or in mixtures per crop per season.
6. MODERATE RESISTANCE IS PRESENT IN *H.ARMIGERA* POPULATIONS – FIELD FAILURES LIKELY.
7. HIGH RESISTANCE IS PRESENT IN *H.ARMIGERA* POPULATIONS – FIELD FAILURES EXPECTED!

Table 2. Grains resistance management strategy for *Helicoverpa armigera* across Australia. Best practice product windows and use restrictions to manage insecticide resistance in *H.armigera.* **Southern QLD, Central & Northern NSW Regions: Balonne, Bourke, Burnett, Darling Downs, Gwydir, Lachlan, Macintyre, Macquarie & Namoi.**

Increasing ↑ SELECTIVITY ↓ Decreasing

Insecticide	June				July				Aug				Sept				Oct				Nov				Dec				Jan				Feb				Mar				Apr				May			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Bacillus thuringiensis																																																
Helicoverpa viruses																																																
Paraffinic oil (Note 1)																																																
Chlorantraniliprole (Note 2, 3)																																																
Indoxacarb (Note 4)																																																
Spinetoram (Note 2, 4, 5)																																																
Emamectin benzoate (Note 2, 4, 5)																																																
Carbamates (Note 2, 4 6)																																																
Pyrethroids (Note 2, 4, 7)																																																

No restrictions	**DO NOT USE during this period**	**No more than one application per crop per season**	**No more than two applications per crop per season**

ADDITIONAL INFORMATION

Notes:

1. Some nC27 paraffinic spray oils can be used to suppress Helicoverpa populations and are best used as part of an IPM program.
2. Observe withholding periods (WHP). Products in this group have WHP 14 days or longer.
3. Maximum one spray of chlorantraniliprole alone or in mixtures per crop per season.
4. Refer to label for warning of insecticide risk to bee populations.
5. Maximum two consecutive sprays alone or in mixtures per crop per season.
6. MODERATE RESISTANCE IS PRESENT IN *H.ARMIGERA* POPULATIONS – FIELD FAILURES LIKELY.
7. HIGH RESISTANCE IS PRESENT IN *H.ARMIGERA* POPULATIONS – FIELD FAILURES EXPECTED!

Table 3. Explanatory notes for product windows in all regions

<table>
<tr><th>Insecticide</th><th>Number of insecticide windows</th><th>Duration of insecticide windows</th><th>Maximum number of applications/crop/season</th></tr>
<tr><td>Chlorantraniliprole (Altacor®)</td><td>2</td><td>10 weeks</td><td>1</td></tr>
<tr><td colspan="4">10 week windows restrict selection to a maximum of 2 consecutive generations of H. armigera (includes 2-3 weeks residual beyond the end of each window i.e. 12-13 weeks total exposure).
Start date of first window correlates well with historical data relating to average daily temperatures that result in early pod-set.
Exposure of 2 consecutive generations is off-set by long non-use periods (8 weeks in southern/central region and 18 weeks in northern region).
Use is not recommended in spring mung beans as there is less likelihood of both H. armigera and bean pod borer being present.</td></tr>
<tr><td>Indoxacarb (e.g. Steward®)</td><td>Northern - 3
Central - 2</td><td>6 weeks</td><td>1</td></tr>
<tr><td colspan="4">6 week windows restrict selection to a single generation of H. armigera.
Each window is followed by a non-use period of a minimum of 6 weeks.
Indoxacarb is an important early season rotation option for chickpeas and faba beans, and provides a robust selective alternative to Altacor® when Helicoverpa pressure is high.</td></tr>
<tr><td>Bacillus thuringiensis</td><td rowspan="3">1</td><td rowspan="3">Season long</td><td>No restrictions</td></tr>
<tr><td>Helicoverpa viruses</td><td>No restrictions</td></tr>
<tr><td>Spinetoram (e.g. Success Neo®)*</td><td>2</td></tr>
<tr><td colspan="4">Low resistance risk and not widely used.</td></tr>
<tr><td>Emamectin benzoate (e.g. Affirm®)*</td><td>1</td><td>Season long</td><td>2</td></tr>
<tr><td colspan="4">Very low resistance frequency and not used widely.
However, emamectin benzoate is a good option for rotation to spread resistance risk away from Altacor®.
BUT industry needs to become more confident with using this product for it to be of value in resistance management.</td></tr>
<tr><td>Carbamates</td><td rowspan="2">1</td><td rowspan="2">Season long</td><td rowspan="2">1</td></tr>
<tr><td>Synthetic pyrethroids</td></tr>
<tr><td colspan="4">H. armigera resistance is present at moderate to high levels, but one strategic application per season in regions where H. punctigera predominates in early spring may be effective.
Carbamates are a rotation tool for indoxacarb and Altacor® either early season in chickpeas or late season in mungbean.</td></tr>
</table>

*Resistance monitoring for selective products is a key component of the RMS and changes in resistance frequencies will result in the introduction of product windows for those insecticides not currently windowed.

The number of uses in the RMS is more restrictive than stated on the Altacor® label, why?

To avoid repeated use of either Steward® or Altacor® within the use window, the number of allowable applications is 1 per crop. Whilst this is currently inconsistent with the Altacor label (2 applications per crop), we expect that there will be changes to the label to ensure consistency in these recommendations.

Does the RMS impact on recommendations for insecticide use in cotton and other crops?

The RMS is not intended to compromise the ability of the cotton industry to use any products registered for *Helicoverpa* in Bollgard® cotton. This is because selection for insecticide resistance is considered low due to the high likelihood that survivors of conventional sprays used in Bollgard cotton would be killed by Bt toxins expressed in plants. For further information go to: http://www.cottoninfo.com.au/publications/cotton-pest-management-guide.

Similarly, the RMS does not attempt to align the use of the Group 28s in mungbeans and chickpeas with use in other grain crops or horticulture. To do so would add a level of complexity that would make the RMS impractical.

Shouldn't other modes of action (MoA) be windowed to prevent the potential development of resistance to these products?

There is little evidence to suggest that other products should be windowed now to slow the development of future resistance. Both Affirm® (emamectin benzoate) and Success Neo® (spinetoram) show no sign of reduced susceptibility in testing (L. Bird, CRDC data). This result is consistent with the relatively limited use these products in the grains industry to date. If a shift in susceptibility is detected in future testing, it is the intention that the product/s will be windowed to limit selection pressure.

The SPs and carbamates are not windowed because there is already well established, relatively stable moderate-high levels of resistance to these MoAs, and limiting their use will not change this situation.

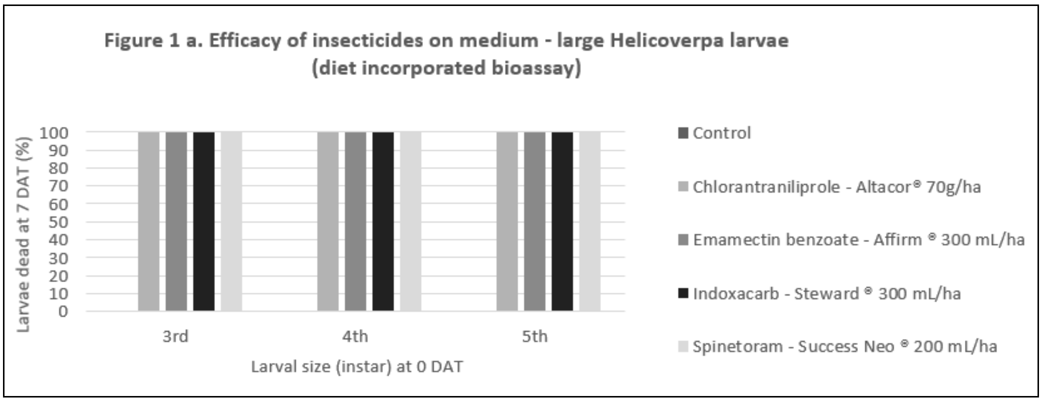
By restricting the use of just the 'at risk' products, keeping the RMS as simple as possible, and allowing maximum choice of registered products we anticipate that the grains industry will be more inclined to use the RMS.

What is the relative efficacy of the 'softer' options for Helicoverpa control in mungbeans and chickpeas?

In 2017, QDAF entomology undertook a number of trials to compare the knockdown/contact efficacy, and residual efficacy (persistence in the crop) of Altacor®, Steward®, Affirm® and Success Neo®. The purpose of these trials was to provide agronomists and growers with information on how well each of the products worked, and to provide confidence to use another option, rather than relying solely on the Group 28 products.

The results show that these products are equally effective on 3rd, 4th or 5th instar larvae that receive a lethal dose of the product – as would be achieved with good spray coverage (Figure 1a). However, there is considerable benefit in products persisting in the crop to control larvae that may hatch after the spray, or emerge from flowers, buds or pods where they may have been protected from an earlier application. The long residual efficacy Altacor ® has been a major factor in its popularity. The data in Figure 1b shows the relative efficacy of these products from 0 – 20 days after treatment in the field (at 5 day intervals).

For more information on the relative performance of these products in terms of feeding potential and recognising larvae affected by the different insecticides, see recent articles on the Beatsheet blog (www.thebeatsheet.com.au).



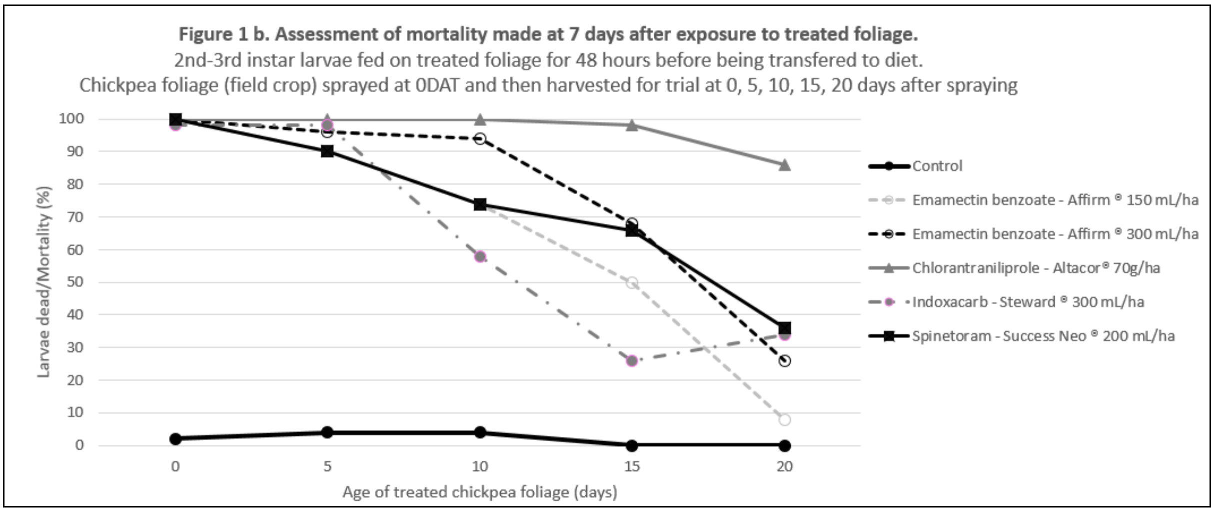


Figure 1. Relative efficacy (a) direct contact and (b) residual, of softer options for Helicoverpa control in chickpea and mungbean crops.

Rutherglen bug build up in canola – population dynamics during the 2017 season

In recent seasons, higher densities of Rutherglen bug (RGB) have been experienced. One of the challenges of this higher RGB pressure has been the movement of large numbers of nymphs from canola stubble into neighbouring summer crops. Through sheer weight of numbers, RGB nymphs can kill sorghum, cotton, soybean, corn and sunflower plants in the rows closest to canola. The movement of nymphs can occur over a period of weeks, and even regular spraying of the affected crops may not prevent significant crop loss.

Understanding how these enormous populations of nymphs develop is key to working out how they might be prevented, or managed, so that they don't affect neighbouring summer crops. Rather than focusing on controlling the nymphs, we were interested in whether there may be an opportunity to control the adults before they reproduce. During the spring of 2017, QDAF entomology monitored a number of canola crops, from the Darling Downs to the Liverpool Plains. We assessed the density of adults in the canola, dissected females to determine if they were reproductive (laying eggs), and assessed the crops for nymphs. We also attempted to determine the timing of egg laying by assessing the density of eggs – however, we were unable to do this effectively. Other than determining that eggs are deposited in the soil and on the leaf litter on the soil surface (not in the crop canopy), we could not reliably assess egg density.

Whilst this is only one season of data, it is presented here to highlight the following key findings.

RGB adults were present in the canola crops much earlier than we expected (Figure 2). Even at the most southerly site (Curlewis, NSW), RGB adults were present in canola from early August. At most sites, numbers increased through September and October.

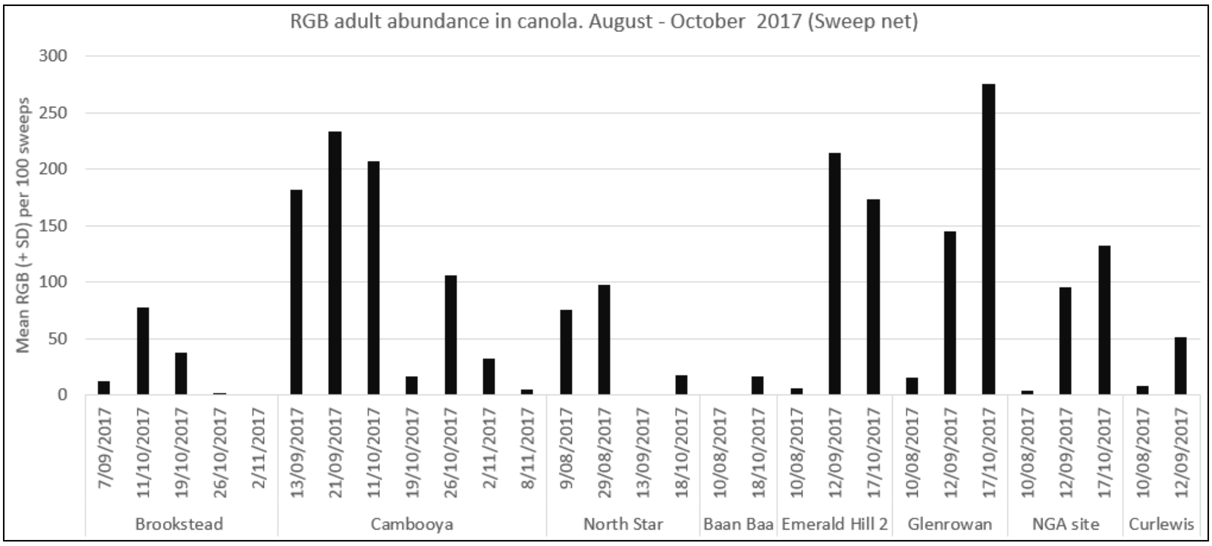


Figure 2. RGB adults were present in canola from late winter (August – September). (SD = standard deviation)

Female RGB were reproductive (had mature eggs in their ovaries ready to lay) from September onwards, and the percentage of the population that was reproductive increased from September through November (Figure 3).

Although the majority of female RGB were reproductive, and laying eggs, we did not see nymphs start to emerge until much later than expected based on the day degrees accumulated during this period (Figure 4).

It is possible that the development of eggs is slowed by the relatively cool temperatures experienced on the soil surface under the leaf litter and crop canopy. When the crop is harvested or windrowed, the temperature of the soil quickly rises, potentially resulting in synchronous hatching of eggs that have been laid over a period of 2-3 months.

More data is needed over additional sites and seasons to confirm our theory, and closer monitoring of soil temperature and RGB egg development is also needed to understand exactly what is happening.

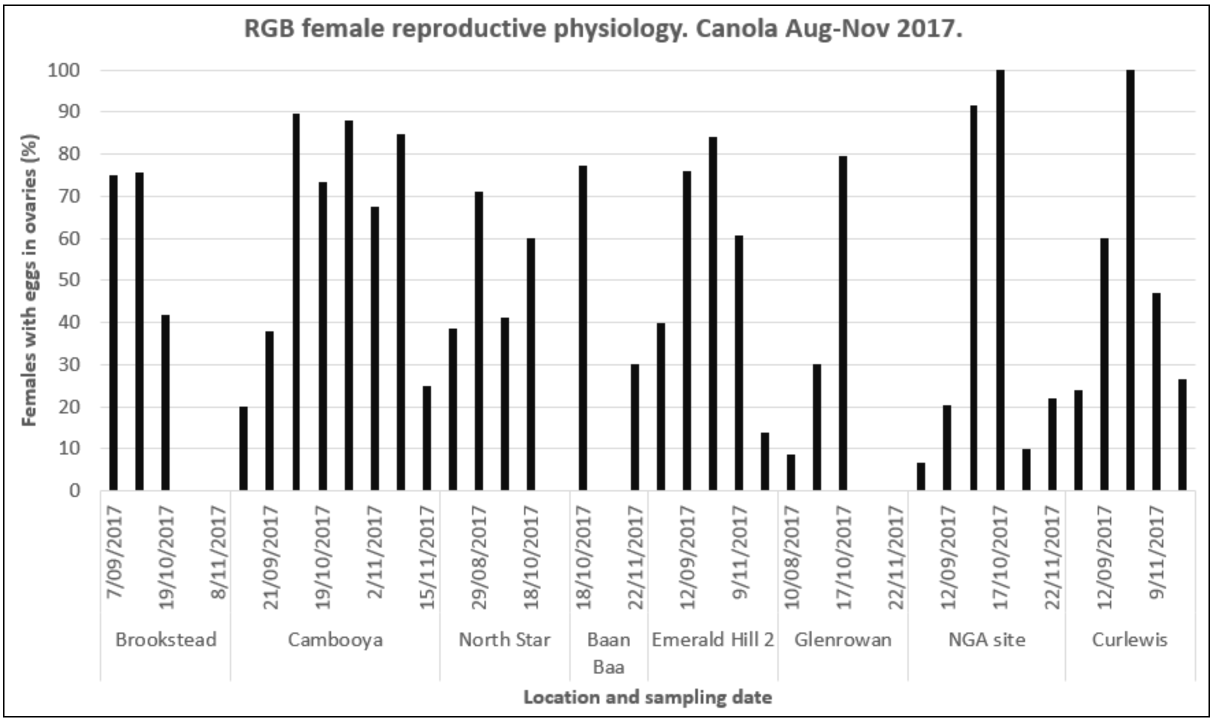


Figure 3. A high proportion of the female RGB sampled were laying eggs from September through November.

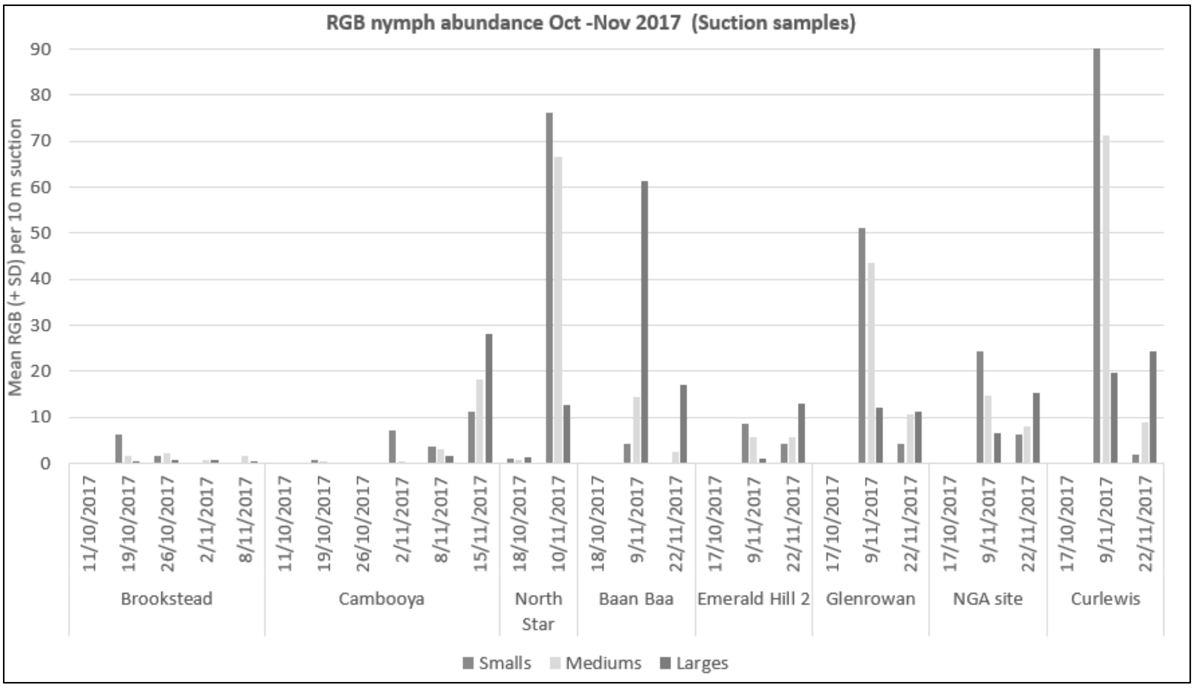


Figure 4. Nymphs did not start to emerge until much later than expected based on the day degrees accumulated during this period, despite the majority of female RGB being reproductive and laying eggs.

The take home message from this RGB work is that there doesn't seem to be an easy fix to prevent the build-up of RGB nymphs in canola stubble. The long period of egg laying by the females, and the potential challenges with controlling nymphs on the ground under the crop canopy, means that there is no obvious opportunity to prevent the population build up.

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.

Information on the *H. armigera* RMS is extracted from material prepared by NIRM to support the implementation of the RMS. The authors acknowledge the contribution of NIRM members to the development of this material.

We are grateful to the growers who allow us access to their farms and crops, and to the agronomists who assist us in locating potential field sites. We also thank the many growers and agronomists who share with us their experiences and insights into the issues they face and the practicalities of the management options we propose.

Reference

NIRM (2018) Science behind the Resistance Management Strategy for *Helicoverpa armigera* in Australian grains. https://ipmguidelinesforgrains.com.au/ipm-information/resistance-management-strategies/

Contact details

Melina Miles
Queensland Department of Agriculture and Fisheries
203 Tor St, Toowoomba. QLD 4350
Ph: 0407 113 306
Email: melina.miles@daf.qld.gov.au

® Registered trademark

Pushing a tropical crop into the arctic zone? Sowing sorghum into cold soil temperatures - risks and rewards

Loretta Serafin[1], Mark Hellyer[1], Annie Warren[1], Andrew Bishop[1] and Michael Mumford[2]

[1]NSW Department of Primary Industries, Tamworth
[2] Department of Agriculture and Fisheries, Toowoomba

Key words

Sorghum, agronomy, sowing time, soil temperatures, flowering, grain yield

GRDC code

DAN00195 Tactical sorghum and maize agronomy for the northern region – NSW component

Take home messages

- Plant establishment was significantly impacted by the super early (early August) and early (late August) sowing times when soil temperatures were between 8.4 and 12.2°C.
- Plant populations from the early August (super early) sowing, particularly at the Mallawa and Gurley sites, were approximately half the population established from the standard sowing time (October) when soil temperatures were consistent with or greater than current recommendations of 16-18°C.
- Viable plant stands were established at sub optimal temperatures and produced higher yields than the standard sowing time at Mallawa and Breeza. Sowing sorghum into cool soils has the potential to shift the flowering window and reduce the risk of heat and moisture stress during flowering and grain fill and increase the likelihood of double cropping opportunities.
- However, this is dependent on being able to establish the crop in a timely manner. At the Breeza site for example, the time taken for emergence was significantly lengthened for the early August and late August sowing. As a result there was little impact on flowering date achieved by varying sowing time compared to the standard window in late September.
- There is a need to further understand the effect of cool and freezing temperatures on germination, emergence, canopy and growing point development before the practice of "super early" or "early" sowing could be extended commercially across the northern grains region.

Background

Grain sorghum is the most important summer cereal crop in NSW, providing important rotational, logistical and cash flow benefits for the northern grains region.

Many in the industry would agree that climatic variability in the past 10 years has seen an increasing trend of crop yield reduction, and sometimes failure, as a result of sorghum crops flowering and filling grain in periods of extreme heat and moisture stress.

NSW DPI and GRDC have partnered in research to evaluate options for sorghum sowing and agronomic management that challenge our current practices. This includes our accepted views on ideal sowing time and hybrid selection by comparing alternative practices which could be readily adopted by growers using current genetics and technology.

Seasonal overview

Three sites were sown in northern NSW in the 2017-18 season; Gurley (south east of Moree), Mallawa (west of Moree) and Breeza on the Liverpool Plains. At each of these sites three treatments were included:

1. Varying time of sowing, based on soil temperature at 8am EST; super early (~ 10°C), early (14°C) and a standard (16-18°C) in an attempt to bring flowering and grain fill forward.
2. Varying sowing depth; standard (3-4 cm) and deep (7-8 cm) seeding depth to chase warmer soil temperatures.
3. Comparing cold tolerance of 9 commercial hybrids: MR Buster, MR Apollo, Cracka, Tiger, HGS114, HGS102, Archer, Agitator, G33.

The 2017-18 season produced three distinct environments as outlined in Table 1.

I. Breeza which experienced cool spring temperatures; 21 days with temperatures <0°C for the early August sowing; and warm summer temperatures 35 days >36°C;

II. Gurley which had mild and wet late spring conditions (109 mm in Oct), warmer flowering and grain fill conditions compared to Breeza;

III. Mallawa which had cool conditions for August (12 days <0°C) and then extreme heat (60 days >36°C) and dry summer conditions for December – January.

Table 1. Summary of weather conditions for sorghum trials sown during the 2017-18 season. Soil temperature is at 8 AM across seven days after sowing.

Site	Time of sowing	Sowing date	Sowing depth	Average Soil T (°C) at sowing	Mean max T (°C)	Mean min. T (°C)	In- crop rain-fall (mm)	*No.* days ≤ 0 °C	*No.* days ≥ 36 °C
Gurley (NE NSW)	Super early	2nd Aug	Shallow	10.8	29.8	13.7	315	2	39
			Deep	11.4					
	Early	21st Aug	Shallow	12.0	30.5	14.5	293	2	39
			Deep	12.2					
	Standard	17th Oct	Shallow	20.0	33.0	17.5	206	0	39
			Deep	19.1					
Mallawa (NW NSW)	Super early	1st Aug	Shallow	8.4	31.5	13.2	222	12	60
			Deep	10.5					
	Early	24th Aug	Shallow	9.2	32.7	14.6	222	6	60
			Deep	10.8					
	Standard	18th Oct	Shallow	18.6	35.2	17.9	149.5	0	57
			Deep	15.6					
Breeza (LP)	Super early	10th Aug	Shallow	9.7	29.3	11.6	225	21	35
			Deep	10.2					
	Early	28th Aug	Shallow	10.8	30.2	12.8	225	12	35
			Deep	11.5					
	Standard	21st Sept	Shallow	15.8	31.4	14.7	220	0	35
			Deep	15.7					

Statistical methods

A split-split plot design was employed at each of the 3 sites. The data was analysed using the REML procedure in ASReml-R and the level of significance for least significant difference (LSD) testing was set at 5%.

Results

Plant establishment

The early August (super early) sowing times established only half the number of plants compared to the standard sowing time (Table 2) at Gurley and Mallawa. Establishment improved for the late August (early) sowing but was still less than the standard.

In addition to the lower plant populations established, the time taken for these plants to emerge was substantially longer. For example there were no plants present until 3 weeks post sowing at Breeza for the two early sowings and plants were still emerging up to 6 weeks post sowing.

There was no difference in the establishment of hybrids except at the Mallawa site where Agitator had significantly lower establishment (data not shown).

Table 2. Established plant populations at sorghum trials sites - averaged across treatments

Site/ Established population (plants/m^2)	Super Early (early August)	Early (late August)	Standard (Mid Oct[1], Late Sept[2])	LSD value
Mallawa[1]	1.9	2.5	4.1	0.9
Gurley[1]	1.6	2.8	4.4	0.6
Breeza[2]	3.2	3.3	5.0	0.5

Days to flowering

There was a large reduction in the time taken to reach 50% flowering at the Mallawa site when moving from the super early (120-136 days) and early (105 -116 days) sowing times (Figure 1, i). The spread of flowering times between hybrids also became smaller with the later planting, from 16 down to 11 days.

Similarly, at Gurley the days to 50% flowering was reduced between each of the sowing times, super early (116 – 132 days), early (101-116 days) and standard (66-69 days) planting dates, as was the spread between hybrids (Figure 3,ii).

This equates to flowering in late November – mid December for the super early panting times and mid-December for the early sowing time at Gurley and Mallawa. The standard sowing time flowered between Christmas and New Year and so no dates were recorded. There was a significant TOS by hybrid interaction effect at both sites. Sowing depth had no significant impact on flowering date at either site.

At Breeza, there was very little impact of sowing time on days to 50% flowering with all three flowering similarly around early to mid-December. This is likely due to emergence being spread over an extended period at this site for the super early and early sowing times.

There was a significant hybrid effect with MR Buster and Agitator flowering much earlier than the other hybrids with MR Apollo being the slowest to reach flowering. This was a similar trend at the other two sites.

At the Breeza site only, the shallow sowing depth was quicker to reach 50% flowering than the deep sowing.

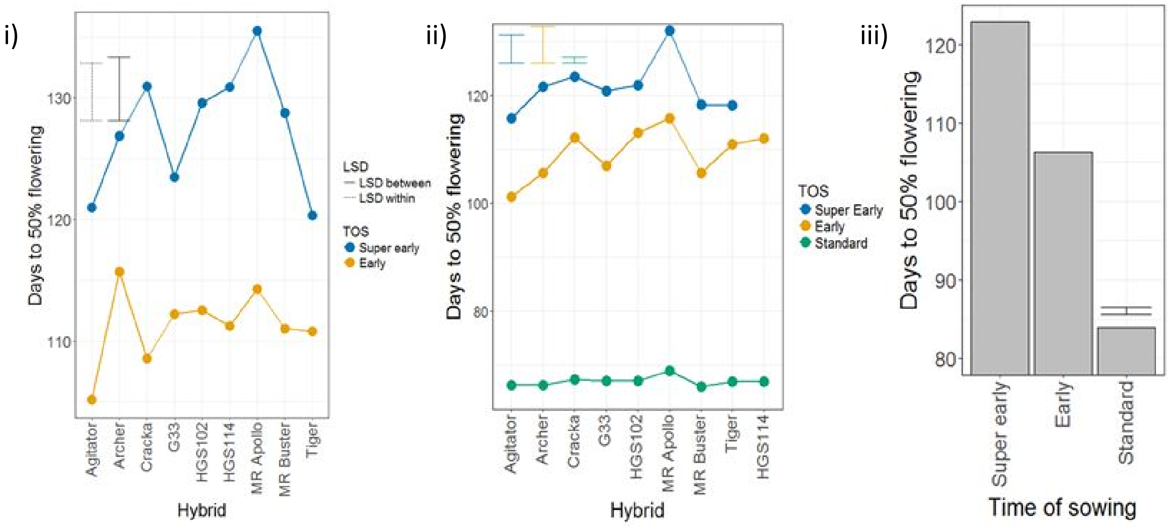


Figure 1. Days to 50% flowering at i) Mallawa, ii) Gurley iii) Breeza

Grain yield

Grain yields ranged from a low of 1.3 t/ha on average at Mallawa to 3.2 t/ha at Gurley and 3.4 t/ha at Breeza averaged across treatments at 0% moisture content.

At Mallawa the early August (super early) and late August (early) sowing time produced higher yields than the standard sowing time despite having highly reduced plant establishment (Figure 2). There was no difference in grain yield associated with varying the sowing depth (data not shown).

At Gurley, the standard October sowing performed generally better than the early August (super early) and late August (early) treatments. MR Apollo showed no significant response to time of sowing which was similar to the Mallawa site (Figure 2). MR Buster, Agitator and Archer showed the same relationship with the standard sowing time out yielding the super early and early sowing times. G33 and HGS102 showed similar yield performance for the super early and early sowing times.

For HGS102 there was a significant interaction between hybrid and seeding depth, with the shallow seeding depth increasing yield whilst other hybrids had no significant response to seedling depth.

At Breeza, yields were generally higher from the early August (super early) and late August (early) sowing times compared to the September sowing even though established plant populations were only two thirds of the plant stands achieved with the standard sowing time in September (Figure 2).

There was also a significant TOS by seedling depth interaction effect with the early TOS having a significantly higher yield than the standard TOS for the shallow but not the deep seedling depth. Archer, Cracka and MR Buster performed relatively well in terms of yield across all three times of sowing at Breeza. G33 and HGS114 performed well in the super early and early sowing times but were disappointing for the standard sowing time. Agitator did not perform well across the three sowing times at this site in 2017/18.

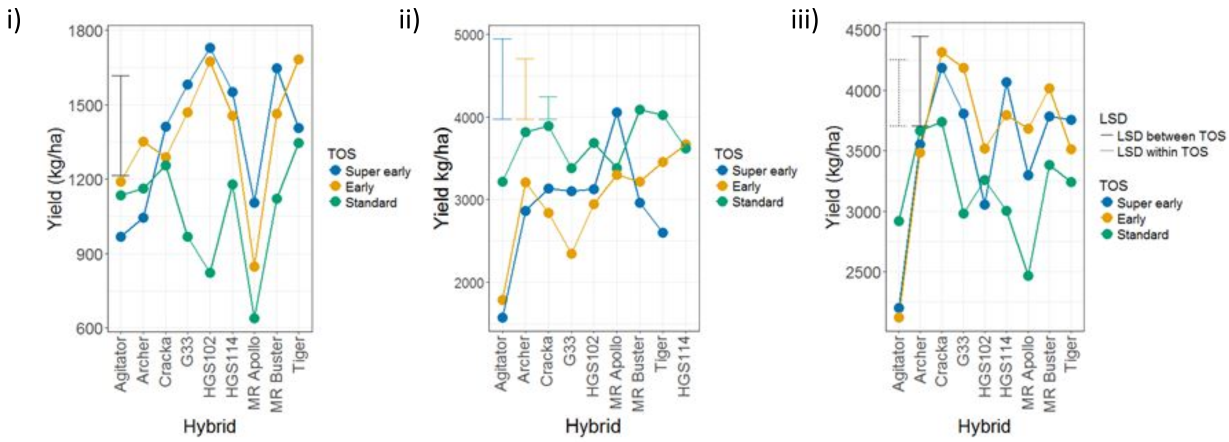


Figure 2. Grain yield at 0% moisture at i) Mallawa, ii) Gurley iii) Breeza

Conclusions

Growers currently have access to a range of tools to vary the time to flowering and the conditions experienced by their sorghum crops during grain fill. These tools are, however accompanied by an increased level of risk.

In this single year of research across three sites, benefits were minor from varying sowing depth to seek warmer soils for early sowing conditions. While differences in soil temperatures between the two depths shallow and deep were detected this did not equate to improvements in plant establishment or grain yield at two of the three sites.

Sowing in early and late August at all three sites, showed that sorghum can be established at sub optimum temperatures and handle some cold (<0°C) conditions. However, this early sowing time came at a significant establishment cost. Further, evaluation of the impacts of severe frosting on plant growth and survival are needed.

At Mallawa and Gurley, establishment was less than half that which occurred in the standard sowing time. Therefore a lot of seed never contributed to grain yields but an input cost had been incurred. The impact of drying soil conditions at these two sites needs to be considered also.

In contrast, at Breeza where soil moisture was controlled through irrigation, establishment losses from the early and late August sowing were still significant but not as great as the other two sites, when compared to the standard sowing time.

At all three sites viable plant stands were established. At Mallawa and Breeza, the two early sowing times resulted in superior yields compared to the standard sowing time. At Gurley it was the opposite, most likely due to the timing of in-crop rainfall.

Flowering data has shown that it is possible to move the flowering and grain fill window to earlier in the season, provided that the time taken for crop establishment is not excessively prolonged by cool early growing conditions such as occurred at Breeza. At Breeza there was little difference in days to flowering between all three sowing times even though sowing time varied from 10th august to 21st September.

It was not possible to detect many differences between hybrids with respect to cold tolerance in this year's field trials, due to confounding background genetics, seed production and quality attributes. A pot trial has been conducted to try and further separate some of these confounding factors.

As expected, these results should be considered preliminary as they are the results of three experimental sites in one season. It is hoped that this research can be continued into the future to further validate these preliminary findings.

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 and NSW DPI, the author would like to thank them for their continued support.

In particular thanks to our trial co-operators; Mark & Wendy Manchee, Gurley; Jason & Geoff Hunt, Mallawa and Scott Goodworth NSW DPI Breeza for their assistance with the sites.

Thanks to Delphi Ramsden, Alice Bowler and Simon Tydd for technical assistance.

Contact details

Loretta Serafin
NSW Department of Primary Industries
4 Marsden Park Road, Calala, NSW
Ph: 0427 311 819 or 02 6763 1100
Email: Loretta.serafin@dpi.nsw.gov.au

Site-specific physical weed control

Michael Walsh and Guy Coleman, University of Sydney

Key words

physical weed control, site-specific weed management, energy requirements

GRDC code

US00084

Take home messages

- Developments in sensing technology will soon allow the direct targeting of weeds within cropping systems
- Site-specific weed control creates the opportunity to use alternate physical weed control technologies
- Energy required to effectively control weeds is an effective approach to identifying suitable physical weed control techniques

Background

The reliance on herbicidal weed control has resulted in the widespread evolution of herbicide-resistant weed populations (Boutsalis et al., 2012; Broster et al., 2013; Owen et al., 2014). Changing regulations and expensive herbicidal development costs combined with the perennial threat of herbicide resistance, ensures future effective weed control is reliant on the inclusion of alternate weed control technologies in weed management programs. Physical weed control techniques were in use well before herbicides were introduced and the development of new options has continued throughout the era of herbicides. However, most of these new technologies have not been adopted, primarily due to cost, speed of operation and fit with new farming systems. The introduction of weed detection and actuation technologies creates the opportunity to target individual weeds i.e. site-specific weed management. This greatly increases the potential cost-effectiveness of many directional physical weed control techniques in conservation cropping systems.

Comparison of physical weed control technologies

There is a diverse array of effective physical weed control options with a proven ability to control weeds. The majority of these have not been commercialized and evidence of their efficacy relates to research findings, making cost-effectiveness comparisons difficult. While inputs and control methods differ significantly between physical control options, all systems share an energy requirement value for activation and use. Therefore, the energy required for effective weed control can be a reasonably accurate approach to comparing the efficiency and efficacy of physical control systems on an energy consumed per weed or hectare basis.

The direct energy requirements for the control of two-leaf weed seedlings were estimated from published reports on the weed control efficacy of a comprehensive range of physical weed control techniques (Table 1). To determine the energy requirement per unit area, a weed density of 5.0 plants m^{-2} was chosen to represent a typical weed density in Australian grain fields, based on results from a recent survey of Australian grain growers (Llewellyn et al., 2016).

Broadcast weed control

Broadcast weed control is defined as the indiscriminate use of a control method on a whole paddock basis when controlling weeds within crops or in fallow situations.

Chemical weed control

Herbicides are the most commonly used form of weed control in global cropping systems primarily due to their high efficacy and reliability. Herbicides are highly cost effective and have a relatively low energy cost of approximately 220 MJ ha^{-1}, covering manufacture and application. Importantly, herbicides remain the only broadcast weed control option that provides highly selective in-crop weed control and, therefore have been critical to the adoption of highly productive conservation cropping systems. No other currently available form of weed control offers similar weed control efficacy with equivalent crop safety.

Physical weed control

Historically, tillage was relied on for weed control as well as seedbed preparation and continues to be used extensively in global cropping systems despite the extensive reliance on herbicides. As a group, soil disturbance-based options are the most energy efficient form of physical weed control (Table 1) with no additional energy inputs beside the draft force requirements. Tillage acts to control weeds by uprooting plants, severing roots and shoots and/or burial of plants. Consequently, the efficacy and impact of this approach is reliant on rainfall and soil moisture. Effective control can only be achieved when disturbed weeds are exposed to a drying environment after the tillage operation. Although tillage can be a highly effective weed control option the soil disturbance involved is not compatible with conservation cropping systems and, therefore this approach needs to be used sparingly.

There are a group of thermal weed control technologies (flaming, hot water foaming and steaming etc.) using chemical or electrical energy that may be used for broadcast weed control (Table 1). In comparison to tillage and herbicide-based options these approaches are considerably more energy expensive. With 100 to 1000-fold higher energy requirements it is not surprising that these technologies have not been widely adopted for use in large-scale cropping systems, although in more intensive operations flaming is used to some extent.

Table 1. Total energy requirement estimates for physical weed control options currently available for broadcast application. Estimates are based on the control of two-leaf weeds present at 5 plants m^{-2}.

Weed control method	Energy consumption (MJ ha^{-1})
Plastic mulching	3
Flex tine harrow	4
Sweep cultivator	11
Rotary hoe	13
Organic mulching	16
Rod weeding	18
Spring tooth harrow	22
Basket weeder	29
Roller harrow	29
Disc mower	31
Tandem disk harrow	36
Flail mower	57
Offset disk harrow	64
UV	1701
Flaming	3002
Infrared	3002
Hot water	5519
Hot foam	8339
Steam	8734
Freezing	9020
Hot air	16902
Microwaves	42001

Site-specific weed control

The opportunity for substantial cost savings and the introduction of novel tactics are driving the future of weed control towards site-specific weed management. This approach is made possible by the accurate identification of weeds in cropping systems using machine vision typically incorporating artificial intelligence. Once identified, these weeds can be controlled through the strategic application of weed control treatments. This precision approach to weed control creates the potential for substantial cost savings (up to 90%) and the reduction in environmental and off-target impacts (Keller et al., 2014). More importantly for weed control sustainability, site-specific weed management creates the opportunity to use alternate physical weed control options that currently are not suited for whole paddock use.

Accurate weed detection allows physical weed control treatments to be applied specifically to the targeted weed. As weed identification processes develop to include weed species, size and growth stage, there exists the potential for some approaches (such as electrical weeding, microwaving and lasers) to be applied at a prescribed lethal dose. This dramatically reduces the amount of energy required for effective weed control (Table 2). For example, microwaving, as the most energy expensive weed control treatment as a broadcast treatment (42,001 MJ ha^{-1}), requires substantially less energy when applied directly to the weed targets (3.4MJ ha^{-1}). Thus, even though the same number of weeds are being controlled (5 plants m^{-2}) the specific targeting of these weeds results in a 99% reduction in energy requirements.

The accurate identification of weeds allows the use of alternate weed control technologies that are not practically suited for use as whole paddock treatments. For example, lasers are typically a narrow beam of light that is focussed on a point target. In a site-specific weed management approach with highly accurate weed identification and actuation, lasers can be focussed precisely on the growing points of targeted weeds, concentrating thermal damage. By reducing the treated area of the weed, off-target losses are further reduced allowing additional energy savings.

Table 2. Total energy requirement estimates for physical weed control options when used for site-specific weed control treatment. Estimates are based on the control of two-leaf weeds present at 5 plants m^{-2}.

Weed control method	Energy consumption ($MJ\ ha^{-1}$)
Concentrated solar radiation	0.0
Precise cutting	0.01
Pulling	0.01
Electrocution: spark discharge	0.1
Nd:YAG IR laser pyrolysis*	0.7
Hoeing	1.3
Water jet cutting	1.4
Stamping	2.1
Nd:YAG IR laser pyrolysis*	2.5
Microwaves	3.4
Abrasive grit	10
Thulium laser pyrolysis*	12
CO_2 laser cutting*	40
Targeted flaming	46
Electrocution: continuous contact	47
Nd:YAG laser pyrolysis*	70
CO_2 laser pyrolysis*	78
Nd:YAG UV laser cutting*	115
Hot foam	117
Dioide laser pyrolysis*	119
Nd:YAG IR laser cutting*	190
Targeted hot water	503

* Different laser weeding systems

Conclusions

By using energy requirements as a level playing field for comparison, the various efficiencies of each control method became more apparent. Furthermore, this approach enabled a better understanding of site-specific opportunities for physical weed control. Targeting treatments on individual plants results in significant energy savings and makes previously impractical options on a broadcast basis, available for use on a site-specific basis. The opportunities here are immense for the future management of problem weeds.

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.

References

Boutsalis P, Gill GS, Preston C (2012) Incidence of herbicide resistance in rigid ryegrass *(lolium rigidum)* across South Eastern Australia. Weed Technol. 26:391-398

Broster JC, Koetz EA, Wu H (2013) Herbicide resistance levels in annual ryegrass (*Lolium rigidum* Gaud.) and wild oat (*Avena* spp.) in southwestern New South Wales. Plant Prot. Quart. 28:126-132

Keller M, Gutjahr C, Möhring J, Weis M, Sökefeld M, Gerhards R (2014) Estimating economic thresholds for site-specific weed control using manual weed counts and sensor technology: An example based on three winter wheat trials. Pest Management Science 70:200-211

Llewellyn R, Ronning D, Clarke M, Mayfield A, Walker S, Ouzman J (2016) Impact of weeds in Australian grain production: the cost of weeds to Australian grain growers and the adoption of weed management and tillage practices. CSIRO, Australia.

Owen MJ, Martinez NJ, Powles SB (2014) Multiple herbicide-resistant *Lolium rigidum* (annual ryegrass) now dominates across the Western Australian grain belt. Weed Res. 54:314-324

Contact details

Michael Walsh
University of Sydney
12656 Newell Highway
Narrabri 2390
Ph: 02 6799 2201
Mb: 0448 847 272
Email: m.j.walsh@sydney.edu.au