MOONIE
QUEENSLAND
THURSDAY 7TH
MARCH 2019

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

GRDC Grains Research Update
MOONIE

Thursday 7th March, Moonie Sports Club

Registration: 8:30am for a 9am start, finish 3.05pm

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00AM	**GRDC welcome**	
9:10AM	**The physiology & genetics of cold temperatures in chickpeas.**	*Neroli Graham and Annie Warren (NSW DPI)*
9:40AM	**New frontiers in cereal breeding for a changing climate –** long coleoptile wheat, crop competitive varieties, new wheat types for late sowing windows & high temperature stress during grain fill.	*Greg Rebetzke (CSIRO)*
10:10AM	**Morning tea**	
10:40AM	**Farming systems research**	*Lindsay Bell (CSIRO) and Andrew Erbacher (DAF Qld)*
11:20AM	**Wheat varietal tolerance to sodicity –** current varieties plus breeding lines.	*Yash Dang (UQ)*
11:45AM	**Sowthistle –** double knock and other options for management.	*Richard Daniel (NGA)*
12:20PM	**Lunch**	
1:20PM	**Deep P - Multi-year crop impacts and profit –** soil tests and process to pick where and when to apply deep-P profitably.	*David Lester (DAF Qld)*
1:40PM	**Grower experiences with deep P –** when, why, how and with what profit outcome?	*Tom Woods ("Billa Billa")*
1:55PM	**Nutrition discussion**	
2:10PM	**Storing & managing pests in planting seed held on farm –** can you sample test a whole silo?	*Phil Burrill (DAF Qld)*
2:40PM	**Seed quality, testing and germination vigour –** types of tests (including tetrazolium), timing, problems,fungicide seed treatments & varieties.	*Ken Cunliffe (AgEtal)*
3:05PM	**Close**	

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

The physiology and genetics of cold temperatures in chickpeas – what do we know and where is the research heading?

Annie Warren, Neroli Graham, Rosy Raman and Kristy Hobson,
NSW Department of Primary Industries

Key words

chilling tolerance, early flowering, *Cicer arietinum*, breeding, prebreeding

GRDC code

BLG111

Take home messages

- During flowering, chickpeas are sensitive to cold (< 15°C) temperatures which cause flower abortion and results in a delay between flowering and pod onset
- While early sowing has the potential to reduce the risk of terminal drought, it moves the flowering window to cooler temperatures
- Current work aims to identify new sources of chilling tolerance for chickpea variety development and to assess the suitability of elite breeding lines for flowering and podding during cool conditions

Introduction

Chickpeas are well adapted to the northern cropping region in Australia and provide a valuable, economically sound, broadleaf rotation in our farming systems. However, various biotic and abiotic factors cause actual yields to fall between 1.7–2.7 t/ha below potential yield across the region (Yield Gap Australia, 2018). Cold temperatures during the flowering window can significantly reduce crop yield through delaying and interrupting pod set, causing loss of early pods. In 2016, agronomists estimated yield losses due to cool spring temperatures in north-west NSW ranged from 0.5–0.7 t/ha. Chickpeas can suffer damage during the flowering window from both frosts, when temperatures fall below -1.5°C, and "chilling" where average day temperature does not exceed 15°C. In this paper, we will focus on chilling temperatures and their impacts on flowering and podding.

While cool spring temperatures have been historically avoided through late sowing, changes to our farming systems mean there is a greater need for flexibility to sow chickpeas earlier to increase subsequent cropping options and to avoid heat and terminal drought at the end of the season. This however, pushes the flowering window to coincide with cooler ambient temperatures. In north west NSW (Tamworth region), average daily temperatures are not consistently above 15°C until late September and in the cool 2016 season, average temperatures remained below the critical temperature until late October (Figure 1). In addition, short bursts of cool temperatures occurring weeks after temperatures have begun to rise can interrupt pod and seed set even in areas that generally experience warm spring temperatures.

This paper outlines current knowledge of chickpea's physiological response to cool temperatures during flowering and what opportunities and challenges exist for improving chilling tolerance through breeding and variety selection.

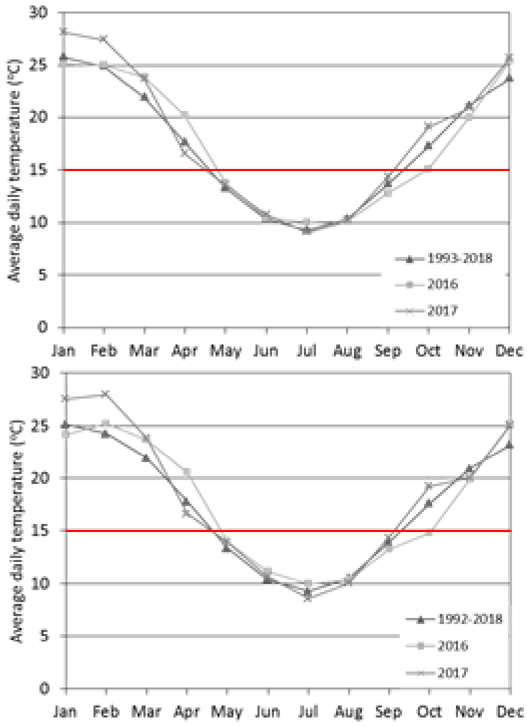

Figure 1. Average daily temperature for Tamworth (top) and Dubbo (bottom) shows cool spring conditions can continue into late September and October

The story so far

Early sown chickpeas consistently suffer from an extended gap between commencement of flowering and first pod appearance. In ideal conditions, chickpeas will produce pods within a couple of days of flowering (Clarke & Siddique, 1998). However, under cool conditions, the time from the beginning of flowering to the first pods appearing can be more than 2 months if temperatures remain consistently cool (Berger et al., 2005). At Warwick, early flowering genotypes took more than 30 days to begin podding when average temperature after flowering did not exceed 14.4°C (Berger et al., 2004). While the length of time between flowering and pod initiation varies across locations and between varieties, the delay in podding remains closely linked to temperature (Berger et al., 2004; Berger et al., 2005; Berger et al., 2012). For every degree drop in average daily temperature between 14 and 10°C, the time between flowering and podding is extended 12 days (Berger et al., 2005). During this time plants may continue to produce flowers that are subsequently aborted, or may cycle back into and out of a vegetative state.

While chickpeas may continue flowering under cool conditions, most flowers are subsequently aborted rather than producing pods. In their work with early sown chickpea in Western Australia, Siddique and Sedgley (1986) found only 38% of flowers carried through to produce harvestable pods among early sown plants, compared to 83% in later sowings. This difference was largely due to flower abortion at low temperature – up to 800 flowers/m^2 were aborted when average daily temperature was below 15°C, but no flower abortion occurred once temperature rose above this critical value (**Table 1**).

Siddique and Sedgley observed that although early sown crops suffer a high flower abortion penalty, this does not necessarily result in inferior yields when compared to later sown crops. Despite high flower abortion, the earliest sown chickpeas still produced the greatest yield. Across 72 genotypes and 5 locations, Berger et al. (2004) found early flowering cultivars were consistently the highest yielding, especially in locations that suffered end of season drought. Flower abortion under cool temperatures therefore constitutes a significant lost opportunity, as early flowering plants that also set pods early have the greatest potential to produce high yields.

Table 1. Effect of cool temperatures at 50% flowering on flower abortion at Merredin, Western Australia 1983

Planting date (1983)	Mean Daily temperature (°C) at 50% flowering	Aborted flowers (m^{-1})
May 17th	12.5	800
May 31st	13.6	500
June 14th	14.7	200
June 30th	16.8	0
July 20th	17.7	0

Note: Modified from Croser et al., 2003

On the small scale…

Cool temperatures reduce pollen vigour and ovary and style size of chickpea flowers, alterations that have been implicated in reduced flower fertilisation and increased flower abortion (Srinivasan et al., 1999). Pollen development and function is affected by cool temperature from the early stages of pollen production from 9 days before anthesis through to pollen tube growth and ovary fertilisation (Figure 2). Cold spells during key points in pollen development at either 9 or 4–6 days prior to anthesis can reduce pod set by 30–60% in susceptible varieties (Clarke & Siddique, 2004). Cool temperature may also decrease the quantity of pollen reaching the flower stigma due to reduced pollen release from anthers as well as a reduction in ovary and style size (Srinivasan et al., 1999). The resulting mismatch increases the difficulty of pollen transfer from anther to stigma (Srinivasan et al., 1999). Once pollen reaches the stigma, pollen germination can be reduced by 30% in susceptible varieties, although some susceptible varieties exhibit normal pollen germination (Clarke & Siddique, 2004; Srinivasan et al., 1999).

Once pollen has germinated on the stigma, pollen tube growth is particularly sensitive to cool temperatures. As a result, far fewer pollen tubes reach the ovary for fertilisation. Srinivasan et al. (1999) found while 100% of flowers at an average temperature of 20°C had pollen tubes reach the base of the style, as few as 23.5% of flowers at 10°C had more than 10 fully grown pollen tubes 1 day after flower opening. This resulted in fertilization of as few as 8% of flower ovules. In highly susceptible varieties, no pollen tubes will reach the ovary within 24 hours of pollen germination under cool conditions (Clarke & Siddique, 2004). As average day temperature increases from 5°C to 25°C, rate of pollen tube growth increases exponentially with only marginal increases in growth rate between 5–15°C (Srinivasan et al., 1999). Knowledge about these specific impacts of cool temperatures on chickpea reproduction have led to development of breeding practices such as pollen selection (Clarke et al., 2004) that are better able to target chilling tolerance.

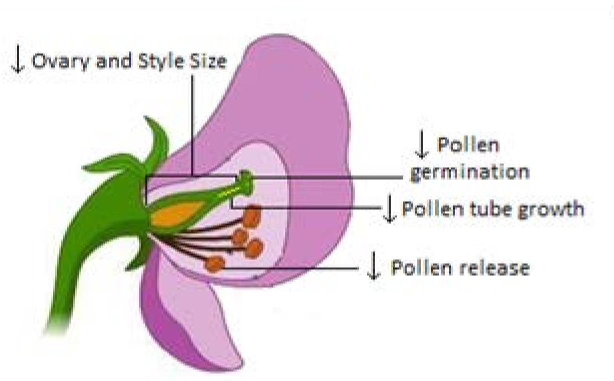

Figure 2. Impacts of cool temperature (< 15°C) on male and female reproductive organs of chickpea flowers

Note: Modified from Science Learning Hub – Pokapū Akoranga Pūtaiao (2011)

Opportunities for breeding chilling tolerant varieties

While cool temperature during flowering is a relatively new issue for the northern region, it has been identified as yield limiting across southern and western Australia since the early introduction of the crop. As a result, significant work has been conducted in Western Australia to develop chilling tolerant material for breeding programs. Clarke et al. (2004) developed two chilling tolerant cultivars, Rupali and Sonali, that could produce pods at 10–12°C and as result pod 20–27 days earlier than existing Western Australian varieties. However, these cultivars have insufficient disease resistance and do not yield comparably to the best yielding varieties in the northern region (K.Hobson, *pers comm*). In addition, time from flowering to podding can range from 30–70 days at temperatures ranging from 10–12°C (Berger et al., 2005). While not suited to northern environments, both Rupali and Sonali have been included in the northern breeding program since 2011 in an attempt to produce well adapted varieties with the ability to set pods at lower ambient temperature. However, the chilling tolerance during flowering and early pod set of progeny derived from either Rupali or Sonali has been insufficient to confer a significant improvement in the ability to set pods early under cool temperatures.

Limited genetic variation within domesticated chickpea restricts further progress in producing cultivars capable of podding at low temperature. However, some wild relatives of chickpea show considerably greater chilling tolerance and are able to set pods within 20 days of the beginning of flowering under cool temperatures, compared to the best chickpea cultivar doing so at 30 days (Berger et al., 2005). While chickpea pod production is reduced by 3–5 times when plants are kept at an average temperature of 10°C compared to 19°C, one particularly promising accession of *Cicer echinospermum* showed no reduction in pod set, setting more than 6 times the number of pods compared to chickpea at the lower temperature (Berger et al., 2012). There is, therefore, potential to include hybrids between chickpea and its wild relatives in breeding programs to make faster progress towards varieties that produce pods and seeds under suboptimal temperatures.

Where are we now?

Current research aims to identify useful sources of tolerance to suboptimal temperatures that can be used in breeding programs to improve future varieties. In Western Australia, both collections of chickpea and wild relatives are being screened by researchers at CSIRO as potential new sources for chilling tolerance during the early reproductive phase. Since current methods for identifying chilling tolerant chickpea lines is an expensive and labour-intensive process, several projects are working on developing tools to streamline identification of chilling tolerant breeding lines. At the University of Western Australia, Dr J Croser and her team are working to improve controlled environment screening for chilling tolerance amongst a wide set of chickpea genotypes. The underlying genetics of early flowering and chilling tolerance in chickpea during flowering is being investigated by NSW DPI at Wagga Wagga and Tamworth to improve knowledge about genetic control of early flowering and podset to potentially work towards developing genetic markers. This project uses a set of recombinant inbred lines formed from hybridisation between domestic chickpea and the wild relative *Cicer echinospermum* which were observed to flower and pod comparatively early in 2016.

In northern and southern NSW, current varieties and elite breeding lines are being assessed for flowering and pod set characteristics under cool spring temperatures through manipulation of sowing date. The aim of this work is to; quantify yield loss from cool temperatures during flowering in the northern and southern NSW regions, expand knowledge of drivers that may improve chilling tolerance, and identify future breeding directions. In 2018, field trials were conducted to benchmark current varieties and identify breeding lines with potential superior chilling tolerance when compared to existing varieties in northern environments. Data collected from the 2018 season is currently being processed for analysis.

References

Berger JD, Buck RP, Henzell JM, Turner NC (2005) Evolution in the genus *Cicer* – vernalization response and low temperature pod set in chickpea (*C. arietinum* L.) and its annual wild relatives. *Australian Journal of Agricultural Research* **56**, 1191-1200.

Berger JD, Kumar S, Nayyar H, Street KA, Sandhu JS, Henzell JM, Kaur J & Clarke HC (2012) Temperature-stratified screening of chickpea (*Cicer arietinum* L.) genetic resource collections reveals very limited reproductive chilling tolerance compared to its annual wild relatives. *Field Crops Research* **126**, 119-129.

Berger JD, Turner NC, Siddique KHM, Knights EJ, Brinsmead RB, Mock I, Edmondson C. & Khan TN (2004) Genotype by environment studies across Australia reveal the importance of phenology for chickpea (*Cicer arietinum* L.) improvement. *Australian Journal of Agricultural Research* **55**, 1071-1084.

Clarke HJ, & Siddique KHM (2004) Response of chickpea genotypes to low temperature stress during reproductive development. *Field Crops Research* **90**, 323-334.

Clarke HJ, Khan TN, & Siddique KH (2004) Pollen selection for chilling tolerance at hybridisation leads to improved chickpea cultivars. *Euphytica* **139**, 65-74.

Clarke HJ, Siddique KHM (1998) Growth and Development. In 'The Chickpea Book: A technical Guide to Chickpea production' (Eds SP Loss, N Brandon, KHM Siddique) pp. 3-10. (Bulletin 1326 Department of Agriculture and Food, Western Australia: Perth)

Croser JS, Clarke HJ, Siddique KHM & Khan TN (2003) Low temperature stress: Implications for chickpea (*Cicer arietinum* L.) improvement. *Critical Reviews in Plant Sciences* **22**, 185-219.

Siddique KHM, & Sedgley RH (1986) Chickpea (*Cicer arietinum* L.), a potential grain legume for south-western Australia: seasonal growth and yield. *Australian Journal of Agricultural Research* **37**, 245-261.

Science Learning Hub – Pokapū Akoranga Pūtaiao. (2011). Mendel's experiments [figure]. Retrieved from www.sciencelearn.org.nz

Srinivasan A, Saxena NP, & Johansen C (1999) Cold tolerance during early reproductive growth of chickpea (*Cicer arietinum* L.): genetic variation in gamete development and function. *Field Crops Research* **60**, 209-222.

Yield Gap Australia (2018) http://yieldgapaustralia.com.au/ (accessed 15 January, 2019)

Acknowledgements

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

The authors would like to thank Helene Davidson and Jessica Simpson for their assistance with data collection and trial management at the Tamworth and Wagga Wagga field sites in the 2018 chilling tolerance work.

Contact details

Neroli Graham
NSW Department of Primary Industries
4 Marsden Park Road Calala NSW 2340
Ph: 02 6763 1274
Email: neroli.graham@dpi.nsw.gov.au

Annie Warren
NSW Department of Primary Industries
4 Marsden Park Road Calala NSW 2340
Ph: 02 6763 1167
Email: annie.warren@dpi.nsw.gov.au

New genetics to improve wheat establishment with deep sowing

Greg Rebetzke[1], W. Spielmeyer[1], B. French[2], C. Zaicou-Kunesch[3], N. Fettell[4]

[1]CSIRO Agriculture and Food
[2]DPIRD Merredin
[3]DPIRD Geraldton
[4]Central west Farming Systems

Key words

wheat, breeding, genetics, dwarfing genes, coleoptile length, establishment

GRDC code

CSP00199, CSP00200

Take home messages

- Current Australian wheat cultivars contain dwarfing genes that reduce coleoptile length by 40%. New dwarfing genes are available that reduce plant height but don't reduce coleoptile length.
- A gene increasing coleoptile length was identified and tagged with DNA markers. Breeding lines and DNA markers for new dwarfing and coleoptile length genes have been delivered to Australian breeders for efficient selection of improved crop establishment
- Deep-sowing studies in WA and NSW Managed Environment Facilities show benefit with new dwarfing and coleoptile length promoting genes in increasing emergence at sowing depths of up to 120mm but without changing plant height
- Moisture-seeking points coupled with new genetics should reliably allow seed placement and emergence from sowing depths of 100mm or greater, and/or with warmer soils

Background

In rainfed environments typical of the eastern and southern wheatbelts, crops are typically sown on the first breaking rains but sometimes moisture accumulated through summer is too deep for sowing with conventional variety × drilling systems. Key to good leaf area development for tillering, growth and weed competitiveness is good crop establishment. An ability to establish wheat crops from seed placed 80mm or deeper in the soil would be useful in situations where the subsoil is moist but the surface dry. Seeding onto moisture at depth extends the opportunities for a greater portion of the cropping program to be sown in the traditional sowing months of May and June or earlier in April following summer rain. A separate but concerning issue is the influence of increasingly warmer soil temperatures on reductions in coleoptile (the shoot that grows from the seed and allows seedling emergence through the soil) length. Earlier sowing into warmer soils will reduce coleoptile length by as much as 60% so that a variety such as Mace with a 75mm coleoptile at 15°C will likely have a 40mm coleoptile at 25°C soil temperature. Some seed dressing and pre-emergent herbicides will reduce this coleoptile length even further to affect establishment.

The green revolution *Rht-B1b* and *Rht-D1b* dwarfing genes reduced plant heights to reduce lodging and increase grain yields and so are present in most wheat varieties worldwide. Their presence also reduces the length of the coleoptile by as much as 40%. This reduces crop emergence when sown at depths greater than 50mm, tiller number and leaf size to reduce water-use efficiency and weed competitiveness.

New dwarfing genes

A range of alternative dwarfing genes have been identified in overseas wheats with potential to reduce plant height and increase yields while maintaining longer coleoptiles and greater early vigour. Some of these genes (e.g. *Rht8* and *Rht18*) have been used commercially overseas but have not been assessed for use here in Australia. We reduced the larger global set of alternative dwarfing genes to *Rht4, Rht5, Rht8, Rht12, Rht13* and *Rht18*, and then developed linked DNA-markers to assist with breeding of these genes in a commercial breeding program. Separately, we then bred these genes using conventional and DNA-based methods into the old, tall wheat variety Halberd for testing and disseminating to Australian wheat breeders.

Genes that promote coleoptile growth

While switching to new dwarfing genes will remove the growth inhibition on early growth, there is a need to promote coleoptile growth, particularly in the presence of conventional dwarfing genes. A gene with major effect on coleoptile length was identified in current wheat cultivars. Through a GRDC funded project, we demonstrated that the gene not only increased coleoptile length but also emergence with deep sowing in field trials conducted over three years at Yanco NSW (Figure 1). The gene was tagged with molecular markers and tested in a wide range of Australian wheat germplasm. We estimated that only 10% of recently released cultivars carry the coleoptile growth promoting gene. The markers were distributed to Australian breeding companies to assist with the selection and the expected increase of gene frequency in future cultivars. Additional genetic variation for coleoptile length and early growth exists in elite germplasm. For breeders to take full advantage of this variation, additional genes controlling this trait need to be identified and tagged with markers for efficient selection and combining growth promoting genes for even better performance.

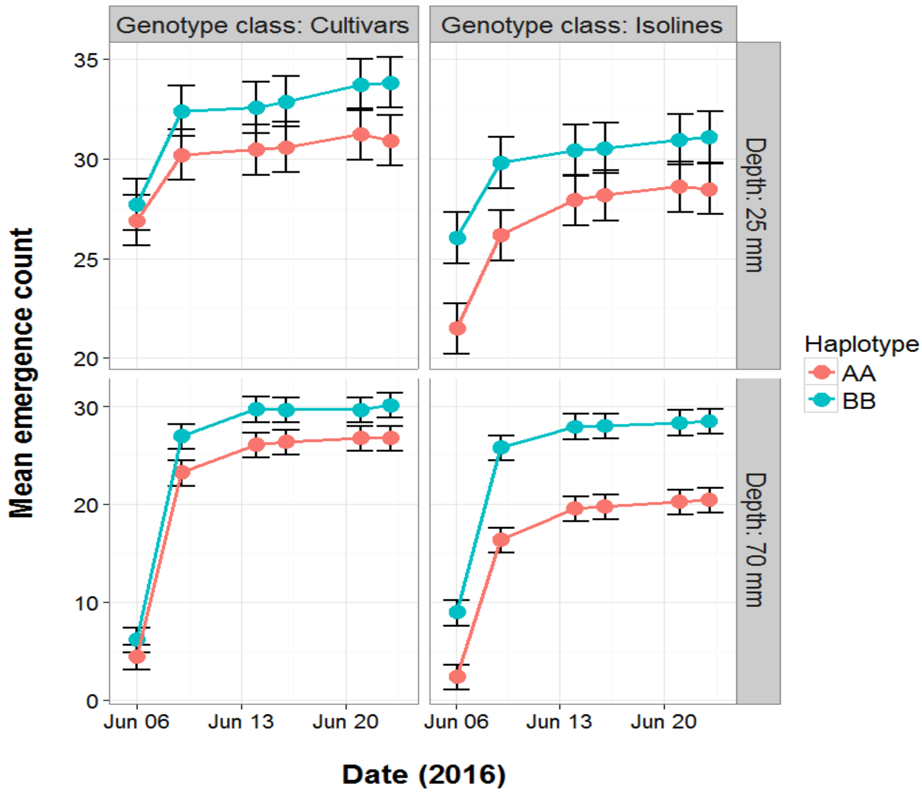

Figure 1. Emergence of wheat cultivars carrying conventional dwarfing genes and tall isolines in Young background in the NSW MEF at Yanco in 2016. Sowing depth treatments were 25 mm and 70 mm depth. 12 cultivars and 12 isolines were grouped according to the presence of the coleoptile length promoting gene (BB, long coleoptiles) and the lack of the gene (AA short coleoptiles).

Preliminary sowing depth field studies

Field studies have commenced on these Halberd-based dwarfing gene lines and show that lines containing these genes produced coleoptiles of equivalent length to Halberd (up to 135mm in length; Figure 2) and established well when sown at 100mm depth in deep sowing experiments conducted at Mullewa and Merredin in 2016 (Figure. 3). Grain yields of lines containing the new dwarfing genes were equivalent to the yields of lines containing the commonly used *Rht-B1b* and *Rht-D1b* dwarfing genes while previous studies have shown the new dwarfing genes were linked to greater grain yields when sown deep owing to greater plant number with improved establishment.

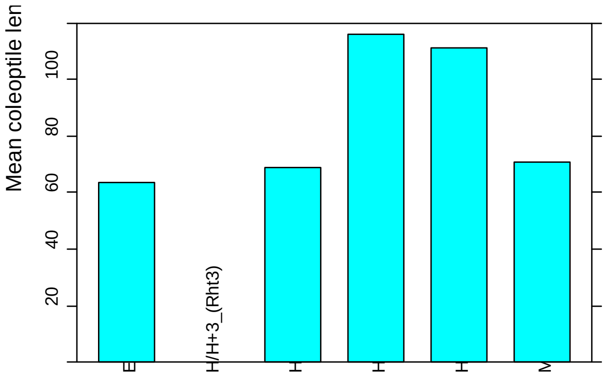

Figure 2. Coleoptile lengths of a tall wheat genotype (Halberd) and genotypes with dwarfing genes *Rht-B1b (syn. Rht1)* and *Rht8* in a Halberd background. Emu Rock and Mace are current commercial cultivars with *Rht-B1b* and *Rht-D1b*, respectively.

The most likely useful new dwarfing genes, *Rht13* and *Rht18*, have been bred into a range of current commercial wheats (Figs 4 and 5). Long coleoptile wheat breeding lines in Mace, Scout, Espada, EGA Gregory and Magenta have been delivered to Australian breeders for testing and use in breeding. If there are no problems with these new dwarfing genes, we may see the first of the long coleoptile wheat varieties in 3-4 years in NVT testing!

Agronomic opportunities

Although there is real promise in the new genetics, there is significant opportunity in coupling new genetics with new existing seeding technologies. Deep sowing is an issue overseas and in the eastern Australian states. The availability of moisture-seeking points commonly used elsewhere should allow the reliable placement of seed at depths of 100mm or greater. These points produce a slot deep into the soil at the base of which a seed is sown at 10-50mm depth. That said, further research is required aimed at tools and methods assessing across different moisture-seeking points to optimise seed placement at depth across a wide range of soil types.

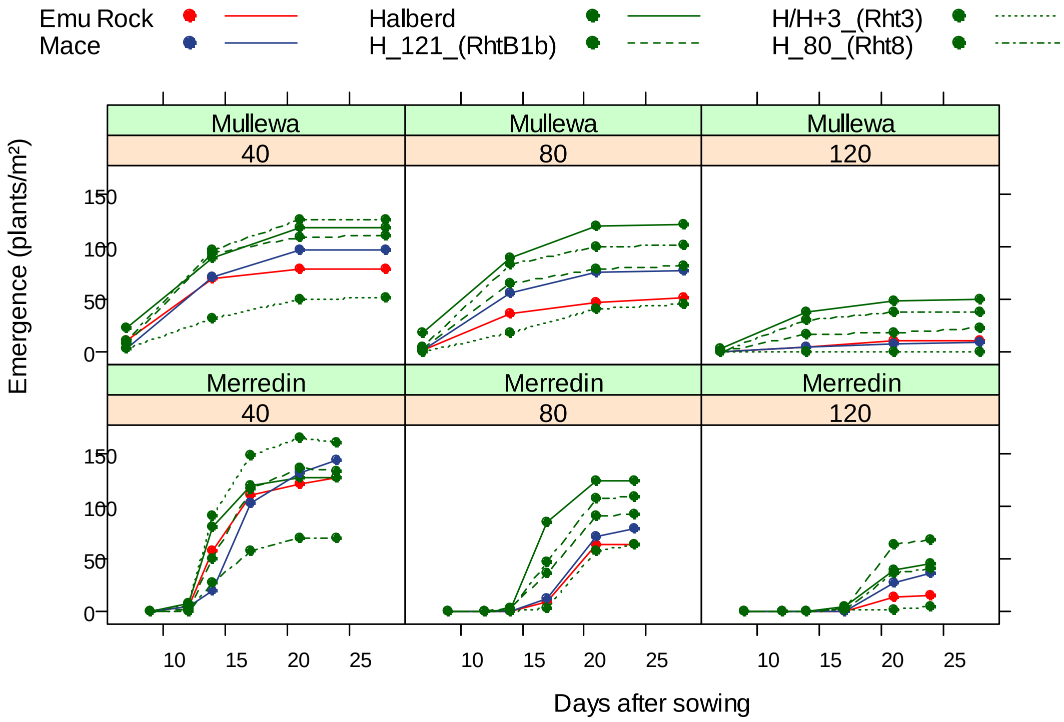

Figure 3. Patterns of emergence of wheat genotypes with different dwarfing genes sown at target depths of 40, 80, or 120 mm at Mullewa and Merredin in 2016 (after French *et al.* 2017).

Summary

Wheat breeders now have the new dwarfing genes to breed longer coleoptile wheat varieties. Genes that increase coleoptile length have also been identified and tagged with markers. These genes are expected to play an important role in improving emergence from depth in the presence of conventional dwarfing genes. Matching new genetics with appropriate agronomy and technologies should ensure the emergence and establishment of deep-sown wheats particularly when sown early to make use of summer rains sitting deep in the soil profile or to increase sowing opportunities in the traditional months of May and June.

References

French B, Zaicou-Kunesch C, Rebetzke G (2017) Alternative dwarfing genes improve emergence from deep sowing. GRDC Updates Perth

Acknowledgements

We'd like to acknowledge the support of the GRDC in funding much of the research reported herein. We'd also like to acknowledge the support of the managers of the GRDC's Managed Environment Facilities for their assistance.

Contact details

Greg Rebetzke
CSIRO
Mb: 0429 994 226
Email: G.Rebetzke@csiro.au

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

Supplementary images

Figure 4. Wheat variety Mace⦶ (left) side-by-side with long coleoptile, Mace⦶ containing the *Rht18* dwarfing gene (right) at Condobolin in 2017.

Figure 5. Wheat variety EGA Gregory⦶ (left) side-by-side with long coleoptile, EGA Gregory⦶ containing the *Rht18* dwarfing gene (right) at Condobolin in 2017.

Impacts of crops and crop sequences on soil water accumulation and use

Lindsay Bell[1], Andrew Erbacher[2], David Lawrence[2], Andrew Verrell[3], Jon Baird[3], Darren Aisthorpe[2], Andrew Zull[2], Jayne Gentry[2], Greg Brooke[3] & Kaara Klepper[4]

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

Key words

fallow, water-use-efficiency, gross margin, grain legumes, cereals, soil water

GRDC code

DAQ00192, CSA00050

Take home messages

- Efficiencies of fallows over the crop sequence were 22% ± 4% - this can be used to estimate average fallow water accumulation but large variation in fallow efficiency (FE) exists for individual fallows
- Lower fallow efficiencies can be expected in low intensity crop sequences (i.e. waiting for full profile before sowing) and in systems with high frequency of legumes
- Higher intensity systems where crops are grown on lower soil water thresholds have higher fallow efficiencies
- While grain legumes (chickpea, fababean, fieldpea, mungbean) often leave more residual soil water at harvest than cereals, this difference is diminished due to lower subsequent fallow efficiencies and hence soil water is often similar at the sowing of the next crop
- Despite the inefficiencies of fallows and similar efficiencies of rainfall use, accumulating more water prior to sowing crops typically increases Crop water use efficiency (WUE), and crop gross margins and achieved higher returns per mm an individual crop.

Introduction

The efficiency that soil water accumulates during fallows and availability of that soil water for use by crops are key drivers of farming system productivity and profitability. Using fallows to accumulate soil water to buffer subsequent crops against the highly variable climate is critical in northern grain production systems. A range of factors can influence the efficiency of fallows (i.e. the proportion of rain that accumulates in the soil profile) including ground cover, seasonality or timing of rainfall events, the length of the fallow and residual water left at the end of the proceeding crop. Further, while accumulating more soil water prior to sowing a crop is always preferable, this often requires longer fallow periods, meaning there are additional costs for maintaining that fallow and the number of crops grown declines. Here we analyse the data from farming systems experiments across seven locations (Emerald, Pampas, Billa Billa, Mungundi, Narrabri, Spring Ridge and Trangie) over the past four years to explore the question; 'how much does the farming system (i.e. mix of crops and their frequency) and different crops influence the accumulation and utilisation of water?'

We explore several factors influencing the accumulation of water during fallows and the availability of water for subsequent crops.

1. How does crop intensity (i.e. the proportion of time in crop or fallow) influence the accumulation and use of water in the farming system?
2. How much does crop choice (e.g. legume vs cereal or other) impact on water extraction and subsequent fallow water accumulation?
3. What is the value of additional soil water for subsequent crop productivity and water use efficiency, and is this sufficient to compensate for longer-fallows required to build this soil water?

Across these projects a common set of farming system strategies have been employed to examine how changes in the farming system impact on multiple aspects of the farming system (outlined below).

Cropping system strategies impacts on rainfall utilisation and soil water dynamics

Here we compare the differences between different farming system strategies over the whole 4 experimental years to see how they differ in terms of fallow efficiency and water use. That is, how efficiently is water used in the system if it is modified to increase/decrease crop intensity, change the mix of crops to grow grain legumes or other break crops more frequently, or increase the nutrient supply to the farming system. Across 10 different contexts we compare the following modifications to the farming system strategies:

- ***Baseline*** – an approximation of common farming system practice in each district: dominant crops only used; sowing crops on a moderate soil water threshold to approximate common crop intensities (often 0.75-1.0 crops per year); and fertilising to median crop yield potential
- ***Higher crop intensity*** – increasing the proportion of time that crops are growing by reducing the soil water threshold required to trigger a planting opportunity (e.g. 30% full profile)
- ***Lower crop intensity systems*** – only growing crops when plant available soil water approaches full (i.e. > 80% full) before a crop is sown and higher value crops are used when possible
- ***Higher legume frequency*** – crop choice aims to have every second crop as a legume across the crop sequence and uses high biomass legumes (e.g. fababean) when possible
- ***Higher crop diversity*** – a greater set of crops are used with the aim of managing soil-borne pathogens and weeds. This implemented by growing 50% of crops resistant to root lesion nematodes (preferably 2 in a row) and 2 alternative crops are required before the same crop is grown
- ***Higher nutrient supply -*** increasing the fertiliser budget for each crop based on a 90% of yield potential rather than the baseline of 50% of yield potential

Efficiency of fallows under different farming systems

Here we have analysed the efficiencies of all fallows within different farming systems across sites in order to examine how different strategies may impact on the efficiency of water accumulation during fallow periods (Table 1). That is, we calculated the ratio of all rain falling during fallow periods to the total accumulated soil water over these fallows across the whole crop sequence (not just individual crops).

Firstly, this shows that there are significant environmental influences on the efficiency of fallows, associated with the timing of rainfall events. Over our four experimental years, environments with more winter-dominated rainfall had lower fallow efficiencies – this is likely due to smaller and less frequent rainfall events occurring during summer fallows meaning that soil water accumulates less efficiently. Overall, though most baseline systems tended to achieve fallow efficiencies of 22% ± 4% over the whole cropping sequence. This is consistent with long-term simulations which show fallow efficiencies of 21-24% for cropping systems with crop intensities of 0.75-1.0 crops per year (i.e. 66-75% time in fallow). Robinson & Freebairn (2017) show fallow efficiencies of 25-30% under no-till in historical research but our data suggests that using a generic 30% FE may over-estimate fallow water accumulation in most cases. Earlier research mostly examined systems where winter cereals were a larger component of the farming system, and cropping systems used now with higher proportion of legumes and summer crops are likely to achieve lower fallow efficiencies (see further results below).

Significant differences in the efficiency of fallows are also found between different farming systems treatments tested across the sites. Key findings are:

- Higher crop intensity increased fallow efficiencies at most sites. This is due to less time in fallows and fallows having lower soil water content meaning higher infiltration rates. The higher crop intensity system at Narrabri so far has similar crop intensities and hence fallow efficiency is similar to the baseline system
- Conversely, systems with lower crop intensity systems had lower fallow efficiencies owing to longer fallows and a greater proportion of rain and time in fallows. The main exception here was at Mungundi where the low intensity system has achieved a similar fallow efficiency to the baseline at this point in time
- Systems with higher legume frequencies had lower fallow efficiencies (5% lower), particularly where they were reliant on summer rain accumulation. At several locations this effect was large, particularly where legumes were followed by a long-fallow period. This is due to the lower and less resilient cover provided by grain legume crops than cereals
- On average, systems aimed at increasing crop diversity have achieved similar fallow efficiencies to the baseline systems. However, there was large site-by-site variability, half the sites had an increase and half lower FE. There was significant differences in how increasing crop diversity is achieved across the various locations (e.g. some involve alternative winter break crops, some involve long fallows to sorghum or cotton), which is likely to bring about these variable results.

Table 1. Comparison of efficiencies of fallow water accumulation (i.e. change in soil water/fallow rainfall) amongst different cropping system strategies at 7 locations across the northern grains region. Colouring of numbers indicate the difference from the baseline system – black = reduction, light grey = increase.

Crop system	CORE - Pampas			Billa Billa	Narrabri	Spring Ridge	Emerald	Mungundi	Trangie (red soil)	Traingie (grey soil)	All site average
	Mix	Win	Sum								
Baseline	0.26	0.30	0.25	0.24	0.30	0.20	0.23	0.17	0.08	0.20	**0.22**
High Nutrient	0.23	0.28	0.32	0.29	0.29	0.16	0.23	0.17	0.13	0.29	**0.24**
High diversity	0.21	0.27	0.28	0.28	0.25	0.12		0.34	-0.13	0.23	**0.21**
High Legume	0.13	0.21	0.25	0.22	0.25	0.13	0.19	0.14	-0.08	0.28	**0.17**
High intensity	0.48			0.35	*	0.28	0.22				**0.33**
Low intensity	*	0.07	0.21	0.29	0.12	0.16		0.19	-0.03	0.19	**0.16**

*Crop system does not yet vary from the baseline in this regard

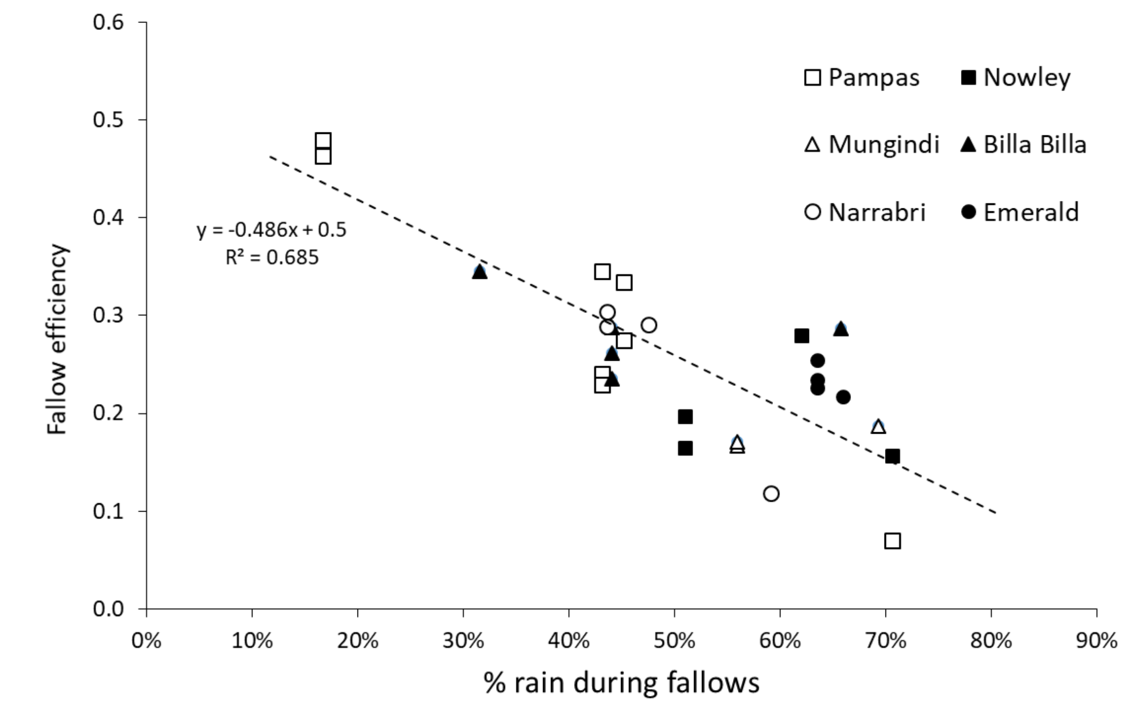

Figure 1. Relationship between the proportion of rain falling during fallow periods (i.e. time in fallow) and efficiency of fallows in the crop sequence (i.e. proportion of fallow rain accumulated in soil) across all farming system locations. Only baseline, low and high intensity systems are plotted, excluding altered crop diversity or legume frequency as this changes fallow efficiencies (see Table 1).

The effect of crop intensity on fallow efficiency is further illustrated in Figure 1. This shows a negative relationship between % of rain falling during fallows (i.e. time in fallow) and the fallow efficiency across all sites. That is, fallow efficiency declines dramatically as the time in fallow (or rain during the fallow) increases. This shows that at a point where 70% of the rain at a location is falling during the fallow that fallow efficiency is declining to 0.16, while in a system where 50% of rain falls during fallows the fallow efficiency is 0.25. What this means is for an environment receiving an average of 600 mm of rainfall per year, a farming system that captures 50% of the rain in fallows (1.3 crops per year), would accumulate 77 mm of water/yr during the fallow period (i.e. 0.5 x 600 mm = 300 mm in fallow @ 0.25 fallow efficiency = 77 mm) and 300 mm/yr would occur in-crop – Total crop water use = 377 mm (63% of rainfall). In contrast a farming system receiving 70% of rain in the fallow period (e.g. 0.6-0.7 crops per year), would accumulate 67 mm in fallow/yr and in-crop rain would be 180 mm per year – Total crop water use = 247 mm per year (41% of rainfall). These results are consistent with the differences in rainfall utilisation between cropping systems of different intensities across all the farming systems research sites (see Table 2).

What this means is that a crop grown after a longer fallow in a lower intensity system must generate 1.5-times the gross margin per mm of water used to be equally profitable. This is achievable in most cases (see results later in this paper) but it does mean that these crops must be managed to maximise their WUE in order to make up for the lower utilisation of water across the system.

Table 2. Differences in the percentage of total rainfall that was used by crops (i.e. in crop rain + change in soil water from sowing to harvest) between cropping systems treatments varying in crop intensity across farming systems experiments.

Systems	CORE - Pampas			Billa Billa	Narrabri	Spring Ridge	Emerald	Mungundi
	Mix	Win	Sum					
Baseline	68	84	86	67	85	63	56	48
Higher intensity	+26	+10	+8	+17	*	*	-2	
Lower intensity	*	-40	-39	-8	-39	-18		-16

*Crop system does not yet vary from the baseline in this regard

Crop-by-crop effects on fallow efficiency

Across the farming systems sites we have monitored fallow water accumulation following a range of different crops – over the 4 research years, we have collected data on residual soil water and final soil water for over 306 different crops. Here we have collated this data in order to compare how different crop types impact on subsequent fallow efficiencies (Figure 2). This data shows the high variability in fallow efficiency that occurs from year to year but is also demonstrates some clear crop effects on subsequent fallow efficiencies.

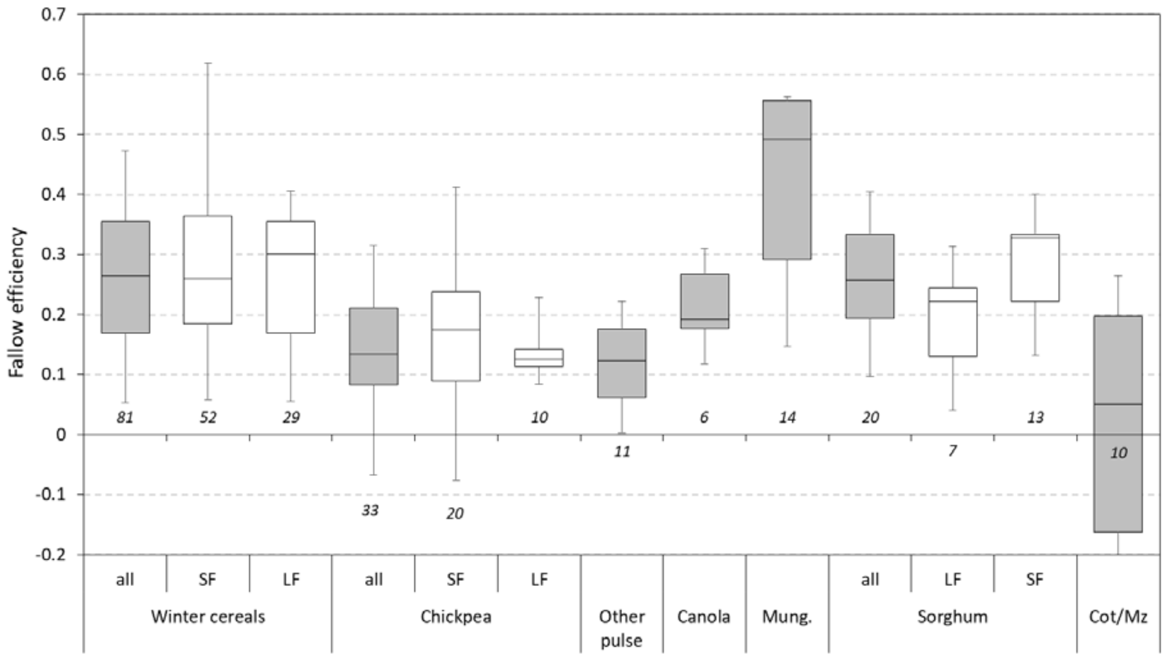

Figure 2. Summary of observed fallow efficiencies following different crops and different fallow lengths (SF – short fallows 4-8 months, LF – long fallows 9-18 months) across all farming systems sites and treatments between 2015 and 2018; winter cereals include wheat, durum and barley; other pulses include fababean and fieldpea. Boxes indicate 50% of all observations with the line the median, and the bars indicate the 10th and 90th percentile of all observations. Italicised numbers indicate the number of fallows included for each crop.

This data clearly shows the higher fallow efficiencies that can be achieved from a winter cereal crop than winter grain legumes and to a lesser degree, canola. The median fallow efficiency following winter cereals was 0.27, while following chickpea and other grain legumes this was 0.14, with canola intermediate (0.19). Median fallow efficiencies following sorghum were also similar to wheat (0.26), but efficiencies of short-fallows during winter after sorghum were more efficient than long fallows. This difference between short and long fallows was less obvious following winter cereals. This is likely due to winter fallows being more efficient than summer fallows, due to lower evaporation losses (and possibly lower soil water content at the start of the fallow). Hence, short fallows after sorghum occurring in winter are more efficient, while long-fallows spanning into summer are less efficient. This also explains the similar fallow efficiency of short (summer) and long fallows (summer + winter) after winter cereals.

What this means is that, the impacts of a particular crop on the accumulation of soil water in the following fallow should be considered in the cropping sequence. For example, a fallow receiving 400 mm of rain after a winter cereal would accumulate 108 mm on average, while the same fallow after a grain legume would have only accumulated 56 mm. This difference could have a significant impact on the opportunity to sow a crop and/or the gross margin of the following crop in the cropping sequence.

Residual water and fallow efficiency effects on soil water after legumes vs cereals

While we have observed lower fallow efficiency following grain legumes in the farming system, a frequently mentioned benefit of legumes is the residual soil water left at harvest that can be used in subsequent crops. In Table 3 we have compiled cases where chickpeas and wheat have been grown in the same season to compare the residual water at harvest and the accumulation of water until the sowing of the following crop. On numerous occasions we observed higher residual soil water at harvest after pulse crops (chickpeas, fababeans or field peas) compared to after wheat. This was often associated with rainfall later in the crops development where the winter cereals were able to extract this water while the pulses were finishing and did not utilise this additional water. On average across these 7 comparisons chickpea had 41 mm more soil water post-harvest compared to wheat, however, at the end of the subsequent fallow this difference was greatly reduced so that on average only 10 mm more water remained in the soil profile after chickpea compared to wheat or barley. What this means, is that you shouldn’t bank on the additional moisture after a grain legume translating into additional soil water available for subsequent crops.

Table 3. Residual soil water at harvest and subsequent fallow water accumulation between chickpea and wheat compared across 7 sites/years

Crop	Residual water at harvest (mm PAW)	Fallow efficiency	Fallow rain (mm)	Final soil water (mm PAW)
***Emerald** - Oct 15 to May 16*				
Wheat	44	0.20	525	150
Chickpea	71	0.19	568	177
***Emerald** - Oct 16 to Apr 17*				
Wheat	93	0.16	341	147
Chickpea	89	0.20		158
***Emerald** – Sep 17 to Jan 18*				
Wheat	56	0.33	364	177
Chickpea	76	0.23		157
***Pampas** – Nov 15 to Sep 16*				
Wheat	61	0.38	459	238
Chickpea	106	0.26		198
***Pampas** – Nov 16 to Apr 17*				
Wheat	41	0.47	299	182
Chickpea	47	0.41		167
***Pampas** – Nov 16 to Sep 17*				
Wheat	9	0.25	344	96
Chickpea	91	0.11		129
***Pampas** – Oct 17 to Apr 18*				
Wheat	28	0.18	228	69
Chickpea	141	0.0		139

Fallow length effects on crop water use efficiency and gross margin

While we have shown above that there are a range of factors that affect fallow efficiency, it is important to factor in how effectively the subsequent crop turns the water available into grain and gross margin. From the seven farming systems sites, 42 crops had eight common crops at the end of fallows of varying length (Table 4). These comparisons showed that in 41 of the 42 crops, longer fallow periods (under the same seasonal conditions) have resulted in more plant available water (PAW) at planting of the common crop. The only crop that didn't increase was an 18 month fallow, which didn't increase from 2/3 full despite 700mm rainfall over a 12 month period.

In every comparison, higher PAW at planting resulted in increased grain yield, which in seven of the eight comparisons improved crop water use efficiency (WUE) i.e. grain yield/(in-crop rain + change in soil water) (WUE). The comparison where higher grain yield didn't translate to higher water use efficiency was the highest yielding crop, with the highest WUE in these comparisons (ie. sorghum at Pampas in 2016/17). However, it is important to also factor-in the fallow rain required to achieve the higher plant available water at sowing. Here we have calculated this as the rainfall use efficiency (RUE) of these crops, i.e. grain yield/ (prior fallow rain + in-crop rain). This shows that once the efficiency of fallow water accumulation is considered then in most cases there was little difference in productivity of the systems in terms of kilograms grain produced per mm of rain (exclusions were a chickpea crop following a 18-month fallow at Pampas in 2017 and a sorghum double-crop at Pampas in 17/18).

While this shows that across fallow lengths leading into crops there is little difference in system productivity, this does not necessarily translate to system profitability. The crops with a longer fallow lead in had higher crop gross margins due to their higher yields. In 6 of the 8 comparisons between crops, higher gross margin returns per mm were achieved for crops with a higher PAW at sowing due to longer fallows prior. The two cases where the shorter fallow crops (wheat at Emerald in 2016, and sorghum at Pampas in 2016/17) had higher $ GM/mm, both had higher crop margins and high starting PAW (> 100 mm) at sowing. Across these comparisons the marginal gain in profit per mm of additional water at sowing ranged from $0.5-14.9, but was mainly between $1.1/mm and $2.2/mm.

Table 4. Comparison of yield and water use of crops with varying lengths of preceding fallow, for a range of crops and locations. Double crop is 0-4 month fallow; Short fallow is 4-8 month; long fallow is 9-18 months.

Site	Fallow prior	Pre-plant PAW (mm)	Grain yield (t/ha)	Crop WUE (kg/mm)	Rainfall Use Efficiency (kg/mm)	Crop gross margin ($/ha)	$/mm rain
Wheat							
Emerald, 2016	Double crop	100	2.35	8.3	5.3	512	1.15
	Short fallow	177	3.36	9.9	4.2	678	0.85
Billa Billa, 2017	Double crop	65	1.13	5.6	4.2	211	0.78
	Short fallow	125	1.49	6.7	4.5	278	0.84
Pampas, 2017	Double crop	53	1.56	3.4	3.4	258	0.56
	Short fallow	169	1.83	5.2	3.5	424	0.81
Sorghum							
Billa Billa, 16/17	Short fallow	131	0.62	2.3	1.7	-138	-0.37
	Long fallow	212	1.31	3.8	2.3	34	0.06
Pampas, 16/17	Short fallow	147	4.51	10.8	8.2	1033	1.88
	Long fallow	238	5.66	10.6	6.8	1082	1.30
Pampas, 17/18	Double crop	96	0.65	2.2	2.2	30	0.10
	Short fallow	146	4.02	8.4	7.2	775	1.39
Chickpea							
Pampas, 2017	Double crop	45	1.30	3.6	3.6	455	1.26
	Short fallow	169	1.68	6.4	3.8	651	1.47
	Long fallow	162	1.80	6.6	1.6	547	0.49
Billa Billa, 2018	Double crop	163	0.82	4.5	2.7	209	0.69
	Short fallow	203	1.48	6.8	3.1	628	1.31

Conclusions

Overall these farming systems experiments have shown that systems with less time in fallow increases system water use and WUE through higher fallow efficiencies. However, significantly higher returns for crops sown on higher plant available water more than compensates for the low efficiencies of fallow water accumulation. This trade-off will be further influenced by the cost structure and risk appetite of the farming enterprise and the availability of labour, since higher intensity systems will increase inputs of labour and machinery and increase risk of crop failures. This is explored further in other papers. Though, this does mean that it is more critical to optimise management and inputs for crops following long-fallows in order to convert the extra water efficiently into yield outcomes.

Further reading

Water use and accumulation

Lindsay Bell, Andrew Erbacher (2018) Water extraction, water-use and subsequent fallow water accumulation in summer crops. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/07/water-extraction-use-and-accumulation-in-summer-crops

Freebairn, David (2016) Improving fallow efficiency. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/improving-fallow-efficiency

Kirsten Verberg, Jeremy Whish (2016) Drivers of fallow efficiency: effect of soil properties and rainfall patterns on evaporation and the effectiveness cf stubble cover https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/drivers-of-fallow-efficiency

Local farming systems experiments

Andrew Erbacher, David Lawrence (2018) Can systems performance be improved by modifying farming systems? Farming systems research – Billa Billa, Queensland https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/07/can-systems-performance-be-improved-by-modifying-farming-systems

Darren Aisthorpe (2018) Farming Systems: GM and $ return/mm water for farming systems in CQ. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/12/farming-systems-gm-and-$-returnmm-water-for-farming-systems-in-cq

Jon Baird, Gerard Lonergan (2018) Farming systems site report – Narrabri, north west NSW https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/07/farming-systems-site-report-narrabri

Andrew Verrell, Lindsay Bell, David Lawrence (2018) Farming systems – Spring Ridge, northern NSW. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/07/farming-systems-spring-ridge-northern-nsw

Lindsay Bell, Kaara Klepper, Jack Mairs, John Lawrence (2018) Farming system impact on nitrogen and water use efficiency, soil-borne disease and profit https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/03/farming-system-impact-on-nitrogen-and-water-use-efficiency-soil-borne-disease-and-profit

Lindsay Bell, Kaara Klepper, Jack Mairs, John Lawrence (2017) Improving productivity and sustainability of northern farming systems: What have we learnt so far from the Pampas systems experiment? https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/07/mproving-productivity-and-sustainability-of-northern-farming-systems-what-have-we-learnt-so-far-from-the-pampas-systems-experiment

Lindsay Bell, David Lawrence, Kaara Klepper, Jayne Gentry, Andrew Verrell, and Guy McMullen (2015) Improving northern farming systems performance. https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2015/07/improving-northern-farming-systems-performance

Acknowledgements

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

References

Robinson JB, Freebairn DM (2017) Estimating changes in Plant Available Soil Water in broadacre cropping in Australia. In 'Proceedings of the 2017 Agronomy Australia Conference', 24 – 28 September 2016, Ballarat, Australia. www.agronomyconference.com

Contact details

Lindsay Bell
CSIRO
PO Box 102, Toowoomba Qld, 4350.
Mb: 0409 881 988
Email: Lindsay.Bell@csiro.au

The impact different farming systems have on soil nitrogen, phosphorus and potassium

Jon Baird[1], Jayne Gentry[2], David Lawrence[2], Lindsay Bell[3], Darren Aisthorpe[2], Greg Brooke[1], Andrew Erbacher[2], Andrew Verrell[1], Andrew Zull[2] & Kaara Klepper[4]

[1]NSW Department of Primary Industries, Narrabri, NSW
[2]Qld Department of Agriculture and Fisheries, Toowoomba, Qld
[3]CSIRO Agriculture and Food
[4]GRDC

Key words

northern farming systems, nutrition, nitrogen, phosphorus, potassium

GRDC codes

DAQ00192, CSA00050

Take home messages

- Most farming systems extract more nutrients than are supplied by common fertilisation strategies
- Increasing the frequency of legumes doesn't necessarily reduce N inputs required across the crop sequence and increases export of potassium
- High yielding legume crops export more N and extract soil mineral N to a similar extent to cereals, often resulting in little additional mineral N for subsequent crops
- We found little difference in soil N extraction or subsequent mineralisation between various grain legumes, challenging assumptions that fababean or field pea provide greater N benefits to the farming system
- The high fertiliser application in the *higher nutrient* system (fertilising to crop yield potential) has maintained higher soil mineral N levels but has rarely increased grain yield or total system N use. Around 50% of additional N applied has remained available in the mineral N pool for subsequent crops
- Increasing crop intensity did not greatly increase nutrient export, but did increase fertiliser inputs across the farming system.

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.

Growers face challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems. Change is needed to meet these challenges and to maintain farming system productivity and profitability. Consequently, Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and CSIRO are collaborating to conduct 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?"

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

Experiments were established at seven locations; a large factorial experiment managed by CSIRO at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres by DAF and the DPI NSW (Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red & grey soils)).

One of the central aspects of this research was to examine how farming systems compared in terms of their requirements for nutrient inputs and their long-term impacts on soil nutrient status and cycling. Several system modifications (described below) explicitly targeted increasing the nutrient efficiency and overall nutrient supply in the farming system to see how these would impact on system productivity and nutrient balance and use-efficiencies. In this paper we examine some of these key system comparisons to explore the following questions:

1. Will increasing the frequency of grain legumes lower the N fertiliser requirements or improve N utilisation in the crop sequence? How does this impact on other important nutrients?
2. What are the consequences of increasing fertiliser inputs to ensure crops maximise their yield potentials? How does this influence system nutrient cycling and balances?
3. What are the implications of increasing crop intensity for nutrient use and requirements?
4. How do different crops (legumes, cereals, others) impact on N cycling and accumulation for subsequent crops?

Farming system descriptions

The following paper focussed on system comparisons between the following systems being implemented across the range of farming systems experimental sites. The systems varied in the following ways from a *baseline* system at each location:

- ***Baseline*** – an approximation of common farming system practice in each district: dominant crops only used; sowing crops on a moderate soil water threshold to approximate common crop intensities (often 0.75-0.8 crops per year); and fertilising to median crop yield potential
- ***High crop intensity*** – increasing the proportion of time that crops are growing by reducing the soil water threshold required to trigger a planting opportunity (e.g. 30% full profile)
- ***High legume frequency*** – crop choice aims to have every second crop as a legume across the crop sequence and uses high biomass legumes (e.g. fababean) when possible
- ***High nutrient supply -*** increasing the fertiliser budget for each crop based on a 90% of yield potential rather than the baseline of 50% of yield potential.

Trial details

Sites were selected to represent a range of climatic conditions, soil types, nutritional status and paddock history. Each site was comprehensively soil tested at the beginning of the project. There is a considerable range in soil fertility across the sites (Table 1) which dramatically influenced the requirements for inputs of N fertilisers in particular at some sites (e.g. Billa Billa and Pampas) where high levels were present at the start of the experimental period.

Table 1. Nutrient status of sites at the beginning of the project

Site	Mineral N (kg/ha)	Colwell P (mg/kg)		BSES P (mg/kg)		Colwell K (mg/kg)	
	0 – 90 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm	0-10 cm	10-30 cm
Billa Billa	366	22	3	33	7	518	243
Pampas	200	64	35	728	711	480	291
Spring Ridge	199	66	19	71	40	670	286
Trangie (grey)	106	50	6	62	10	506	235
Emerald	99	45	12	70	21	438	225
Narrabri	58	44	10	433	407	588	209
Mungindi	61	19	5	111	86	752	428
Trangie (red)	19	30	9	53	15	427	268

Experimental procedures included measuring mineral nitrogen (nitrate and ammonia), both pre-sowing and post-harvest for each crop planted over the past four years. Grain content was also analysed for nitrogen (N), phosphorus (P) and potassium (K).

How does increasing legume frequency impact on system N inputs and use?

Grain legumes are integral in current farming systems with areas consistently increasing. This increase in frequency of legumes has been due to several factors including high grain prices but also a belief that they improve soil fertility and reduce overall N fertiliser input costs. Here we compare the impact of increasing the frequency of legumes on the N inputs, exports, and total system N use compared the baseline system. It is important to note here that as the project only has four years of data all these systems have only planted 1 or 2 extra legume crop compared to the baseline.

Higher legume systems exported more N from the system in grain than the baseline systems in 8 out of the 11 comparisons across the farming system sites (Table 2). On average across all sites the high legume sequences exported an additional 30 kg of N from the system (ranging from 78 to -7 kg/ha). The higher legume system showed mixed results in relation to reducing the amount of N fertiliser required for a cropping system (Table 2). For example, the higher legume system reduced nutrient inputs at some sites, such as Emerald which reduced the total N fertiliser requirement by 83 kg N/ha compared to the baseline system. While at Trangie (grey soil) and Pampas, the higher legume system actually increased N fertiliser required in subsequent crops by 25 kg N/ha compared to the local baseline system. Altogether across all sites there was little saving in the N inputs used in cropping systems employing higher frequencies of grain legumes. This was also reflected in the total system N use (soil mineral N depletion plus fertiliser N inputs) over the 3.5 years of cropping systems employed so far. Only 6 of the 11 higher legume systems reduced total N use compared to the baseline system, with the largest reduction of 88 kg at Emerald. However, the other sites recorded higher total N use from the legume system.

Overall these results indicate that across our farming systems experiments the implementation of additional legume crops in the crop sequence has had little positive benefit on reducing N fertiliser input needs or reducing soil N use. The legumes are utilising soil mineral N to the same extent as cereal crops and have higher N export which offsets N fixation inputs. Also notable is that this result is consistent across the full range of starting soil N conditions, from locations with very high starting mineral N status to locations with low mineral N status where legumes would require to fix N to meet their needs. These results significantly challenge the common held assumption that grain legumes will have benefits for reducing N fertiliser needs in the crop sequence. As our capacity to grow high yielding grain legumes has increased as has our harvest index and hence the ratio of N removed in grain to that left in biomass, thereby diminishing the contributions of residual N after the crop.

Table 2. Cumulative nitrogen dynamics for the *baseline and higher legume* systems at 11 sites (Northern grains region) between 2015 and 2018

Site	N export (kg/ha)		Applied fertiliser N (kg N/ha)		Mineral N change (kg N/ha)		System total N use (kg N/ha)	
	Baseline	Higher legume	Baseline	Higher legume	Baseline	Higher legume	Baseline	Higher legume
Billa Billa	220	259	12	17	249	194	261	211
Emerald	227	249	91	8	52	47	143	55
Mungindi	79	80	54	54	-22	-6	32	48
Narrabri	177	227	127	127	43	36	170	163
Spring Ridge	227	305	211	211	25	35	236	246
Trangie (grey soil)	113	106	54	80	-213	-221	-167	-141
Trangie (red soil)	108	117	84	78	-31	-38	53	40
Pampas (mod intensity)	271	309	13	39	248	257	261	296
Pampas (high intensity)	249	303	101	108	285	280	386	388
Pampas (summer)	237	233	78	109	288	231	366	340
Pampas (winter)	287	347	42	17	275	274	317	291

Note: Total N use is calculated from applied fertiliser and the mineral N balance - (ammonia and nitrate N) prior to sowing 2015 minus the mineral N post the 2018 harvest

How does increasing legume frequency impact on soil phosphorus and potassium export?

Phosphorous export has been variable across sites, with some higher legume systems exporting more and some less compared to baseline (Table 3). However, the higher legume system did increase the amount of potassium exported on average across all sites relative to the baseline system (14 kg K/ha). Pampas (mixed) had the greatest amount of exported potassium, a total of 31 kg K/ha from 2015 to 2018. Although this is not unexpected as legume seed has more than double the K content than cereal grains, K levels will need to be monitored to ensure the system does not cause deficiencies for future crops. In situations where K deficiency may be an emerging issue or where levels are marginal, this greater export under a higher legume system may mean that nutrients need to be replaced sooner or a higher level of replacement will be required.

Longer term trends of underlying fertility will be assessed with further collection of soils and benchmarking these results in 2019 against the initial baseline levels that were measured at the start of the project.

Table 3. Cumulative phosphorus and potassium removal of the higher legume systems at 11 sites in the northern grains region (2015 – 2018)

Site	P export (kg/ha)		Applied fertiliser P (kg N/ha)		K export (kg K/ha)	
	Baseline	Higher legume	Baseline	Higher legume	Baseline	Higher legume
Billa Billa	41	34	27	36	57	66
Emerald	29	32	22	21	56	63
Mungindi	12	14	7	7	24	25
Narrabri	26	34	24	24	42	54
Spring Ridge	32	35	33	33	53	64
Trangie (grey soil)	15	14	35	35	19	22
Trangie (red soil)	17	19	35	35	23	26
Pampas (mod intensity)	37	42	23	20	53	84
Pampas (high intensity)	41	41	25	29	59	87
Pampas (summer)	40	33	21	21	45	70
Pampas (winter)	40	46	18	22	66	95

Note: P and K export calculated by grain content (%) x DW grain yield (kg/ha)

What are the consequences of increasing fertiliser inputs on nutrient balance and use?

With declining soil fertility across the northern region there is increasing interest in identifying ways to either halt or reverse this trend. Past research suggests that maximising biomass production is one way to achieve this; more biomass will increase soil organic matter levels which will build the natural supply of nutrients such as N and P. To maximise biomass production, supplying adequate crop nutrition is critical, along with providing nutrients to promote soil microbial processes.

The capacity to address nutrient depletion and increase crop biomass and yield potential under favourable conditions was investigated, by implementing a system that increases nutrient supply budgets to target 90th percentile yield (higher nutrient) compared to only 50th percentile yields in the baseline.

As predicated the higher nutrient system increased the amount of N fertiliser applied at each site over the cropping sequence. On average across all sites an extra 83 kg N/ha was applied between 2015 and 2018 relative to the baseline system. The additional N increased N export at seven of the eleven sites. This was most significant at Trangie (red soil), which exported 49 kg N/ha more than the baseline system (Table 4). It is interesting to note that this site had the lowest starting mineral N levels, resulting in the highest N application rates during the first four years of the project.

The additional N that was applied in the higher nutrient system reduced the depletion of background soil mineral N status at ten of the sites. On average across all sites the higher nutrient system had 43 kg more soil mineral N at last sampling than the baseline – meaning about 55% of the additional N applied was found in the mineral N pool at this time or we are recovering about 55% of the additional previous N applications in subsequent years. However, this recovery % varied greatly across the sites, ranging from full recovery (e.g. Billa Billa, Pampas summer rotations) to low recovery of less than 10% (e.g. Mungindi and Pampas winter rotations). This value is likely to be highly dependent on the timing of sampling influenced by the previous crop, residue loads and types, and soil moisture conditions.

These results show that applying N fertiliser to aim for a 90th percentile yield potential may reduce the mining of soil available N, especially in soils with high fertility (such as Billa Billa) and that significant amounts of additional N applied remains in the mineral N pool and is available in subsequent crops. To confirm this, longer term trends of underlying soil fertility such as organic carbon or total N pools will need to be assessed.

Table 4. Cumulative nitrogen export, inputs in fertiliser, depletion of the soil mineral N pool (starting soil N – final soil N) and total system N use (soil mineral N use + applied N) between the higher nutrient and baseline system at 11 sites in northern grain region (2015 – 2018)

Site	N export (kg/ha)		Applied fertiliser N (kg N/ha)		Mineral N extraction (kg N/ha)		System total N use (kg N/ha)	
	Baseline	Higher nutrient	Baseline	Higher nutrient	Baseline	Higher nutrient	Baseline	Higher nutrient
Billa Billa	220	253	12	62	249	190	261	252
Emerald	227	246	91	147	52	33	143	180
Mungindi	79	86	54	125	-22	-26	32	99
Narrabri	177	158	127	201	43	15	170	215
Spring Ridge	227	235	211	316	25	-2	236	314
Trangie (grey soil)	113	96	54	160	-213	-174	-157	-14
Trangie (red soil)	108	157	84	261	-31	-225	53	36
Pampas (mod intensity)	271	257	13	89	248	229	261	318
Pampas (high intensity)	249	278	101	209	285	193	386	402
Pampas (summer)	237	243	78	116	288	235	366	351
Pampas (winter)	287	277	42	100	275	267	317	367

Note: Total N use is calculated from applied fertiliser and the mineral N balance - (ammonia and nitrate N) prior to sowing 2015 minus the mineral N post the 2018 harvest

The additional P applied to the higher nutrient system did not influence grain P export across the first four seasons in the Farming System project, as sites resulted in minor variances between the higher nutrient and baseline systems. Similarly, there was no difference between K export of the higher nutrient systems and the baseline systems at the eleven sites in the northern grains region, as we did not see significant yield responses to the higher nutrient application strategies.

Table 5. Cumulative phosphorous and potassium removal and phosphorus inputs from the higher nutrient system and the baseline system across northern farming systems experiments (2015 – 2018)

Site	P export (kg/ha)		Applied fertiliser P (kg N/ha)		K export (kg K/ha)	
	Baseline	Higher nutrient	Baseline	Higher nutrient	Baseline	Higher nutrient
Billa Billa	41	42	27	66	57	58
Emerald	29	32	22	35	56	60
Mungindi	12	11	7	22	24	20
Narrabri	26	24	24	33	42	42
Spring Ridge	32	31	33	33	53	54
Trangie (grey soil)	15	13	35	35	19	16
Trangie (red soil)	17	21	35	35	23	29
Pampas (mod intensity)	37	39	23	34	53	56
Pampas (high intensity)	41	41	25	46	59	61
Pampas (summer)	40	40	21	31	45	46
Pampas (winter)	40	38	18	39	66	64

Note: P and K export calculated by grain content (%) x dry weight (DW) grain yield (kg/ha)

What are the implications of increasing crop intensity for nutrient use and requirements?

The Northern region farming system is centred on growing crops mainly on stored soil moisture. With very low fallow efficiencies, the belief is often, “use it or lose it”. However, the grains industry are often unsure the impact a higher crop intensity cropping system has on underlying soil fertility. The question is often asked, “will growing more crops improve or reduce soil fertility?” So far across the various farming systems sites, four have significantly increased the cropping intensity compared to the baseline crop sequence (Billa Billa, Emerald, Pampas). The NSW sites (Narrabri and Spring Ridge) did not meet water thresholds to trigger planting additional crops. They were fertilised with the same regime as *baseline* i.e. 50th yield potential.

Although Billa Billa, Emerald and Pampas did grow extra crops between 2015 and 2018, there was no increase in cumulative grain yield and thus N, P and K export was actually lower or similar across the three sites between the higher intensity and the baseline systems (Table 6).

At Pampas the higher intensity system had an additional 88 kg N/ha applied to the cropping sequence compared to the baseline (Table 6), but the cumulative exported N was lower by 22 kg N/ha. Interestingly the higher intensity system at Pampas resulted in a reduction of 37 kg N/ha mineral N more than the baseline system. This means that the extra crop produced at Pampas resulted in a loss of 137 kg N/ha (of plant available N) from the system, while the baseline system increased mineral N by 10 kg N/ha. It is unclear where this N has ended up, but it is possible this has been accumulated in the soil carbon pool. Analysis of soil carbon levels and the completion of additional seasons will help to answer the impact cropping intensity has on soil fertility.

Table 6. Cumulative nitrogen dynamics of the higher intensity and baseline systems at 3 sites in northern grains region (2015 – 2018)

Site	N export (kg/ha)		Applied fertiliser N (kg N/ha)		Mineral N change (kg N/ha)		Total system N use (kg N/ha)	
	Baseline	Higher intensity	Baseline	Higher intensity	Baseline	Higher intensity	Baseline	Higher intensity
Billa Billa	220	195	12	13	249	220	261	233
Emerald	227	211	91	94	52	30	143	124
Pampas	271	249	13	101	248	285	261	385

Note: Total N use is calculated from applied fertiliser and the mineral N balance - (ammonia and nitrate N) prior to sowing 2015 minus the mineral N post the 2018 harvest

Table 7. Cumulative phosphorus and potassium removal from the higher intensity and baseline systems at 3 sites in the northern grains region (2015 – 2018)

Site	P export (kg/ha)		Applied fertiliser P (kg N/ha)		K export (kg K/ha)	
	Baseline	Higher intensity	Baseline	Higher intensity	Baseline	Higher intensity
Billa Billa	41	31	27	29	57	40
Emerald	29	29	22	29	56	43
Pampas	37	41	23	25	53	59

Note: P and K export calculated using grain content (%) x DW grain yield (kg/ha)

How do different crops impact on N cycling and fallow accumulation?

Grain legumes fix N and are renowned for increasing mineralisation during the subsequent fallow period prior to the next crop. Also some legumes are thought to be more efficient at doing this than others (e.g. fababean provides more N benefit than chickpea). The diversity of crops grown across various sites in this project provides an opportunity to compare the mineral N dynamics in-crop and also in the fallow period after harvest for various crop types across multiple seasons.

In three of four comparisons between chickpea and wheat that were grown in the same season (Emerald 2015 and 2016, Pampas 2016) we did not observe any additional N accumulation after chickpea compared to wheat and had the same mineral N available for subsequent crops. There may have been a small amount of extra N at the end of the chickpea crop but this was often associated with a higher N at sowing and hence crop N extraction was similar or in some cases higher. For example at Emerald in 2016, chickpea utilised 130 kg N/ha from the soil mineral pool compared to 114 kg N/ha for wheat. The one exception across these comparisons was during a long-fallow at Pampas after winter crops in 2015. This showed that following chickpea accumulated an additional 38 kg of N accumulated compared to wheat, but owing to lower soil N at harvest there was still actually less mineral N available following chickpea than wheat.

A further comparison of mineral N dynamics between different legumes grown in the same season occurred across 3 locations (Narrabri and Spring Ridge in 2016, Pampas 2015). These results show very little significant difference between the various legumes in N utilisation, and accumulation during the subsequent fallow.

While these results suggest there has been little N benefit for subsequent crops following grain legumes across sites, because mineral N status is affected by mineralisation rates, denitrification, and microbial tie-up, it may be that these crops may provide additional N supply in the subsequent crops. This does raise questions about the commonly held belief that legumes will provide N benefits for subsequent crops and that some legumes are better than others. More seasons and sites may be required to more fully understand this.

Table 8. Comparisons of crop effects on soil N use and subsequent fallow N accumulation across multiple sites and seasons in the northern grains region

Site Season	Crop	Sowing mineral N (kg N/ha)	Harvest mineral N (kg N/ha)	End of fallow mineral N (kg N/ha)	Subsequent fallow mineral N accumulation (kg N/ha)
Emerald 2015					
	Wheat	105	59	153	94
	Chickpea	78	32	126	94
Emerald 2016					
	Wheat	126	12	114	102
	Chickpea	153	23	141	118
Narrabri 2016					
	Chickpea	69	38	43	5
	Fieldpea	86	41	49	8
	Fababean	77	41	38	-3
Spring Ridge 2016					
	Chickpea	157	173	277	105
	Fieldpea	169	156	248	92
	Fababean	160	154	237	84
Pampas 2015 – long fallow					
	Wheat	184	117	179	62
	Fababean	186	58	153	97
	Chickpea	203	68	168	100
	Field pea	190	94	217	123
	Canola	186	93	183	90
Pampas 2016 – short fallow					
	Wheat	83	17	61	44
	Chickpea	93	34	76	42

Discussion

The first four years of the farming system project showed that modifying crop systems through higher nutrients, higher intensity and the higher frequency of legumes provided limited benefits for improving nutrient status relative to localised growers practice (baseline). Only when higher nutrients were provided did we manage to balance the net export of all nutrients (N, P, K) relative to the inputs in several cases. However, there have been few cases where we have seen a positive yield advantage from providing these additional nutrients. However as soils age and their inherent fertility declines this may change.

It must be noted that although nutritional benefits were limited in the first four years of the project between systems, there were legumes (in particular chickpea) planted commonly within the baseline systems (20-33% of crops planted). Growing chickpea in the baseline system has followed current local grower practice, however has resulted in smaller differences between the higher legume, higher nutrients and baseline systems.

Future comprehensive soil analysis across all sites will be interesting to investigate to detect changes in other parameters such as total N and organic carbon levels. Longer-term examination of cropping systems may lead to greater differentiation between systems and geographical location, providing greater insights into the impact different farming systems have on nutrient balances and long-term soil fertility.

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 would also specifically like to thank all the farm and field staff contributing to the implementation and management of these experiments, the trial co-operators and host farmers.

Contact details

Jon Baird
NSW DPI
21888 Kamilaroi Highway, Narrabri, NSW
Ph: 02 67992434
Mb: 0429 136 581
Email: jon.baird@dpi.nsw.gov.au

Cover crops can boost soil water storage and crop yields

Andrew Erbacher[1], David Lawrence[1], David Freebairn, Neil Huth[2], Brook Anderson[2] and Graham Harris[1]

[1]DAF Qld
[2]CSIRO

Key words

cover crops, millet, ground cover, soil water storage, fallow management, stubble, evaporation, infiltration, plant available water

GRDC code

DAQ00211

Take home messages

- Cover crops can increase fallow water storage, and improve crop performance and returns in northern farming systems
- In each experiment, a cover crop treatment provided the highest plant available soil water by the end of the fallow
- The best cover crop treatment depended on the length of the fallow. A later spray-out, with more resilient cover, was best in the longer fallow. However, delaying spray-out too long had a dramatic effect on water storage
- Cover crop saved 2-3 fallow herbicide sprays and dramatically improved establishment at one of the sites
- Yields and returns were increased by the best cover crop treatment at each trial, but yield effects appear to be in excess of those expected from the increased soil water storage

Cover crops in the northern region

Growers typically use cover crops to protect the soil from erosion in low stubble situations, return biomass that helps maintain soil organic matter and biological activity, and to provide additional nitrogen when legumes are used. However, cover crops also offer an opportunity to increase infiltration and fallow moisture storage for better and more profitable grain and cotton crops across the northern region of New South Wales (NSW) and Queensland.

Advances in agronomy and commercial agronomist support have seen growers better use their available soil water and improve individual crop performance. However, more effective capture and storage of rainfall across the whole farming system remain as major challenges for northern grain and cotton growers where only 20-40% of rainfall is typically transpired by dryland crops, up to 60% of rainfall is lost to evaporation, and a further 5-20% lost in runoff and deep drainage. Every 10 mm of extra stored soil water available to crops could increase dryland grain yields for growers by up to 150 kg/ha, with corresponding benefits to dryland cotton growers as well.

GRDC funded farming systems projects (DAQ00192/CSA00050) are assessing ways to improve this system water use, and to achieve 80% of the water and nitrogen limited yield potential in our cropping systems. GRDC's Eastern Farming Systems project and Northern Growers Alliance (NGA) trials both suggest that cover crops and increased stubble loads can reduce evaporation, increase infiltration and provide net gains in plant available water over traditional fallow periods.

Consequently, cover crops may be a key part of improved farming systems; providing increased productivity, enhanced profitability and better sustainability.

Scientific rationale

Stubble and evaporation

Retained stubble provides ground cover, protects the soil from rainfall impacts and so improves infiltration to store more water in the soil. Conventional wisdom is that increased stubble loads can slow down the initial rate of evaporation, but that these gains are short-lived and lost from accumulated evaporation after several weeks. However, further rain within this period and the manipulation of stubble to concentrate stubble loads in specific areas, provide an opportunity to reduce total evaporation and to accumulate more plant available water.

Dryland grain systems

Cover crops are used in southern Queensland and northern NSW to overcome a lack of stubble and protect the soil following low residue crops (e.g. chickpea, cotton) or following skip-row sorghum with uneven stubble and exposed soil in the 'skips'.

Growers typically plant white French millet and sorghum and spray them out within ~60 days to allow recharge in what are normally long fallows across the summer to the next winter crop. Allowing these 'cover crops' to grow through to maturity led to significant soil water deficits and yield losses in the subsequent winter crops. However, the Eastern Farming Systems project showed only small deficits (and even water gains) accrued to the subsequent crops when millets were sprayed out after 6 weeks, with average grain yield increases of 0.36 t/ha. Furthermore, the Northern Growers Alliance showed that the addition of extra stubble (from 5-40 t/ha) after winter crop harvest appeared to reduce evaporation, with initial studies showing between 19 mm and 87 mm increases in plant available water. These gains will be valuable if validated in further research and captured in commercial practice.

Our current project is monitoring sites intensively to quantify the impact of different stubble loads on the accumulation of rainfall, the amount of water required to grow cover crops with sufficient stubble loads, the net water gains/losses for the following crops and the impacts on their growth and yield. This paper reports on the first two sites in southern Queensland, which will be used in simulation/modelling later in the project to assess the wider potential and economic impacts of cover crops in both grain and cotton production systems.

Experiment 1 – Yelarbon (pivot-irrigated cotton, short fallowed to pivot irrigated cotton)

The Yelarbon experiment was on a pivot-irrigated paddock that grew cotton in 2016/17. The crop was picked and root cut in May, before offset discs were used on 12 June 2017 to pupae-bust and to level wheel tracks of the pivot irrigator. Nine cover treatments (Table 1) with five replicates were planted on the same day using barley (100 plants/m^2), barley and vetch mixtures (30 plants/m^2 each) and tillage radish (30 plants/m^2). Rain that night aided establishment, and the surrounding paddock was planted to wheat for stubble cover two weeks later.

Three planned termination times matched key growth stages of the main cereal treatments: Early-termination at first node (Z31) when the crop begins stem development; Mid-termination at flag leaf emergence (Z41) when the reproductive phase begins; and Late-termination at anthesis (Z65) for peak biomass production. Biomass of the cover crop treatments at their relevant termination times ranged from 1166 kg dry matter (DM)/ha (early) to 8175 kg DM/ha when the crop was grown through to grain harvest (Table 1).

The subsequent cotton crop was planted on 15 November 2017 and irrigated in line with the surrounding crop that was taken through to harvest. We consequently included a 'grain harvest' treatment in line with the farmer's practice, which was used to determine the farmer's irrigation schedule for the wider paddock and our experimental plots. Above ground biomass was also monitored across the growth of the cover crops until termination and through the subsequent fallow. Establishment counts were taken on each plot and hand cuts used to estimate cotton yields.

Table 1. Cover treatments applied at the Yelarbon site prior to planting cotton

Treatment	Cover crop	Termination time	Biomass (kg/ha)
1.	Control (Bare)		
2.	Cereal	Early-sprayout	1166
3.	Cereal	Mid-sprayout	4200
4.	Cereal	Late-sprayout	5104
5.	Cereal	Mid-sprayout + Roll	4200
6.	Cereal	Grain harvest	8175
7.	Cereal + legume	Mid-sprayout	4928
8.	Cereal + legume	Late-sprayout	4149
9.	Tillage radish	Mid-sprayout	4692

Soil water

Soil water was estimated using soil cores to measure gravimetric soil water at key times across the fallow and the subsequent cotton, along with regular neutron moisture meters (NMM) and EM38 readings in each plot. These NMM and EM38 readings and the percentage ground cover were recorded every two-to-four weeks while the cover crops were growing, and every four weeks once all cover crops were terminated, and until canopy closure of the following cotton was achieved. Final EM38 and NMM readings were recorded at cotton defoliation.

The water cost of growing the barley cover crops, relative to the control treatment in the early stages of the fallow was ~40 mm for the early-termination, ~70 mm for the mid-termination and ~120 mm for the late-termination (Figure 1). However, by the end of the fallow, and a subsequent 170 mm of rainfall/irrigation in 8 events from mid-termination to cotton plant, the mid-termination treatment caught up to the control, and the early-termination had accumulated an additional 14 mm of water. Not surprisingly, this early-termination proved to be the best cover crop treatment on the short fallow. The crop that continued to harvest was ~145 mm behind by the end of the fallow. This treatment mirrored the wider paddock and so set the following pivot irrigation schedule.

Crop performance

The irrigation schedule matched to the harvested crop provided more than adequate water across the cover crop treatments; yields for all cover crop treatments were similar. However, the Control with limited ground cover was the poorest performer with ~3 bales/ha lower yield, lower infiltration in early growth stages and less extraction of water late in the crop.

The nominal costs to plant the cover crops ($50/ha) and to spray them out ($20/ha) were almost matched by the savings from three less fallow weed sprays ($60); so the measured cotton yield responses were very profitable. For grain growers, the extra 14 mm stored moisture from this early-termination cover crop would typically produce ~200 kg grain in wheat at a water use efficiency of 15 kg grain/mm water, which is worth ~$50/ha (at $270/t) and would produce an overall return of $40/ha. Any further possible benefits from cover crops, which appear to have occurred in the cotton crop, have not been included.

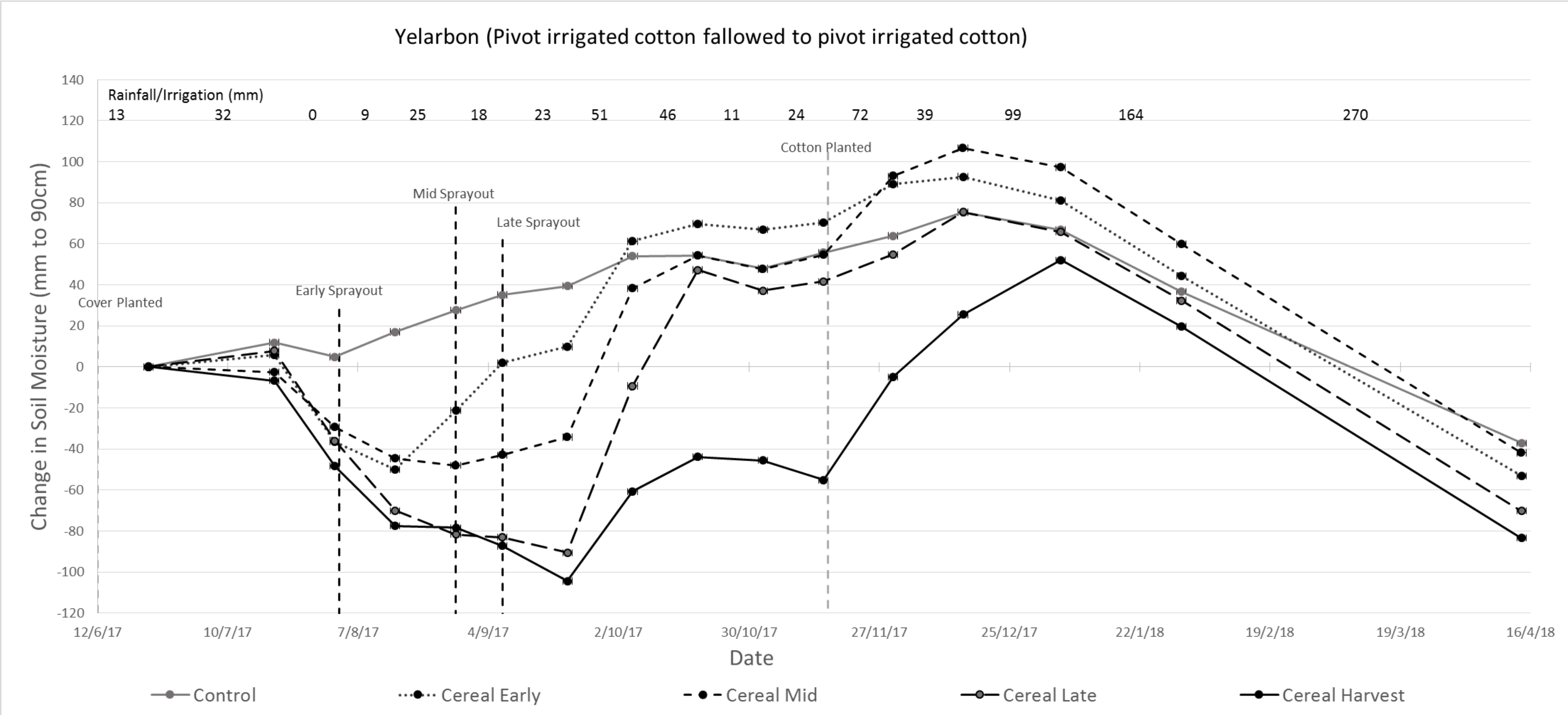

Figure 1. Changes in soil water (mm to 90 cm) from planting of key cover crop treatments until defoliation of the subsequent cotton crop at Yelarbon

Table 2. Net change in water storage over the life of the fallow (relative to the Control) and final cotton yield for each cover crop treatment at Yelarbon.

Treatment	Cover crop	Terminate	Water gain (cf control)	Cotton yield (Bales/ha)
1.	Control (Bare) Starting water ~100mm PAW		56 mm (fallow gain)	9.3
2.	Cereal	Early	+14 mm	12.9
3.	Cereal	Mid	-1 mm	12.7
4.	Cereal	Late	-14 mm	11.9
5.	Cereal	Mid + Roll	-2 mm	12.6
6.	Cereal	Harvest	-111 mm	14.1
7.	Cereal + Legume	Mid	-16 mm	11.9
8.	Cereal + Legume	Late	-7 mm	13.9
9.	Tillage Radish	Mid	-40 mm	14.4

Experiment 2 – Bungunya (Skip-row sorghum, long- fallowed to dryland wheat)

The Bungunya experiment was in a long-fallow paddock following skip-row sorghum that was harvested in early February 2017. The paddock had deep phosphorus applied in August 2017 and was 'Kelly-chained' in September 2017 to level the paddock, which left it with little cover until the planned wheat crop. Cover crops were planted into ~120 mm of plant available soil water on 11 October. The subsequent wheat was planted on 1 May 2018, with hand cuts for yield done on 12 October and mechanical harvesting on 26 October. Soil water, cover crop and stubble biomass, ground cover, wheat establishment and yields were measured in the same way as the experiment at Yelarbon.

Table 3. Cover treatments applied at the Bungunya site prior to planting wheat

Treatment	Cover crop	Termination time	Biomass (kg/ha)
1.	Control (Bare)		
2.	Millet (White French)	Early-sprayout	1533
3.	Millet (White French)	Mid-sprayout	2327
4.	Millet (White French)	Late-sprayout	4365
5.	Millet (White French)	Mid-sprayout + Roll	2476
6.	Millet (White French)	Late-sprayout + Roll	4737
7.	Sorghum	Mid-sprayout	2481
8.	Lab Lab	Mid-sprayout	1238
9.	Multi-species (millet, lab lab, radish)	Mid-sprayout	1214

Soil water

The water cost of growing the millet cover crops, relative to the Control treatment in the early stages of the fallow was ~50mm for the early-termination, ~40 mm for the mid-termination and ~60 mm for the late-termination (Figure 2). The lab lab mid-termination treatment also cost ~60 mm to grow, relative to the Control treatment. These figures reflect rainfall and different rates of infiltration between soil water measurements:

- Plant to Mid-termination, 65 mm in 3 events (12/10/17 to 22/11/17)
- Mid-termination to plant, 205 mm in 11 events (22/11/17 to 1/5/18)
- Plant to maturity 41mm in 3 events (1/5/18 to 10/10/18)
- Maturity to soil sample 72mm in 7 events (10/10/18 to 5/11/18)

By early March, with a subsequent 175 mm of rain in ten falls after the mid-termination, these millet treatments had all recovered to have effectively the same soil water as the Control, except where the late-terminated millet was rolled; it had gained ~20 mm more water than the other treatments.

When the subsequent wheat crop was planted, the mid-terminated millet had ~14 mm more soil water than the Control treatment, the late millet ~19 mm more, and the late millet that was also rolled had ~36mm more soil water (Table 4). Interestingly, water extraction by the wheat crop was greater from all of the millet cover crop plots than the Control, which had lower yields; perhaps due to, or resulting in less root development.

Crop performance

All cover crop treatments increased the yield of the final wheat crop (Table 4) and saved two fallow weed sprays (~$40/ha). However, the biggest yield increases were from the cereal cover crops, especially the late-terminated millet and the sorghum.

The water differences at planting (end of the fallow) may explain some of the yield difference. However, the establishment of the wheat crop was dramatically better where cover crops were used, more so where cereals were used but also for lab lab. The expected yield increases from the higher fallow water storage alone would typically be ~200 kg grain in wheat (WUE 15 kg grain/mm water) for the mid-terminated millet (worth ~$50/ha), ~280 kg grain for the late millet (worth $75/ha) and ~540 kg grain for the late +rolled millet (worth $150/ha). These gains would represent net returns of $20/ha, $45/ha and $120/ha respectively. However, the measured yield gains for these treatments were 950 kg/ha, 1461 kg/ha and 1129 kg/ha respectively, representing increase returns of between $250 and $380 /ha.

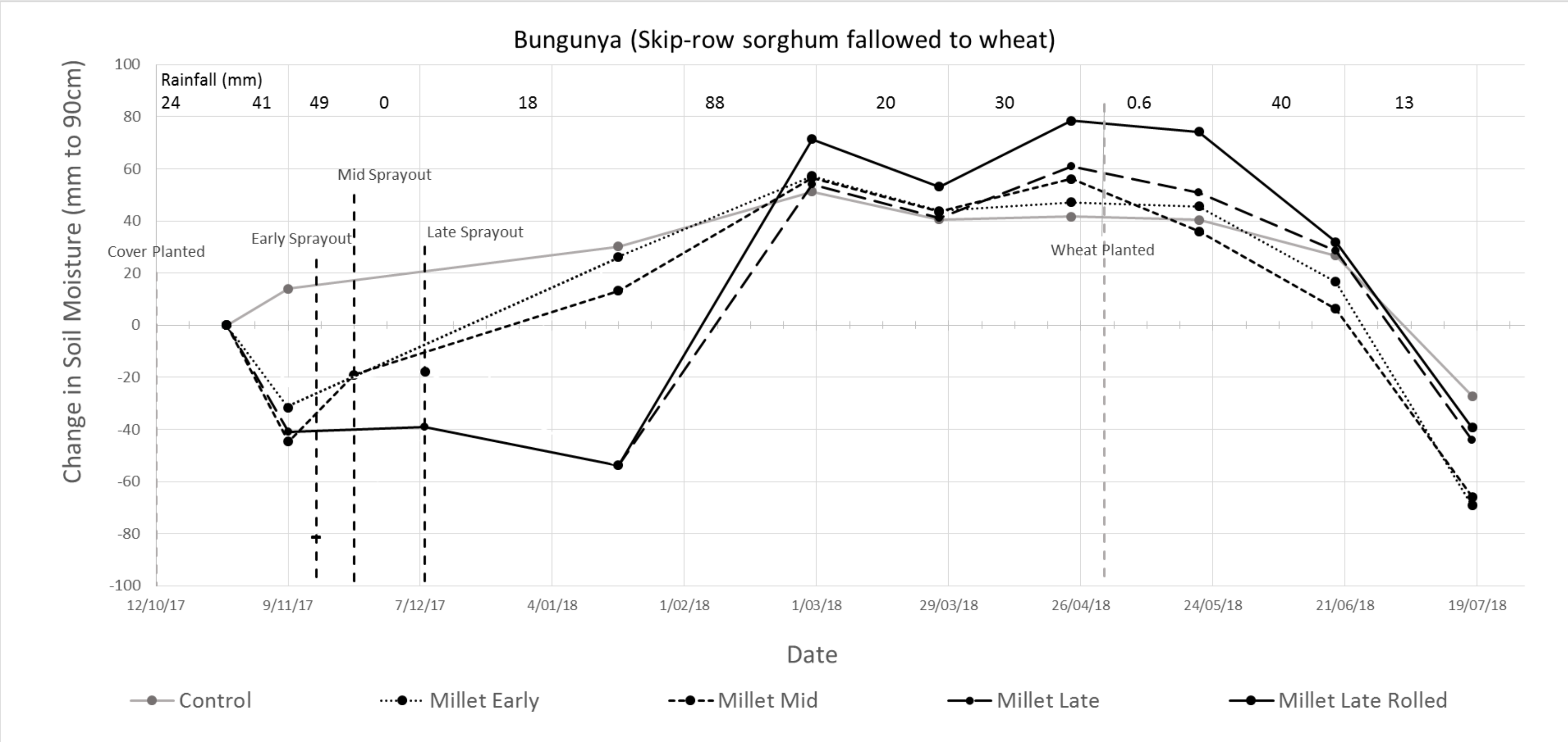

Figure 2. Changes in soil water (mm to 90 cm) from planting of the millet cover crop treatments sprayed out at different crop growth stages until harvest of the later wheat crop at Bungunya

Table 4. Net change in water storage over the life of the fallow (relative to the Control) and final wheat yield for each cover crop treatment at Bungunya.

Treatment	**Cover crop**	**Terminate**	**Water gain (cf control)**	**Wheat yield (kg/ha)**
1.	Control (Bare) Starting water ~120mm PAW		42mm (fallow gain)	1436 f
2.	Millet (White French)	Early	+5 mm	2223 cd
3.	Millet (White French)	Mid	+14 mm	2386 bc
4.	Millet (White French)	Late	+19 mm	2897 a
5.	Millet (White French)	Mid + Roll	+17 mm	2359 bc
6.	Millet (White French)	Late + Roll	+36 mm	2565 b
7.	Sorghum	Mid	+17 mm	2634 ab
8.	Lab Lab	Mid	-4 mm	1795 e
9.	Multi-species (millet, lab lab, radish)	Mid	+21 mm	1954 de

Conclusions

The project results show that cover crops can indeed help increase net water storage across fallows that have limited ground cover. How often these soil water results will occur across different seasons will be explored across the rest of the project with further experiments and simulation modelling.

However, more dramatic are the early yield results for the subsequent cotton and wheat crops at each site. These yield responses are very large and represent big improvements in returns; far beyond what could be expected from the increases in net soil water storage across the fallows. Wheat establishment was dramatically improved in the Bungunya experiment, and there was greater water extraction (especially at depth) in the Yelarbon experiment. How much of the responses can be attributed to these factors, how often such results might occur, and the contributions of other different factors to these gains remains to be explored.

Acknowledgements

The research undertaken in this project was made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the CRDC, DAF Queensland, CSIRO and DPINSW. The authors would like to thank them all for their continued support. Special thanks to Glen Smith at 'Koarlo', David Woods at 'Coorangy', and the DAF Biometry, Technical and Research Infrastructure staff that supported the heavy management and monitoring loads of these experiments.

Contact details

Andrew Erbacher
DAF Queensland, Lagoon Street, Goondiwindi
Ph: 0475 814 432
Email: andrew.erbacher@daf.qld.gov.au

David Lawrence
DAF Queensland, Tor Street, Toowoomba
Mb: 0429 001 759
Email: david.lawrence@daf.qld.gov.au

Economic performance and system water-use-efficiency of farming systems

Lindsay Bell[1], Andrew Zull[2], Darren Aisthorpe[2], David Lawrence[2], Andrew Verrell[3], Jon Baird[3], Andrew Erbacher[2], Jayne Gentry[2], Greg Brooke[3] and Kaara Klepper[4]

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

Key words

gross margin, costs, income, nutrients, crop rotation

GRDC code

DAQ00192, CSA00050

Take home messages

- Large gaps in profitability are possible between the best and worst systems – differences of $200-700 per year were found between systems at each site
- Intensity is the major factor driving good/poor economic performance of the farming system - more so than crop choice. Matching intensity to environmental potential seems to be the most important lever to optimise farming system profitability
- Increasing crop intensity increased costs and risks, and either reduced or equalled the system water use efficiency (WUE) of baseline systems across all sites over the experimental period
- Lower crop intensity had lower system WUE and gross returns, but because of lower inputs and costs may achieve a more favourable return on investment at lower risk. These systems had similar profitability under lower rainfall conditions but were suboptimal in more favourable environments
- Increasing legume frequency can achieve similar profitability and system WUE, especially if nutrient balance differences were considered, but often had higher production costs
- Increasing crop diversity and growing alternative crops as a means of managing diseases or weeds had significant costs at many sites, but in some locations was able to increase or equal system profitability. These systems were more favourable at locations with more available rainfall
- Increasing nutrient supply incurred higher costs and hence, rarely increased system profitability, but if costs of system nutrient balance systems were attributed (i.e. nutrient export – inputs), similar or higher system WUE ($/mm water use) were achieved.
- We found that a system water use efficiency of $2.50 of crop income/mm of rainfall over the cropping sequence is achievable and could be used to benchmark current farming systems.

Introduction

Leading farmers in Australia's northern grains region perform well in terms of achieving the yield potential of individual crops. However, the performance of the overall system is harder to measure and less frequently well considered. Analysis suggests that fewer than one third of crop sequences achieve more than 80% of their potential water use efficiency despite having adequate nitrogen fertiliser inputs (Hochman et al. 2014). The key factors appear not to be related to in-crop agronomy but to the impact of crop rotations and are thought to relate to issues occurring across the crop sequence such as poor weed management, disease and pest losses, sub-optimal fallow management and cropping frequency. Similarly, farming systems are threatened by the emerging challenges of increasing herbicide resistance, declining soil fertility and increasing soil-borne pathogens, all of which require responses to maintain total system productivity. Questions are emerging about how systems should evolve to integrate practices that:

- Maximise capture and utilisation of rainfall particularly when using high-value, low-residue crops
- Reduce costs of production and the likelihood of climate-induced risk
- Respond to declining chemical, physical and biological fertility
- Improve crop nutrition and synchrony of nutrient supply
- Suppress or manage crop pathogen populations
- Reduce weed populations and slow the onset, prevalence and impact of herbicide resistance.

Because of the multi-faceted nature of these challenges, an important need is for a farming systems research approach that develops an understanding of how various practices or interventions come together, quantifies synergies or trade-offs and shows how these interventions impact on whole-of-system productivity, risk, economic performance and sustainability of farming systems.

As a result, research was initiated 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 test the impacts of modifications of the farming system on multiple attributes (e.g. nutrients, water, pathogens, soil health, and economics) across multiple sites. Experiments were established at seven locations; a large factorial experiment at Pampas near Toowoomba, and locally relevant systems being studied at six regional centres across central and southern Qld (Emerald, Billa Billa, Mungindi) and northern NSW (Spring Ridge, Narrabri and Trangie).

Assessing how changes to the farming systems alter the profitability and efficiency of the farming system is critical. This paper examines the economic performance of different modifications that we have tested. This will help quantify the costs or benefits of changing the farming system to deal with a particular issue (e.g. weeds or disease issue), and the trade-offs for the different cropping intensities and nutrient strategies.

In this research we used the key metric of "system water use efficiency" to compare system productivity or profitability per mm of rain across environments and cropping systems. Most agronomists and farmers would be familiar with the concept of crop water use efficiency (i.e. kg grain yield/mm crop water use) for comparing how efficiently crops under different management or environments perform. However, for comparing the cropping system as a whole across multiple years with different crops, a different approach is required. This also needs to account for both rainfall capture and loss during the fallow over a sequence of crops, the differences in the inputs required, as well as the productivity of different crops which may be influenced both positively, or negatively, by previous crops in the sequence or rotation. Hence, in the farming systems project we have been evaluating the system WUE as the $ gross margin return per mm of system water use (i.e. **rain minus the change in soil water content**) over the period of interest.

$$System\ WUE\ (\$\ GM/mm) = \frac{\sum\{(\text{yield} \times \text{price}) - \text{variable costs}\}}{(\sum rain + \Delta\ Soil\ water)}$$

System modifications

Across these projects a common set of farming system strategies were used to examine how changes in the farming system aimed at addressing particular challenges impact on multiple aspects of the farming system. These different farming system strategies are not predetermined and hence play out differently in different locations, based on the environmental (climate & soil) conditions at that location. Below we outline the common set of farming system modifications employed across the farming systems experimental sites over the past 3.5 years.

- ***Baseline*** – an approximation of current best management practice in each district against which each of the system modifications are compared: involves only dominant crops used in the district; sowing crops on a moderate soil water threshold (i.e. 50-60% full profile) to approximate moderately conservative crop intensities (often 0.75-1 crop per year); and fertilising to median crop yield potential
- ***High crop intensity*** – aims to increase the proportion of rainfall transpired and reduce unproductive loses by increasing the proportion of time that crops are growing; this is implemented by reducing the soil water threshold required to trigger a planting opportunity (e.g. 30% full profile) so that cropping intensity is increased relative to the baseline
- ***Low crop intensity systems*** – this aims to minimise risk by only growing crops when plant available soil water approaches full (i.e. > 80% full) before a crop is sown and higher value crops are used when possible. This requires longer fallows and will lower crop intensity relative to the baseline
- ***High legume frequency*** – crop choice is dictated to have every second crop as a legume across the crop sequence and uses high biomass legumes (e.g. fababean) when possible.
- ***High crop diversity*** – a greater set of crops are used with the aim of managing soil-borne pathogens and weed herbicide resistance risk through crop rotations. This implemented by growing 50% of crops resistant to root lesion nematodes (preferably 2 in a row) and 2 alternative crops are required before the same crop is grown in the crop sequence
- ***High nutrient supply -*** increasing the fertiliser budget for each crop based on 90% of yield potential rather than the baseline of 50% of yield potential.

At several sites there are also some additional, locally relevant system modifications being implemented. These include higher fertility treatments where the high nutrient supply system is also complimented with the additions of a large amount of organic amendments with the aim of boosting background soil fertility. The aim is to see if this can be maintained when used in combination with the higher nutrient input strategy. At Emerald, a system aimed at implementing an integrated weed management package is included. This tests the implications of using combinations of agronomic management options particularly focussed on summer grass weeds (e.g. feather-top Rhodes grass) such as higher levels of crop competition and use of multiple herbicide modes of action. At Mungindi, two low intensity systems have been implemented, one involving only grain crops and the other implementing cotton in the rotation when conditions are appropriate.

Finally, at the core experimental site at Pampas, each of these system modifications are being tested in a factorial where some modifications are combined. These are also being tested across rotations spanning those employed across the northern region, either winter-crop focussed, mainly summer crops, or a mix of both which is driven entirely by soil water.

Economic calculations

Over the 3.5 experimental years of experiments conducted for each system we have collected data on the grain yields of crops, the total inputs of fertilisers, seed, herbicides and other pesticides, and operations. This allows us to calculate the cash-flow, accumulated income (sum of grain yield x price for all crops in the sequence) and gross margins (income minus costs) for each of the cropping systems deployed at each location (Table 4 and 5). We have used consistent prices for each commodity and inputs across all locations to avoid introducing discrepancies in the data (Table 1). All grain yields were corrected to 12% moisture irrespective of harvest moisture levels. Grain commodity prices used were based on inflation corrected average grain prices for each crop over the past 10 years.

Table 1. Commodity prices (10-year average) for each crop grown across the farming systems experiments

Crop	$/t grain#
Barley	218
Wheat (durum & APH)	269
Canola	503
Chickpea	504
Fababean	382
Fieldpea	350
Sorghum	221
Maize	281
Mungbean	667
Sunflower	700
Cotton	1090 ($480/bale lint)

#farm gate price with grading & additional harvesting costs already deducted

Prices for inputs of fertilisers, herbicides, other pesticides and seed were based on market prices at purchase for each input. Costs for operations differed by crop to reflect different contract rates or machinery requirements, but fertiliser applications ($8/ha) and each spraying operation ($3/ha) were held constant. It should be noted we have not attempted to correct for overhead or other fixed costs associated with the farming enterprise, as these are likely to vary significantly from farm to farm and region to region.

Cropping sequence deployed

Tables 2 (core site) and 3 (regional sites) show the diversity and differences in crop sequences that have been deployed across the various farming systems at each experimental location over the first 3.5 years of the farming systems experiments. These tables are intended as a guide for interpreting the subsequent analysis of profitability across these various systems, and what differences in crop sequence are associated with those. This is also relevant for subsequent papers in this series presenting results on the nutrient use and balance and soil water dynamics across the various farming systems.

Table 2. Summary of crop sequences deployed across the 3.5 years of the experiment (winter – WIN, summer – SUM, year season started) across the various farming systems at the core site at Pampas. Crop abbreviations: W – wheat, Cp – Chickpea, Fb – Fababean, Fp – Fieldpea, Cn – Canola, Dm – Durum wheat, Mg – Mungbean, Sg – Sorghum, Mz – Maize, Ct – Cotton, Sf – Sunflower, (m) – millet cover crop

System		Win15	Sum15	Win16	Sum16	Win17	Sum17	Win18	Sum18
Mixed Opportunity	**Baseline**	**W**	**x**	**x**	**Sg**	**Cp**	**x**	**x**	**Sg**
	Higher nutrient	W	x	x	Sg	Cp	x	x	Sg
	Higher legume	Fb	x	x	Sg	Cp	x	x	Sg
	Crop diversity	Cn	x	x	Sg	Cp	x	x	Ct
	Crop div. + nutrient	Cn	x	x	Sg	Cp	x	x	Ct
	Higher leg. + diversity	Fp	x	x	Sg	Cp	x	x	Ct
	Lower intensity	W	x	x	Ct	W	x	x	x
Higher intensity	**Baseline**	**W**	**Mg**	**x**	**Sg**	**Cp**	**Sg**	**x**	**Sg**
	Higher nutrient	W	Mg	x	Sg	Cp	Sg	x	Sg
	Higher legume	Fb	Mg	x	Sg	Cp	Sg	x	Mg
	Crop diversity	Cn	Mg	x	Sg	Dw	Sf	x	Sg
	Crop div. + nutrient	Cn	Mg	x	Sg	Cp	Sf	x	Sg
	Higher leg. + diversity	Fp	Mg	x	Sg	Cp	Sf	x	Mg
Summer	**Baseline**	**W**	**x**	**x**	**Mz**	**x**	**Sg**	**x**	**x**
	Higher nutrient	W	x	x	Mz	x	Sg	x	x
	Higher legume	Fb	x	x	Mz	x	Mg	x	x
	Crop diversity	W	x	x	Ct	x	Sg	x	x
	Crop div. + nutrient	W	x	x	Ct	x	Sg	x	x
	Higher leg. + diversity	Fb	x	x	Ct	x	Mg	x	x
	Lower intensity	x	Mz	x	Mg	x	x	x	Ct
Winter	**Baseline**	**W**	**x**	**Cp**	**x**	**W**	**x**	**x[#]**	**x**
	Higher nutrient	W	x	Cp	x	W	x	x	x
	Higher legume	Fb	x	W	x	Cp	x	x	x
	Crop diversity	Cn	x	Dm	x	Cp	x	x	x
	Crop div. + nutrient	Cn	x	Dm	x	Cp	x	x	x
	Higher leg. + diversity	Fb	x	Dm	x	Fp	x	x	x
	Lower intensity	W	x	x	x	Cp	(m)	x	x

[#] no sowing opportunities occurred within the acceptable window in this season

Table 3. Summary of crop sequences deployed across the 3.5 years of the experiment (winter – WIN, summer – SUM, year season started) across all regional sites for the different farming systems. Crop abbreviations: W – wheat, B – Barley, Cp – Chickpea, Fb – Fababean, Fp – Fieldpea, Cn – Canola, Dm – Durum wheat, Mg – Mungbean, Sg – Sorghum, Ct – Cotton, Sf – Sunflower, (lower case) indicates terminated crop.

Site	*System*	Win15	Sum15	Win16	Sum16	Win17	Sum17	Win18
Billa Billa	**Baseline**	**W**	**x**	**B**	**x**	**W**	**x**	**Cp**
	Higher nutrient	W	x	B	x	W	x	Cp
	Higher fertility	W	x	B	x	W	x	Cp
	Higher legume	W	x	Fb	Mg	x	Sg	Cp
	Crop diversity	W	x	Fp	Sg	x	x	Cn
	Higher intensity	W	Mg	x	Sg	W	Sg	x
	Lower intensity	W	x	x	Sg	x	x	W
Emerald	**Baseline**	**W**	**x**	**Cp**	**x**	**W**	**Sg**	**x**
	Higher nutrient	W	x	Cp	x	W	Sg	x
	Higher fertility	W	x	Cp	x	W	Sg	x
	Higher legume	Cp	x	W	x	Cp	Sg	x
	Higher intensity	W	Mg	W	x	W	Sg	x
	IWM	W	x	Cp	x	W	Sg	x
Mungindi	**Baseline**	**W**	**x**	**Cp**	**x**	**(w)**	**x**	**W**
	Higher nutrient	W	x	Cp	x	(w)	x	W
	Higher legume	W	x	Cp	x	(w)	x	Cp
	Crop diversity	x	Sf	x	Sg	x	x	Dm
	Lower intensity (cotton)	W	x	x	Ct	x	x	W
	Lower intensity (grain)	x	Sg	x	x	(w)	x	Cp
Narrabri	**Baseline**	**W**	**x**	**Cp**	**x**	**B**	**x**	**x**
	Higher nutrient	W	x	Cp	x	B	x	x
	Higher legume	W	x	Fb	x	W	x	x
	Crop diversity	W	x	Fp	x	Cn	x	x
	Higher intensity	W	x	Cn	x	W	x	x
	Lower intensity	W	x	x	Ct	(b)	x	x
Spring Ridge	**Baseline**	**W**	**x**	**Cp**	**x**	**W**	**x**	**x**
	Higher nutrient	W	x	Cp	x	W	x	x
	Higher legume	W	x	Fb	x	W	x	x
	Crop diversity	W	x	Fp	x	W	x	x
	Higher intensity	W	x	x	Sg	Cp	x	x
	Lower intensity	W	x	x	x	x	Ct	x
Trangie	**Baseline**			**W**	**x**	**W**	**x**	**B**
	Higher nutrient			W	x	W	x	B
	Higher legume			W	x	Cp	x	W
	Crop diversity			W	x	Cp	x	Fp
	Lower intensity			W	x	x	x	B

Economic performance of farming systems

As would be expected the total income and gross margins varied substantially across all sites, owing to the difference in rainfall, and hence crop productivity, and input costs required (Tables 4 & 5). While we have used a common approach and assumptions for calculating total income, costs and gross margin returns across all sites, care should be taken when comparing the economic performance between sites. There are large cost differences incurred between sites, due to differences in starting nutrient levels and weed status, which greatly influence the GM outcome between sites. For this reason, we focus mainly on comparing the economic outcomes between systems at the same site.

Best and worst system gross margins

Within each experimental comparison there was a significant gap between the best and the worst cropping system (Table 4 & 5). The difference between the highest grossing and lowest grossing system over the 3.5 experimental years (in $/ha/yr) was $550 at Billabilla, $304 at Emerald, $214 at Mungindi, $434 at Narrabri, $210 at Spring Ridge, $329 for the mixed opportunity systems at Pampas, $348 for summer rotation systems at Pampas, and $766 for winter rotation systems at Pampas. Overall, this highlights that there is a significant difference in the profitability of farming systems within a particular situation.

The best (or worst) system at each location was also not consistent. At most regional sites (except Emerald), the baseline cropping system designed to replicate current best management practice in a district performed the best or as well as any altered system. At Emerald, the High legume and High fertility systems performed the best, $150/ha/yr. higher than the baseline. Amongst the Pampas systems, the gross margin returns of the baseline systems was exceeded by systems with higher crop diversity or high legume frequency by $120-$380 per year over the experimental period.

Across all comparisons, the systems that produced the lowest gross margins were those where cropping intensity was altered. Higher crop intensity achieved the lowest gross margin at Billabilla, Emerald, Spring Ridge and lower crop intensity the lowest GM at Narrabri, Pampas and Mungindi. What this means is that getting cropping intensity wrong for your environment is a major driver of suboptimal system performance.

System modification effects on economics

While there was significant variation in the relative performance of different system modifications across sites, there were several consistent impacts from some of the system modifications.

- Higher nutrient strategy increased input costs significantly due to the higher fertiliser inputs to meet the crop nutrient budget that matched crop yield potential. Across all sites, this increased system costs by $150-$300 per ha over the crop sequence (or $50-$100 per year). So far we have seen few yield or economic responses to this higher nutrient supply approach (except Emerald), so this reduced gross margins compared to the baseline, and resulted in lower return on costs at most sites.

- Higher crop diversity has not significantly altered the costs of the production system, though there are some notable site differences (Table 2). The performance of the alternative crops at each location has been the central driver of how these systems have performed relative to the baseline. Across the regional sites gross margins were between $223 and $1430 less over the whole crop sequence ($64-$400 per year lower). At Pampas diversifying the cropping system has consistently exceeded the returns of the baseline crop sequence by between $372 and $1180 of the 3.5 years ($106-$340/year higher).

- Higher legume frequency systems have increased the variable costs of production in most cases, mainly due to higher costs for pesticides. While in several locations these systems achieved similar or higher GM to the baseline, because of these higher costs they have a lower return on costs in most cases.
- Lower crop intensity systems generally incurred lower costs but this was not universal across all sites; 5 of the 8 lower intensity systems had lower costs than the baseline with the 3 sowing cotton having similar or slightly higher costs. Despite the more conservative approach of waiting until the soil profile was full to sow a crop, this did not necessarily increase the outlay required to run such a system. At most sites, the maximum cash outlay required in the low intensity system was similar to the baseline, and in some cases lower (e.g. Spring Ridge).
- Higher intensity systems did not increase total crop income at any of the regional sites as expected and typically brought about an increase in costs, so that net returns were generally lower and the return on costs was dramatically lower. This highlights the risks associated with these systems. At Pampas, there was an increase in total crop income from increasing crop intensity of $500-$900 over the experimental period ($140-$300), but costs also increased which diminished the benefit to GM to less than $150/ha/yr.

Benchmarks for system WUE

The data generated here could provide a useful benchmark for farmers and advisers to compare their own current production system performance against. As mentioned above, the costs of production are likely to vary significantly across different situations, based on soil nutrient status, weed burdens, and operating costs. For this reason, examining potential total income per mm may be helpful to assess system productivity. Across all sites and systems, the maximum achieved income was $3.0 /mm, but a benchmark of $2.50/mm would be an achievable target at most locations (i.e. 80% of the potential).

Table 4. Total revenue generated, costs of production (fertilisers, seed, operations, chemicals), gross margins (GM), returns on variable costs (RVOC, ratio of income to costs), system WUE ($ gross margin/mm water use) and the maximum cash outlay achieved over the 3.5 years for each farming system tested at each of the 5 regional locations across the northern grains region.

Site	System	Total income ($/ha)	Total costs ($/ha)	Total GM ($/ha)	ROVC	Syst. WUE ($ GM/mm)	Max. cash outlay ($/ha)
Billa Billa	**Baseline**	**3946**	**672**	**3274**	**5.9**	**2.26**	**-284**
	Higher nutrient	3942	878	3065	4.5	2.16	-293
	Higher fertility	3579	826	2753	4.3	1.91	-289
	Higher legume	3606	853	2753	4.2	2.08	-306
	Crop diversity	3176	758	2419	4.2	1.83	-257
	Higher intensity	2288	973	1315	2.4	0.93	-513
	Lower intensity	2287	597	1690	3.8	1.29	-298
Emerald	**Baseline**	**3013**	**1341**	**1673**	**2.3**	**0.91**	**-449**
	Higher nutrient	3278	1383	1895	2.4	1.06	-454
	Higher fertility	3537	1373	2164	2.6	1.20	-449
	Higher legume	3409	1201	2209	2.8	1.20	-352
	Higher intensity	2549	1404	1146	1.8	0.64	-365
	Integrated Weed management	3307	1360	1947	2.4	1.08	-449
Mungindi	**Baseline**	**1581**	**573**	**1008**	**2.8**	**0.89**	**-271**
	Higher nutrient	1496	840	657	1.8	0.58	-297
	Higher legume	1487	654	833	2.3	0.75	-271
	Crop diversity	634	378	256	1.7	0.23	-274
	Lower intensity (cotton)	1287	680	607	1.9	0.54	-286
	Lower intensity (grain)	371	366	5	1.0	0.00	-266
Narrabri	**Baseline**	**3260**	**780**	**2480**	**4.2**	**1.36**	**-307**
	Higher nutrient	3263	916	2348	3.6	1.29	-354
	Higher legume	2902	718	2184	4.0	1.19	-286
	Crop diversity	1959	910	1049	2.2	0.58	-431
	Higher intensity	3304	878	2427	3.8	1.34	-381
	Lower intensity	1740	778	962	2.2	0.61	-395
Spring Ridge	**Baseline**	**3248**	**1381**	**1867**	**2.4**	**1.56**	**-840**
	Higher nutrient	3083	1449	1634	2.1	1.37	-840
	Higher legume	3388	1512	1875	2.2	1.54	-971
	Crop diversity	3041	1396	1644	2.2	1.38	-855
	Higher intensity	2531	910	1621	2.8	1.36	-431
	Lower intensity	3130	773	2357	4.0	1.58	-578

Table 5. Total revenue generated, costs of production (fertilisers, seed, operations, chemicals), gross margins (GM), returns on variable costs (RVOC, ratio of income to costs), system WUE ($ gross margin/mm water use) and the maximum cash outlay achieved over 3.5 years for each farming system tested the core experimental site at Pampas across mixed opportunity, summer-dominated or winter-dominated cropping systems.

	System modification	Total Income ($/ha)	Total Costs ($/ha)	Total GM ($/ha)	ROVC	Syst. WUE ($ GM/mm)	Max. cash outlay ($/ha)
Mixed opportunity	**Baseline**	**3466**	**769**	**2697**	**4.51**	**1.51**	**-263**
	Higher nutrient	3555	1106	2448	3.21	1.36	-355
	Higher legume	3976	919	3057	4.33	1.71	-296
	Crop diversity	3736	667	3069	5.60	1.73	-252
	Crop div. + nutrient	3699	1058	2641	3.50	1.49	-426
	Higher leg. + diversity	3153	723	2430	4.36	1.36	-283
	Lower intensity	3753	953	2800	3.94	1.65	-516
Higher intensity	**Baseline**	**3940**	**994**	**2945**	**3.96**	**1.66**	**-255**
	Higher nutrient	3889	1385	2504	2.81	1.39	-313
	Higher legume	4208	1139	3070	3.70	1.72	-289
	Crop diversity	4411	828	3583	5.33	2.04	-221
	Crop div. + nutrient	4268	1411	2857	3.02	1.64	-406
	Higher leg. + diversity	3994	977	3017	4.09	1.69	-262
Summer	**Baseline**	**3167**	**649**	**2518**	**4.88**	**1.44**	**-366**
	Higher nutrient	3386	863	2522	3.92	1.46	-410
	Higher legume	3725	883	2842	4.22	1.60	-422
	Crop diversity	4330	831	3499	5.21	2.02	-477
	Crop div. + nutrient	4664	1153	3511	4.05	2.03	-549
	Higher leg. + diversity	4818	1010	3807	4.77	2.19	-489
	Lower intensity	2835	471	2364	6.02	1.37	-228
Winter	**Baseline**	**3775**	**698**	**3077**	**5.41**	**1.90**	**-312**
	Higher nutrient	3746	884	2862	4.24	1.77	-330
	Higher legume	4667	741	3926	6.29	2.28	-237
	Crop diversity	4807	549	4257	8.75	2.44	-237
	Crop div. + nutrient	4295	1020	3275	4.21	2.01	-430
	Higher leg. + diversity	4580	664	3915	6.89	2.22	-220
	Lower intensity	2444	601	1844	4.07	1.07	-411

System WUE adjusted for nutrient balance

One of the complications with comparisons across the various sites here is that there were significant differences in starting soil N status which greatly influenced the need for fertiliser inputs and hence costs at those sites. For example, at Billabilla there was a large amount of mineral N at the start of the experiment (> 300 kg N/ha), and hence for the first 3 years no N fertilisers were needed to satisfy crop nutrient budgets. Hence, this site had significantly lower N fertiliser costs which arbitrarily biases the system WUE (GM$/mm). Similarly, accounting for differences in system nutrient export or balance will help to better define the real cost of the farming system. In an attempt to adjust for these differences, in Table 6 we have adjusted the system WUE to take into consideration the different nutrient balances across sites and some systems. This reduces the system WUE (GM$/mm) of sites which have exploited a high soil mineral N and adjusts for differences in P application relative to P export across sites.

What this shows is that across sites the differences in system WUE (GM$/mm) between the baseline and higher nutrient or higher legume systems is diminished once these factors are considered.

Hence, taking into consideration the impacts of the farming system on the natural resources (in this case nutrients) can significantly alter the relative profitability of different farming systems over the long-term. This clearly shows that if the costs of nutrients exported from the farming system are accounted for, and not treated as an externality, it demonstrates the value of systems aimed at maintaining long-term soil fertility.

Table 6. Gross margin return per mm under baseline, and systems with higher nutrient, higher legume frequency and higher intensity when corrected for site and system differences in nutrient balance (i.e. change in soil mineral N, net P balance (export – applied) and K removal). Nutrients were valued at \$1.3/kg N, \$2.5/kg P, \$0.9/kg K.

Site	Baseline	High nutrient	High legume	High intensity
Pampas - Opportunity	1.28	1.16	**1.45**	
Pampas - Summer	1.18	1.25	**1.38**	1.40
Pampas - Winter	1.61	1.52	**1.99**	
Billa Billa	**1.98**	**1.99**	1.85	0.70
Emerald	0.84	1.01	**1.12**	0.62
Narrabri	**1.31**	1.27	1.12	
Spring Ridge	**1.50**	1.36	1.45	
Mungindi	**0.89**	0.62	0.72	

Cross-site analysis of system WUE

While there are several interesting differences between different farming systems at each experimental location, here we examine across the full range of sites how modifications to the farming system that were common across several sites (i.e. *higher nutrient, higher legumes, crop diversity, higher intensity, lower intensity*) have influenced the economic performance compared to the baseline at each site. This was done by calculating the system WUE (\$ GM/mm) and the return on investment (i.e. income:cost ratio) as a proportion of that achieved in the baseline. Hence, the baseline achieves a value of 1.0, and systems achieving 0.8 have a 20% lower value and systems achieving 1.2 have a 20% higher value for these economic metrics.

Across the various sites there are some variable and some consistent results in terms of the relative performance of the farming systems.

- Higher nutrient supply achieved a 10% lower system WUE (GM\$/mm) at most sites, due to the higher costs associated with supplying nutrients to satisfy a 90th percentile crop yield rather than fertilising for the median yield. Only at Emerald did we observe a positive yield response to additional nutrient supply and hence this is the only location where system WUE was increased – though return on investment was similar. At Mungindi the additions of more nutrient reduced grain yield and hence income in one year and added significantly to the costs of this system. We may expect this result with only good seasonal conditions expected to realise the benefits of such a strategy.
- Increasing legume frequency achieved either higher or similar system WUE (GM\$/mm) to the baseline across most sites. However, interestingly the return-on-investment for these systems was lower in most cases owing to higher costs for growing legumes.
- Increasing crop diversity was either equally or more profitable than the baseline system at Spring Ridge and Pampas across all crop rotation systems (summer, winter and opportunity). However, at all other locations system WUE (GM\$/mm) was reduced by 20-70% through implementing more diverse crop rotations. Few sites had significant soil-borne disease

issues at the initiation of the study and hence rotational benefits have not yet been observed. The exception was Pampas where there have been rotation benefits for subsequent crops. This demonstrates that there can be significant costs or risks associated with implementing alternative crops to address weed or pathogen issues.

- Increased crop intensity has only achieved a slightly higher systems WUE (GM$/mm) at Pampas while at most locations there has been significant downsides. These systems also have higher costs and hence the return on investment is typically lower.
- Lower crop intensity systems have also achieved lower system WUE (GM$/mm) at most locations, and lower than most other system modifications. The exceptions are where a sufficiently high value crop has been grown (e.g. cotton) that has offset the longer fallows required. However, because of the lower inputs and costs associated with these systems they achieve much more favourable return on investment often equal to other system modifications.

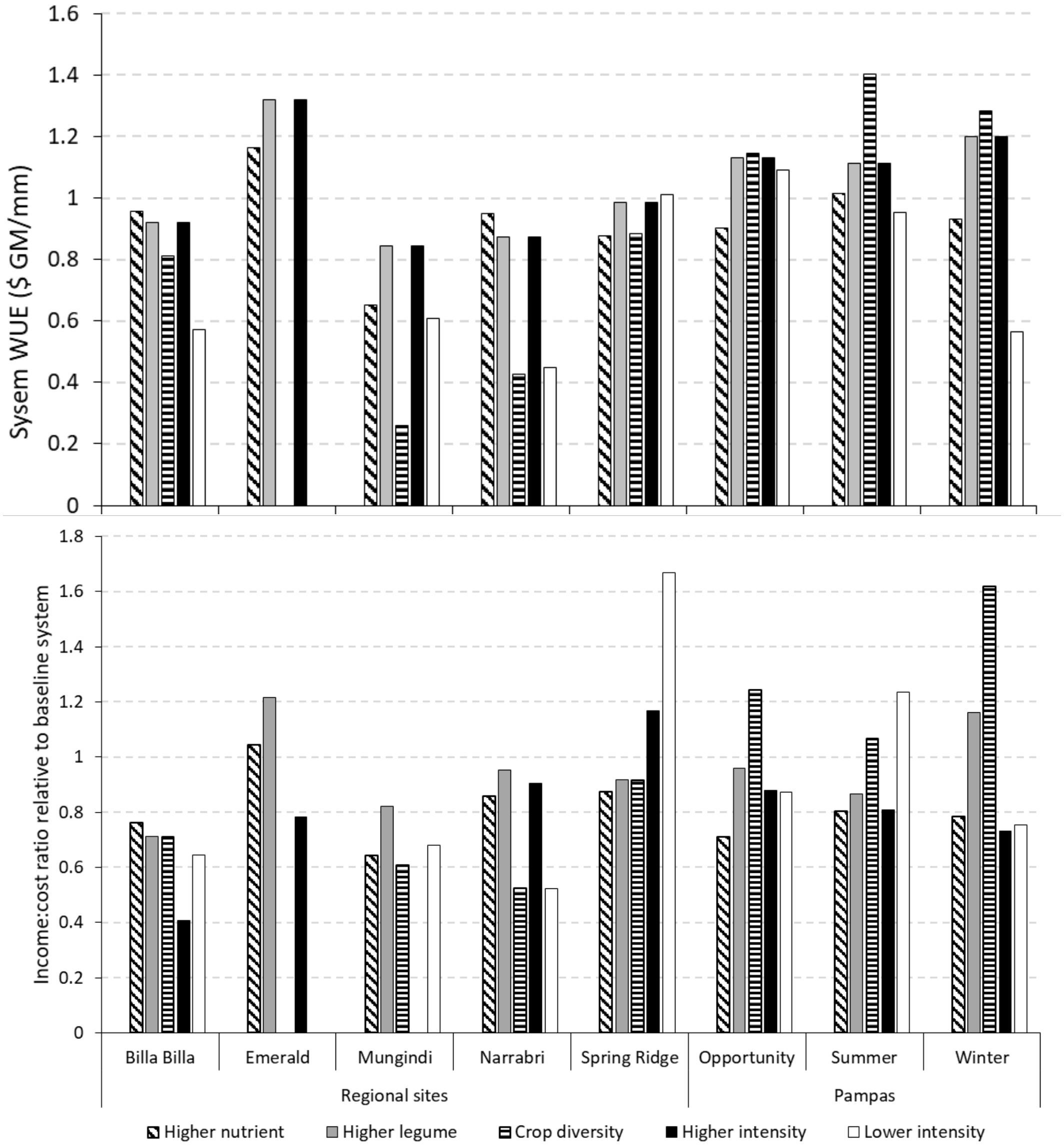

Figure 1. Relative system water use efficiency (i.e. $ GM/mm) of modifying farming systems compared to the baseline at 5 regional sites and under 3 different seasonal crops at the Core site (Pampas).

In order to explore any environmental response of economic performance of the different farming systems, in Figure 2 we plot across all experimental sites the relationships between total system water use and economic returns over the experimental period. These plots demonstrate several important findings.

Firstly, as expected the revenue or income generated increased as the amount of water available increased. That is, the locations that received the lowest rainfall over the 3.5 years of the experiment (Mungindi and Spring Ridge) had lower total income and lower sequence GM. However, this relationship did not continue to increase as the amount of rainfall increased, reaching a maximum at around 1500-1600 mm. This may suggest that the systems that used more rainfall than this failed to convert the additional rainfall effectively into higher incomes or gross returns. Secondly, it can be seen that different farming systems responded differently for their return per mm of water use across the various environments.

- The low intensity systems had a very flat relationship – they achieved similar income and system GM (GM$/mm) to the other systems under dryer conditions, but as the amount of water available increased they fell below the other systems. This indicates that these systems are favourable under lower rainfall situations, but less so under more favourable conditions.
- Figure 6 shows that systems with increased crop diversity and higher legume frequency had an advantage over the baseline in locations that had more available rainfall. This is shown by the triangles (crop diversity) and squares (higher legume) exceeding the filled circles (baseline) consistently at locations that used > 1600 mm of rainfall over the experimental period. This suggests that there is likely to be greater benefit from employing these system modifications in more favourable conditions than in lower rainfall environments, where risks for alternative break crops or legumes are higher.

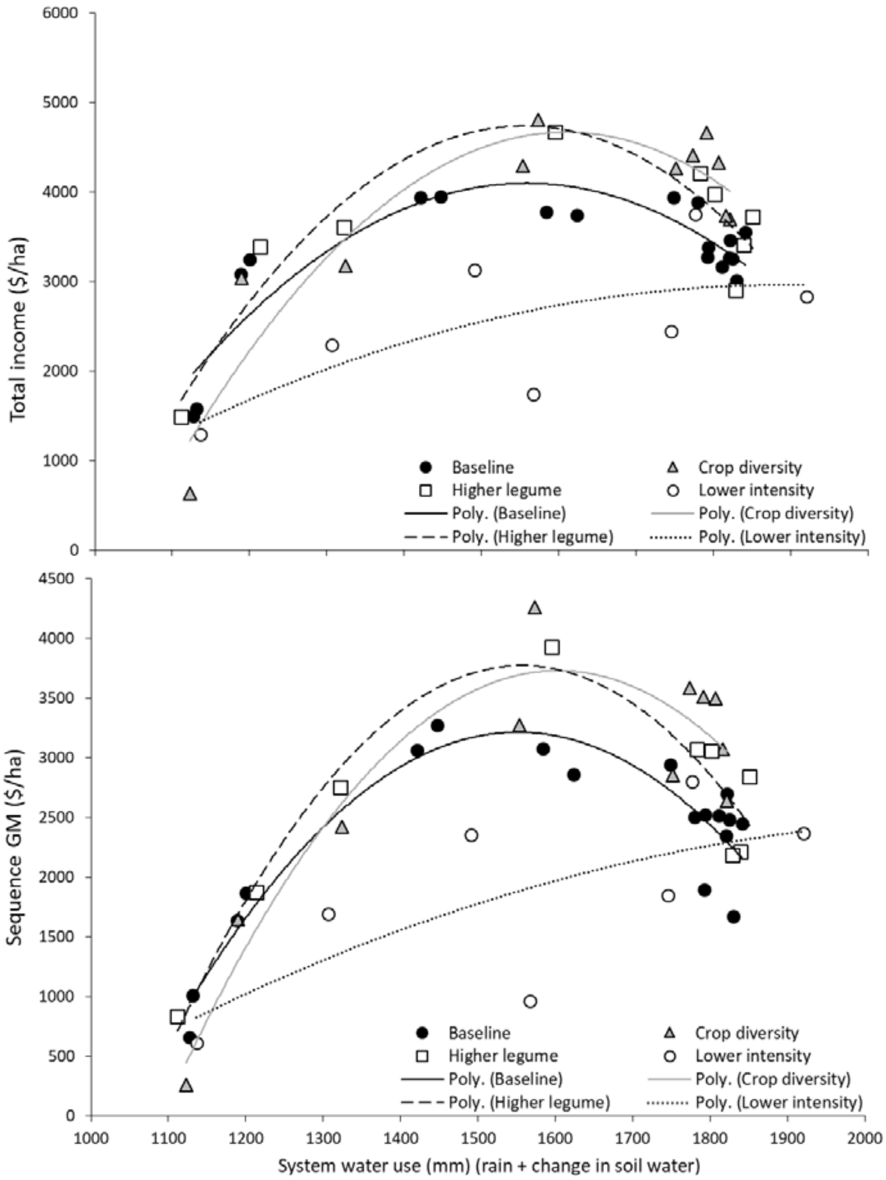

Figure 2. Relationships across sites between total system water use (rain - change in soil water) and sequence, total income and sequence total income ($/ha) (top), and sequence gross margin GM ($/ha) (bottom) over 3.5 years between different farming systems modifications – baseline (black circles), increasing crop diversity (grey triangles), increasing legume frequency (squares) and low intensity (hollow circles).

Conclusions

The economic performance of the farming system integrates many of the various factors that may influence their short and long-term productivity (water use efficiency, nutrient inputs and balance, yield responses to crop rotation). Across all farming systems sites, several of the modified farming systems could achieve similar or even greater profits, however this was not consistent across all sites. That is, in many cases there are options to address particular challenges (e.g. soil-borne diseases or weeds, nutrient rundown) that can be profitable. However, in some locations the options seem much more limited, particularly where risky climatic conditions (or challenging soils) limit the reliability of alternative crops in the farming system. The results here provide a snapshot in time over only a 3.5 year period. The longer term impacts of some of these farming systems strategies may yet to be fully realised and hence, some consideration of these results against this longer-term view is also required.

References

Hochman Z, Prestwidge D and 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 (CSA00050, DAQ00192) 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 specifically like to thank all the farm and field staff contributing to the implementation and management of these experiments, the trial co-operators and host farmers.

Contact details

Lindsay Bell
CSIRO
PO Box 102, Toowoomba Qld, 4350.
Ph: 0409 881 988
Email: Lindsay.Bell@csiro.au

Wheat varietal tolerance to sodicity with variable subsoil constraints

Yash Dang[1], Jack Christopher[2], Monia Anzooman[1], Malini Roy Choudhury[1] and Neal Menzies[1]

[1] School of Agriculture and Food Sciences, The University of Queensland
[2] Queensland Alliance for Agricultural and Food Innovation, The University of Queensland

Key words

calcium concentration, EM38, plant available water, soil constraints, wheat varieties

GRDC code

UA00159 Improving wheat yields on sodic or magnesic or dispersive soils

Take home messages

- Common soil constraints in semi-arid regions such as the northern region include; high sodicity in surface and subsoil, high salinity and phytotoxic concentration of chloride (Cl) in subsoil, and alkaline surface soils with acidic subsoil
- The yield penalty due to soil constraints is greater in years with below average in-crop rain (ICR)
- Yield ranking at sites without soil constraints is not a good predictor of performance at sites with soil constraints
- Certain genotypes rank relatively more tolerant to sodic soils with variable subsoil constraints than others
- Less water extraction occurs between emergence and anthesis (plant available water capacity, (PAWC)) at constrained sites as compared to sites without soil constraints
- Wheat grain yield increased significantly with increasing calcium concentrations in young mature leaves

Introduction

High sodicity in surface soil and subsoil, high salinity and phytotoxic concentration of chloride (Cl) in subsoil, as well as alkaline surface soils with acidic subsoil are common soil constraints in many semi-arid regions worldwide and in particular in Australia. These constraints reduce the ability of crop roots to extract water and nutrients from soil. Sodic soils tend to have severe soil structural problems including poor aeration and restricted water transmission, resulting in reduced root growth (Dang *et al.* 2006). Subsoil constraints, reduce the ability of crop roots to extract water and nutrients from the deeper layers in the soil, especially from layers high in salt content and soil chloride concentrations (Dang *et al*., 2008).

Successful dryland crop production in the north-eastern grain growing region of Australia depends on utilising soil moisture accumulated in the period preceding sowing. Due to the high clay content of soils in this region, these soils can potentially store 200-250 mm of water in the soil profile or more. However, soil constraints, especially in the subsoil, reduce the effective rooting depth thus also limiting plant access to water and nutrients and as a result, limiting crop yield (Dang *et al*., 2006). Several soil physiochemical constraints in the surface and subsoil interact with each other to determine the local environment for root growth. Rarely do the various soil constraints occur independently (Nuttall *et al*., 2003). The effects of soil constraints vary both spatially and over time. Spatial variation can occur within a field, across the landscape and with depth in the soil profile. There are also complex interactions that exist among the various physio-chemical constraints (Dang *et al.* 2006). These complicated interactions limit the agronomic and management options. The variable impact on crop growth and yield is compounded by the complex interactions between the range of soil constraints and environmental factors. In particular the timing and amount of rainfall relative to the crop growth stage. Selection of genotypes tolerant to soil constraints and identification of traits for pre-selection may provide a long-lasting tangible solution to improve wheat yields on these soils.

Materials and methods

A series of paired experiments were conducted during 2015-18 to evaluate wheat genotypes on two sites in southern Queensland. Sites were a distance of 0.5 to 5 km apart, with one site containing a range of soil constraints predicted to reduce wheat yields (Dang *et al.* 2006), with the other relatively non-constrained. The long-term average annual rainfall for the area is 617 mm with an average in crop rainfall for wheat growing season (mid-May to mid-November) of 170 mm. Each year the exact location of both experimental sites was changed, but they were within the same area on similar soil type. The soils at both sites were grey Vertosols. Sites were on a <1% slope and sown to wheat genotypes in mid-May to mid-June each year. Wheat genotypes were selected to represent the diversity of Australian wheat germplasm, including current and older varieties with a range of morphological and physiological traits (Table 1).

Soil and plant sampling and analysis

Two soil samples were taken per location, using a 50-mm diameter tube and a hydraulic sampling rig. Soil samples were extruded onto a plastic liner and then sub-sampled into a surface interval (0.0–0.1 m), then successive 0.2 m intervals to 1.5 m and analysed for soil physical and chemical properties.

At anthesis, 50 youngest fully mature leaves (YML) were obtained randomly from each replicate plot of each genotype, rinsed with distilled deionized water and dried at 70˚C for 48 hours. Dried plant samples were ground into a fine powder to pass a 0.5-mm sieve. To determine concentrations of sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), zinc (Zn), phosphorus (P), aluminium (Al), boron (B), copper (Cu), iron (Fe) and manganese (Mn), plant material was digested in a di-acid mixture of nitric and perchloric acid. Concentrations of ions were measured on an inductively coupled plasma-optical emission spectrometer (ICP). For chloride, ground samples of YML were extracted in hot water at 80˚C for 4 hours. The chloride concentration was determined using an auto-analyser.

Crop water use

We used an electromagnetic induction (EMI) instrument (Geonics EM38®) to measure apparent electrical conductivity in a vertical coplanar at critical wheat growth stages (emergence, stem-elongation, mid-tillering, anthesis, heading and maturity) to monitor crop water use. Since EMI provides only qualitative values for electrical conductivity, calibration is needed. Volumetric water content was measured on a separate 50-mm diameter soil sample to 1.5 m taken using the hydraulic soil sampling rig.

Statistical analyses

Analysis of variance for data on soil water, grain yield for each site was done using Genstat 16. The effect of sites and genotypes was analysed in a two-way factorial design. Significant differences between treatments were assessed using Fisher's l.s.d. (P=0.05). We used a paired t-test to examine whether, at a particular depth in the profile, the mean of a soil attribute differed significantly between the sodic and non-sodic sites.

Results and discussion

Soil constraints

Average and standard errors of soil constraints for the four sites are given in Figure 1. Compared to non-sodic sites, the sodic sites had significantly higher exchangeable sodium percentage (ESP) up to 0.6 m soil depth, significantly higher electrical conductivity (EC) and chloride concentrations to depth of 1.5 m. A value of ESP ≥6% in the surface soil would result in poor germination and water infiltration in soil (Rengasamy 2002). The sodic sites had chloride concentration >800 mg/kg below approximately 0.6 m soil depth, a threshold that generally results in reduced water and nutrient uptake and yield reduction in bread wheat (Dang *et al.* 2008). The non-sodic site had higher soil pH (>8.0) to a depth of 0.4 m soil and significantly lower pH (<5.0) below 0.9 m soil depth as compared to non-sodic sites. Acidic subsoils at sodic site containing toxic levels of aluminium or deficient amounts of calcium also restrict root proliferation.

Table 1. Details of wheat varieties (adapted from Anzooman *et al.* 2018)

Name	**Type**	**Breeder**[1]	**Grade**[2]	**Target Australian region, comment**
Axe⌽	Cultivar/Hexaploid	AGT	AH	SA, relatively drought tolerant
Aurora⌽	Cultivar /Durum	DBA	ADR	NSW and Qld
Baxter	Cultivar/Hexaploid	QDAF	APH	NSW and Qld
Batavia	Cultivar/Hexaploid	QDAF	APH	NSW and Qld
Bremer⌽	Cultivar/Hexaploid	AGT	AH	WA
Corack⌽	Cultivar /Hexaploid	AGT	APW	WA, relatively drought tolerant
Caparoi⌽	Cultivar /Durum	NSW DPI	ADR	Qld, NSW, WA and SA
Dharwar	Cultivar/Hexaploid	India		Indian cultivar, drought tolerant, deep rooted, tall
Elmore⌽	Cultivar/Hexaploid		AH	Nematode and rust tolerant
Emu Rock⌽	Cultivar/Hexaploid	InterGrain	AH	WA
Flanker⌽	Cultivar/Hexaploid	LPB	APH	NSW & Qld, resist. stripe, stem & leaf rust
EGA Gregory⌽	Cultivar/Hexaploid	EGA	APH	NSW and Qld
Gladius⌽	Cultivar/Hexaploid	AGT	AH	
Hyperno⌽	Cultivar /Durum	AGT	APDR	SA,NSW- performs well in high yield envir.
Hartog	Cultivar/Hexaploid	QDAF	APH	NSW and Qld
Hydra⌽	Cultivar/Hexaploid	InterGrain	APW	WA
Impala⌽	Cultivar/Hexaploid	LPB	ASFT	NSW and Qld
Krichauff	Cultivar/Hexaploid	UA	ASW	South
Test line 1	Elite breeding line			NSW and Qld
Lancer⌽	Cultivar/Hexaploid	LPB	APH	NSW and Qld
Mace⌽	Cultivar/Hexaploid	AGT	AH	NSW and Qld, less susceptible to downgrading
Mitch⌽	Cultivar/Hexaploid	AGT	AH	NSW and Qld
Magenta⌽	Cultivar/Hexaploid	InterGrain	APW	WA
Pelsart	Cultivar/Hexaploid	QDAF		NSW and Qld
Janz	Cultivar/Hexaploid	QDAF	APH	Once widely grown in eastern Australia
Jandaroi⌽	Cultivar/Durum	NSW/DPI		NSW, SA, rust diseases resistant
Scout⌽	Cultivar	LPB	APW	Victoria and SA, resistant to leaf rust
SeriM82	Breeding line	CIMMYT		Once grown in many countries but not Aust.
Spitfire⌽	Cultivar/ Hexaploid	LPB	APH	NSW and Qld
Sunco⌽	Cultivar/Hexaploid	AGT	AH	NSW and Qld
Suntop⌽	Cultivar/Hexaploid	AGT	APH	NSW and Qld
Sunmate⌽	Cultivar/Hexaploid	AGT	APH	NSW and Qld
Trojan⌽	Cultivar/hexaploid	LPB	APW	South and WA
Tammarin Rock⌽	Cultivar/Hexaploid		AH	WA
Wallup⌽	Cultivar/Hexaploid	AGT	APH	WA
Westonia	Cultivar/Hexaploid		APW	WA, widely adapted in international trials
Wyalkatchem⌽	Breeding line	InterGrain	APW	WA
Ventura ⌽	Cultivar/Hexaploid	AGT	ADR	NSW and Qld
Viking⌽	Cultivar/Hexaploid	LPB	APH	NSW and Qld
Wylie⌽	Cultivar	EGA	AH	NSW and Qld
Yitpi⌽	Cultivar/Hexaploid	AGT	AH	SA and Victoria
Zen⌽	Cultivar/Hexaploid	InterGrain	ASW	WA

[1] Breeding program abbreviations: Australian Grain Technologies (AGT), International Maize and Wheat Improvement Centre (CIMMYT), Commonwealth Scientific and Industrial Research Organisation (CSIRO), Enterprise Grains Australia (EGA), International Centre for Agricultural Research in the Dry Areas (ICARDA), Long Reach Plant Breeders (LPB), Queensland Department of Agriculture and Fisheries (QDAF), Durum Breeding Australia (DBA), University of Adelaide (UA).[2]Grain quality grade abbreviations: Australian Hard (AH),Australian Premium White (APW), Australian Standard White (Kumaraswamy), Australian Premium Durum (Florentino et al.), Australian Soft (ASFT), Australian Standard Noodle Wheat (ANW), Australian Premium White Noodle (APWN) is classified in the WA zone only, Australian Prime Hard (APH) is classified for the Northern & South Eastern zone only.

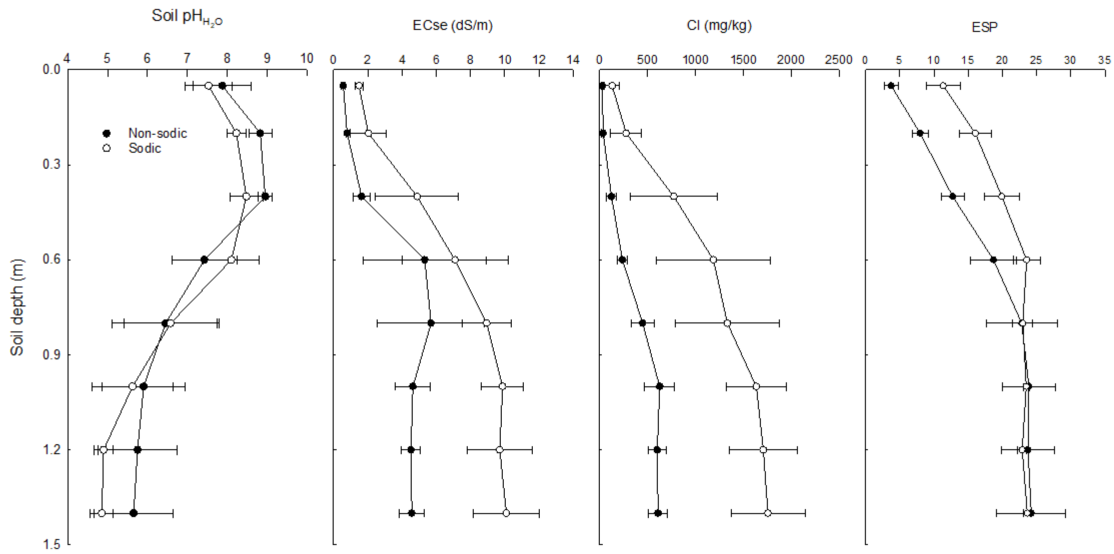

Figure 1. Average and standard errors of soil constraints for the sites during 2015-18 experiments

Yield penalty in sodic soil with subsoil constraints was seasonally variable

Substantially higher in-crop rainfall in 2015 and 2016 led to high average wheat grain yields at both sites with no significant differences between the sites for the 36 and 38 genotypes, respectively (Table 2). High in-crop rainfall allowed crops to grow with reduced reliance on extraction of water from the deeper soil profile. However, near average in-crop rainfall in 2017 and 2018 resulted in significantly reduced average wheat yield at the sodic site as compared to the non-sodic site. Sadras *et al*. (2003) in southern Australia hypothesised that plant available water is the key link between crop functionality and complex combinations of subsoil constraints, and that negative responses of subsoil constraints were more frequent in sites where conditions contributed to severe water deficits, i.e. low in-crop rainfall, less available water at sowing, and greater evaporative demands. Hochman *et al*. (2004), using APSIM simulation of wheat grown over 100 years in southern Queensland on relatively low and high subsoil constraint grey Vertosols, showed that yield differences vary from <200 kg/ha in some years to nearly 3 t/ha in others. The yield penalty due to subsoil constraints was seasonally variable; in-crop rainfall in the early part of the season (1 May to 15 August) was positively correlated with differences in grain yield ($P < 0.001$). Dang *et al.* (2008) in northern grain region showed that the presence of substantial higher chloride concentration (>800 mg Cl/kg) in the sodic subsoils restrict the ability of roots to extract subsoil water. Dang et al. (2010) analysing the results of 44 field trials in the case of bread wheat conducted in the northern region showed that yield penalty due to high subsoil chloride (>800 mg Cl/kg) was significantly higher in average in-crop rainfall seasons compared to high in-crop rainfall seasons.

Table 2. Date of wheat sowing (DOS) and harvesting (DOH), in crop rainfall (ICR) and site mean yield for wheat genotypes grown on non-sodic and sodic sites in 2015-18. Site wheat grain yield within a year followed by same letter are not significantly different (P<0.05)

Year	Field operations		in-crop rainfall (mm)		Wheat grain yield (t/ha)	
	Date of sowing	Date of harvest	Non-sodic	Sodic	Non-sodic	Sodic
2015 (36)	19.5.15	22.10.15	209	209	4.06^{a}	3.64^{a}
2016 (38)	25.5.16	10.11.16 (S) 17.11.16 (NS)	325	374	4.02^{a}	4.00^{a}
2017 (44)	10.6.17	31.10.17	132	128	1.61^{a}	0.37^{b}
2018 (18)	24.5.18	02.11.18	133	133	2.37^{a}	1.16^{b}

Numbers in parenthesis indicate the number of wheat genotypes grown in each year.

Yield ranking at non-sodic sites is not a good predictor of performance at sodic sites

Year 2015

Due to the timely in-crop rainfall (Figure 2), wheat grain yields at both sites were higher than normal and the grower reported his best crop yield ever at both sites. Site mean yields were 4.06 t/ha (sodic) and 3.64 t/ha at the non-sodic site (Table 2). In this 'non-water limited season', a number of genotypes exhibited higher yields at the sodic site than at non-sodic site (Figure 3). These included the breeder's line LPB10-2555. Cultivars Baxter, Gregory$^{\phi}$ and Mace$^{\phi}$ which have been shown to perform well under subsoil constraints, also exhibited higher yield at the sodic site than the non-sodic site as did the land race Dhawar Dry.

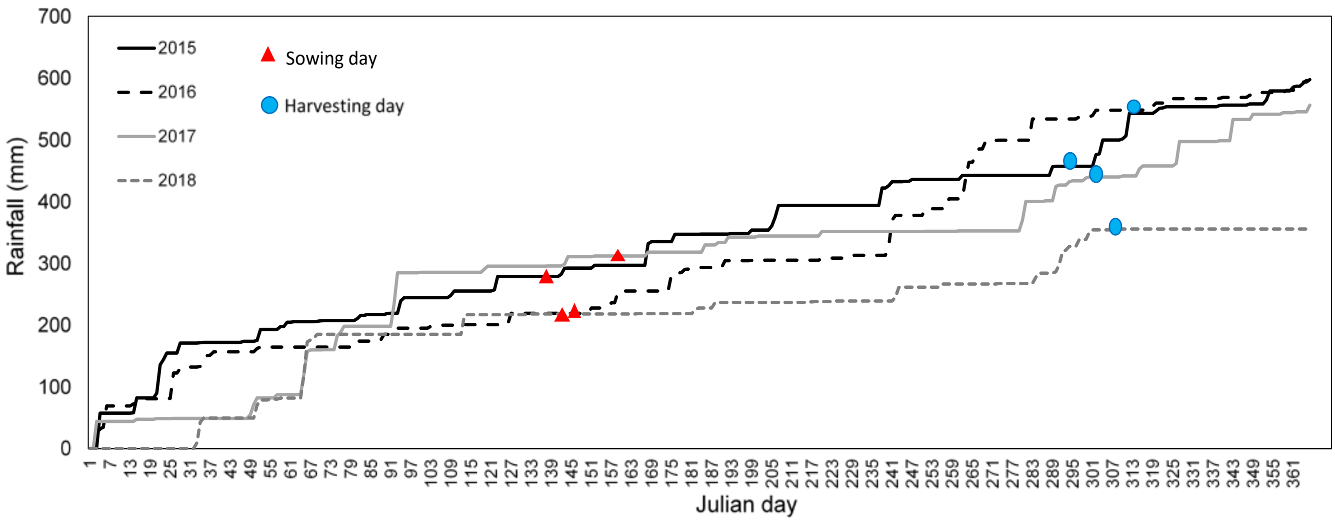

Figure 2. Cumulative rainfall during 2015-18 at the sites

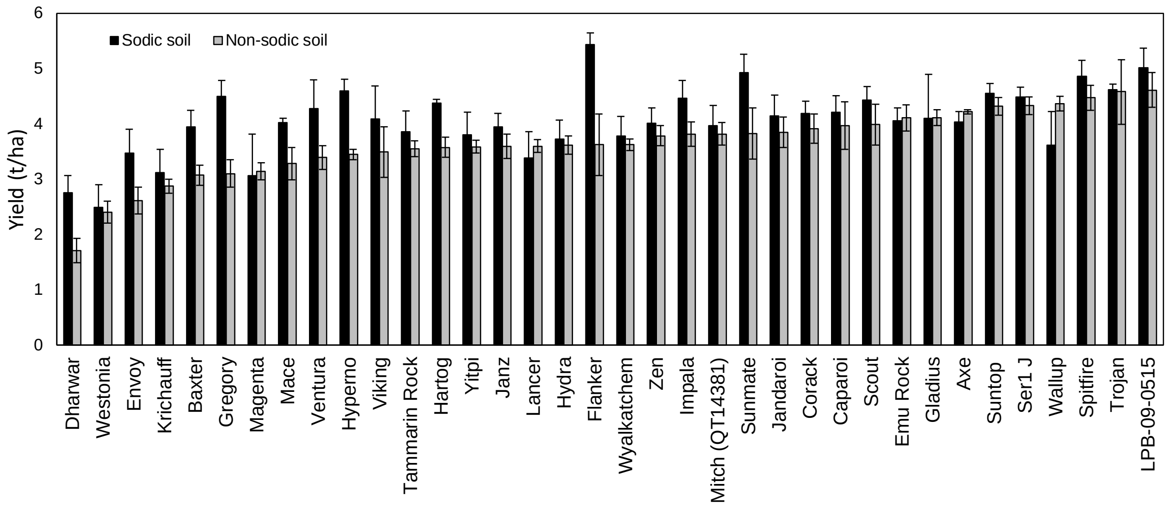

Figure 3. Genotype mean yields of 36 wheat lines at the non-sodic and the sodic site in 2015, ranked in ascending order of yield at the non-sodic site

Year 2016

Significant in-crop rainfall also occurred in 2016 just prior to each of the most critical crop developmental stages. As a result, the crop experienced little if any water-stress (Figure 2). This led to high grain yields at both sites with the non-sodic site averaging 4.02 t/ha and the sodic site 4.00 t/ha, with no significant difference between sites. Trial mean yield levels in 2016 were similar to those in 2015. A small number of genotypes exhibited higher yields at the sodic site versus the non-sodic site (Figure 4). These included Mitch bread wheat and Aurora durum. Baxter exhibited lower yield than many other genotypes at the sodic site. This result contrasts with 2015 where Baxter has been a better performer than many other lines on the sodic site. Baxter is favoured by the grower at the sodic site as the historically best performing cultivar at this site. This result suggests that results in both 2015 and 2016 are likely to be a poor indication of performance in the terminal drought environments that are more common in this region.

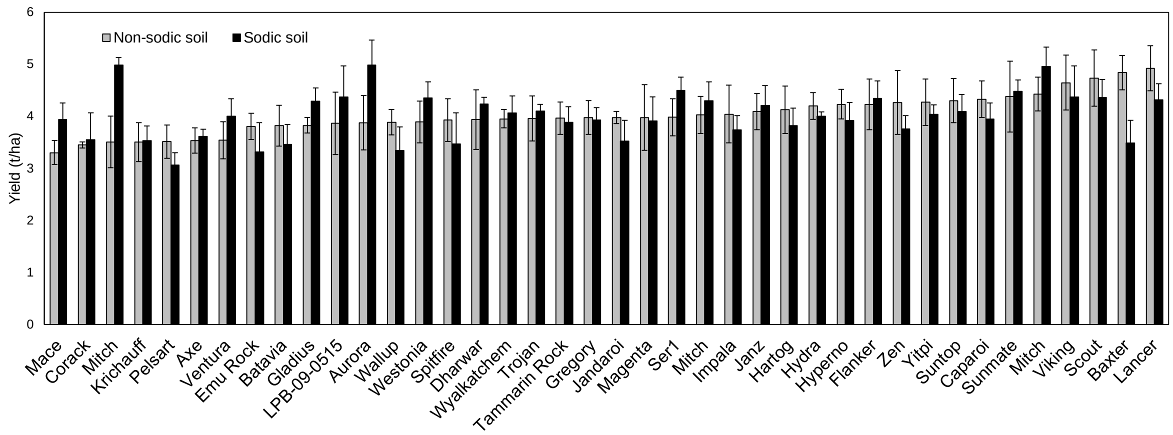

Figure 4. Average yields of 38 wheat lines at the non-sodic and sodic sites in 2016, ranked in ascending order of yield at the non-sodic site from left to right

Despite similar yields at the two sites in 2016, some symptoms of stress during early crop development were evident at the sodic site. The trial at the non-sodic site exhibited a mean emergent plant density of 86 m^2 which is close to the target population density of 100 m^2. In contrast, strong crust formation at the sodic site (Figure 5) resulted in reduced emergence averaging only 38 m[2].

Figure 5. Crust formation at the sodic site in 2016 significantly reduced emergence. Crust segments in the lower portion of the image were removed to reveal etiolated (yellow) seedlings that failed to emerge when trapped beneath the crust

In addition to the difference in emergence between sites, there was also a difference in crop duration to anthesis. The average period from sowing to anthesis at the sodic site was 112 DAS (days after sowing), which was considerably shorter than at the non-sodic site (124 DAS). Plants at the sodic site seemed to have exhibited a remarkable ability to compensate for these early setbacks, likely due in large part to plentiful late season rainfall.

Year 2017

Crop establishment was reduced at both the sites due to dry top soil and a lack of follow up rainfall after sowing (Figure 2). However, the effect was much greater at the sodic site where establishment was 26% less than that at the non-sodic site. The lack of rainfall also meant that a surface crust failed to form at the sodic site as occurred in 2016. This suggests that the reduction in establishment observed at the sodic site was not mainly due to soil crusting. Wheat genotypes grown at the sodic site exhibited substantial yield reductions (62%-83%; av. 76%) as compared to the non-sodic site (Figure 6).

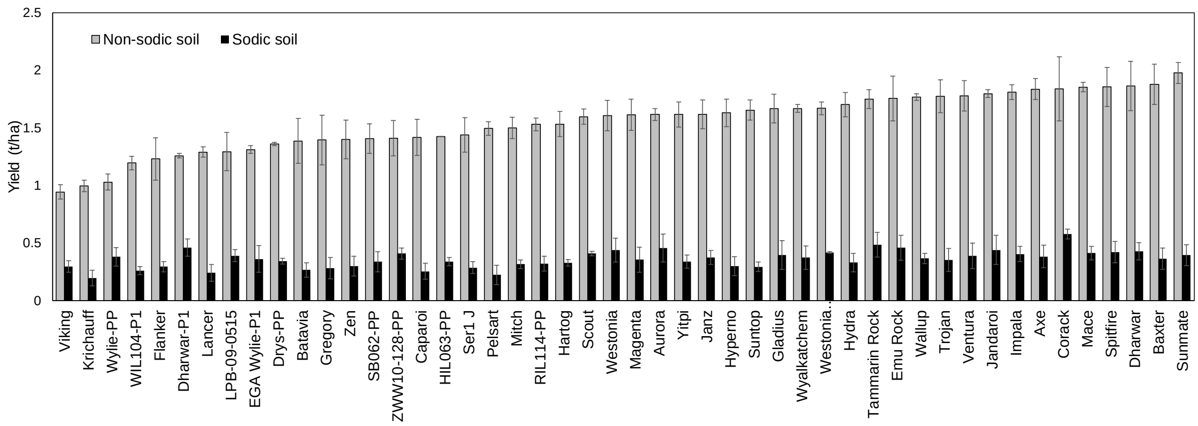

Figure 6. Mean grain yields of wheat lines at the sodic and the non-sodic site in 2017, ranked in descending order of yield at the non-sodic site.

As anticipated, northern adapted lines such as Baxter and Sunmate⦶ were highly ranked at the non-sodic site. However, rankings at the non-sodic site were not a good indicator of rank at the sodic site.

Southern and western region lines such as Corack⟮D, Tammarin Rock⟮D and Emu Rock⟮D were highly ranked at sodic site (Figure 6). Durum genotypes were not poorly ranked at the sodic site, suggesting that sodium toxicity was not an important driver of yield. Mapping population parents Batavia and Pelsart both ranked poorly at the sodic site and there was little difference between the two. This suggests that the Batavia x Pelsart mapping population is not likely to be useful in dissecting the genetics of tolerance to sodicity with variable sub-soil constraints.

Year 2018

Crop establishment was reduced at both sites due to dry top soil and a lack of follow up rainfall after sowing. The impact was greater at the sodic site where establishment was 35% less than that at the non-sodic site (Figure 7). Similarly to 2017, the lack of rainfall after sowing failed to form surface crusting at the sodic site as occurred in 2016. This suggests that the reduction in establishment observed at the sodic site in 2018 was not largely due to soil crusting. Some other physical and/or chemical impacts of sodicity probably resulted in poor establishment. Wheat genotypes grown at the sodic site exhibited significant yield reductions (33%-66%; av. 51%) as compared to the non-sodic site. Although differences between wheat genotypes were not significant (P<0.09), the yield ranking for wheat genotypes between sites were similar to those observed in 2017. Wheat genotype yield rankings at the non-sodic site do not give a good indication of ranking at the sodic site. The ranking of certain wheat genotypes changed significantly in the presence of soil constraints. The cultivars Corack⟮D, Mitch⟮D, Trojan⟮D and Mace⟮D ranked highly at the non-sodic site. The wheat genotypes LBP10-255, Corack⟮D, Janz and Sunco ranked highly at the sodic site.

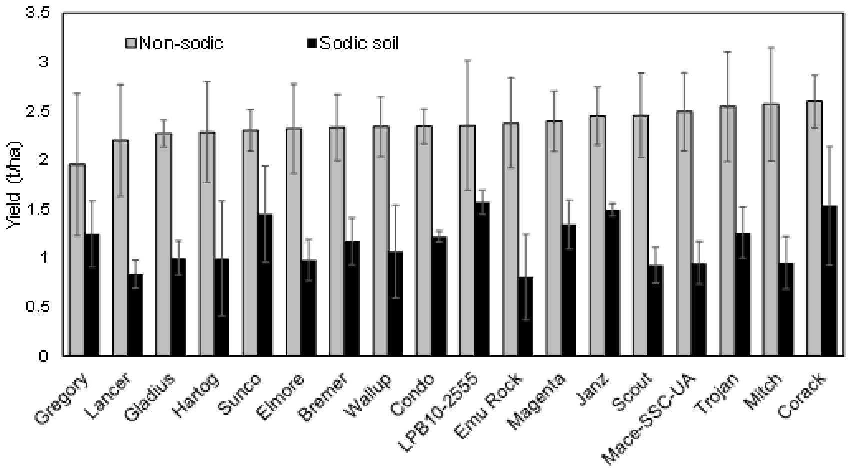

Figure 7. Mean grain yields of wheat lines at the sodic site in 2018, ranked in ascending order of yield at non-sodic site in 2018.

Soil water extraction was correlated with yield

Extraction of soil water from the soil profile was examined using the difference in the soil electromagnetic conductivity measured using an EM38 at near full soil water profile at sowing and that measured at different wheat growth stages (emergence, early tillering, mid-late tillering, head emergence and anthesis). In 2015 and 2016, there were no significant differences in the water extraction between sites and genotypes (data not shown). In 2017, the relationships between wheat grain yield and difference in EM38 reading between sowing and different growth stages of wheat were positive, however, this relationship was strongest at anthesis when soil water depletion was near its greatest. Further, this relationship was stronger in sodic soils as comparted to the non-sodic site (Figure 8). Positive relationships between grain yield of wheat genotypes and differences in water extraction between sowing and anthesis were obtained at both sodic and non-sodic sites.

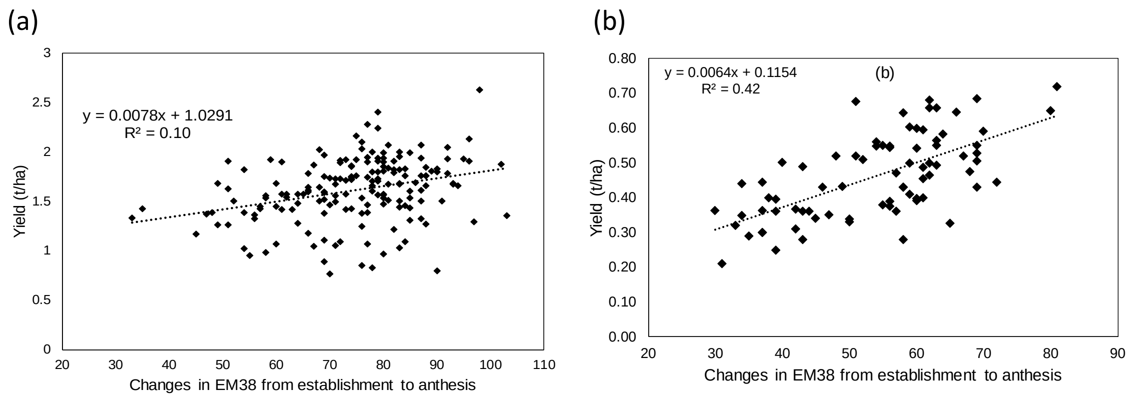

Figure 8. Relationships between soil water extraction between sowing and anthesis with wheat grain yield at (a) non-sodic site and (b) sodic site in 2018.

Calcium concentration in young mature leaf was correlated with higher yield

In 2015 and 2016, there were no significant differences in the concentration of elements measured in the youngest mature leaves between sites and genotypes (data not shown). By contrast, in 2017 and 2018, calcium and potassium concentrations were significantly higher in the youngest mature leaves at the non-sodic site than in the sodic site (Figure 9). However, the differences between wheat genotypes were significant only for calcium. This suggests that leaf calcium concentration might be useful to distinguish performance between sites and genotypes. This result agrees with observations made in previous seasons, where good discrimination in performance was observed between sodic and non-sodic sites (Dang *et al.* 2016).

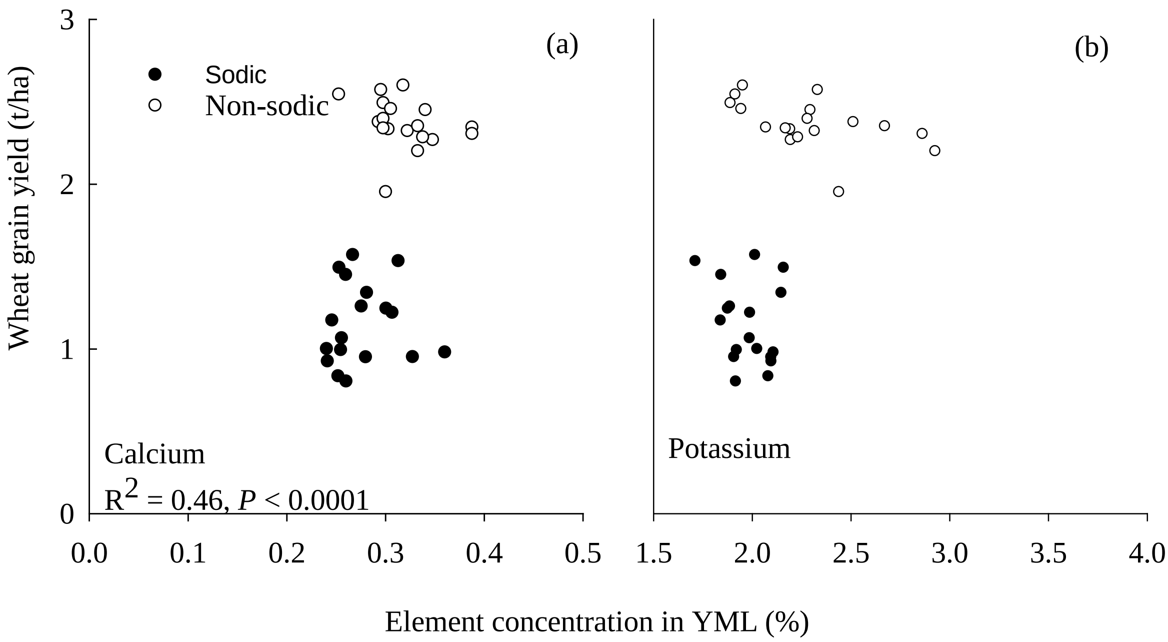

Figure 9. Relationships between element concentration in young mature leaf of wheat at anthesis and wheat grain yield at (a) non-sodic site and (b) sodic site in 2018

Discussion

Crop performance under non-sodic conditions is not a good indicator of that in the presence of sodicity

Experiments in 2017 and 2018 indicated substantial differences between performances of wheat genotypes under sodic soil conditions with subsoil constraints. Results indicated that performance under non-sodic conditions were not a good indicator of performance in the presence of sodic soils with variable subsoil constraints. Comparing the grain yields of wheat genotypes grown at the sodic site to that at the non-sodic site, significantly higher ESP to a depth of 0.6 m in the sodic soil resulted in reduced grain yields of wheat genotypes. It has been shown that ESP >6 % in the surface soil (Rengasamy *et al.* 2002) and >19 % in the subsoil (Nuttell *et al.* 2003) reduce grain yield of most crops. Grain yield on sodic soils is often less than 50% of the potential yield. Dalal *et al.* (2002) found that wheat yield in north-eastern Australia decreased from 3.5 t/ha to <2 t/ha as a result of sodicity (expressed as ESP) increasing from 4 to 16 % in the topsoil (0-0.1 m soil depth). In southern Australia, Rengasamy *et al.* (2002) reported a nearly linear decline in grain yield with increasing ESP in the surface soil for 30 different crop and pasture types. It is important to note that although all genotypes of wheat had reduced grain yield when grown at the sodic site compared to the non-sodic site in 2017 and 2018, the ranking of different genotypes varied at the different sites. In general, wheat cultivars Baxter and Sunmate⦶ were highly ranked at the non-sodic site. However, rankings at the non-sodic site were not a good indicator of rank at the sodic site. Southern and western regions lines such as Corack⦶, Tammarin Rock⦶ and Emu Rock⦶ were highly ranked at the sodic site. These results suggest that selection and recommendation of wheat genotypes for sodic sites needs to be based on testing done in the presence of soil constraints.

Differences in soil moisture extraction was the major determinant of performance differences in sodic soils with sub-soil constraints

All genotypes of wheat grown at the sodic site had reduced water extraction as compared to the non-sodic site in 2017 and 2018. Shaw (1997) showed a strong negative relationship between the effects of exchangeable sodium in the root zone on measured PAWC over the rooting depth of a crop in clay soils. Dalal *et al.* (2002) reported decreased PAWC from 120 mm to 80 mm with increasing ESP from 5 to 30% in the top 0.6 m soil depth in clay soils from north-eastern Australia. In the present study, the presence of high chloride concentration in the subsoil (below 0.90 m soil depth) at the sodic site likely further restricted water extraction, resulting in further reduction in PAWC. Dang *et al.* (2008) showed that subsoil chloride concentrations had a greater effect in reducing soil water extraction and grain yields of five crop species studied than did salinity or sodicity, per se. Subsoil chloride in the 0.90-1.10 m soil depth layers at >800 mg/kg has been shown to reduce wheat grain yield by 10% (Dang *et al.* 2008). In the present study, the chloride concentration in the subsoil at the sodic site was well above this threshold chloride concentration.

Concentrations of calcium in wheat may provide a useful surrogate trait to select for adaptation to sodic soil with variable subsoil constraints

The relationship between calcium concentration in youngest mature leaves with grain yield of wheat genotypes grown on the sodic and non-sodic sites was clear. The calcium concentration in youngest mature leaves of wheat genotypes grown on sodic soil was <0.35% and most genotypes had calcium concentration ≤ 0.25%. These levels were less than the critical limit (0.25%) for plant growth (Reuter *et al.* 1997). Most wheat genotypes grown at the sodic site had sodium concentrations <0.05% (data not shown). Generally, sodium becomes physiologically toxic to wheat at plant tissue levels greater than 0.1% (R. Munns, *pers. comm*.). Most of the wheat genotypes in the present study had sodium concentration <0.1% which corroborates with an earlier report suggesting that most of the Australian wheat genotypes accumulate sodium in the tissue well below the critical level (Liu *et al.*

2000). Wheat accumulated higher concentrations of potassium in the youngest mature leaves, but the differences between genotypes grown on the sodic site compared to the non-sodic site were not significant. Potassium concentration in the youngest mature leaves of wheat was well above the critical concentration for the growth of wheat (Reuter *et al.* 1997). The decrease in grain yield of wheat genotypes in the present study, beside other factors, is likely due to a combination of factors that include decrease in water extraction and calcium concentration in the plant tissues in the sodic soil.

Conclusions

Differences in wheat grain yield between sites varied greatly between seasons. In 2017 and 2018, wheat yields were lower at the sodic sites with variable subsoil constraints. In contrast, there was little difference in yield between sites in 2015 and 2016 due to higher than normal in-crop rainfall which reduced reliance on stored soil water. The yield ranking for genotypes at the non-sodic sites was not well correlated with that at sodic sites. Thus, selection for yield potential at non-sodic sites is not a good predictor of performance at sodic sites. However, yield rankings of genotypes continued to differ between unconstraint and constraint sites. Overall, certain genotypes tended to rank relatively more tolerant to sodic soils with variable subsoil constraints than others. The difference in water extraction between emergence and anthesis (PAWC) was significantly different between genotypes at sodic site as compared to non-sodic. Most wheat genotypes grown at the sodic sites had calcium concentrations below the critical level of $<0.25\%$ in the youngest mature leaves. Wheat grain yield increased significantly with increasing calcium. We successfully identified and quantified useful genetic variation in tolerance to sodic soils with variable subsoil constraints suggesting potential to breed new cultivars with superior tolerance.

References

Anzooman M, Christopher J, Mumford M, Dang YP, Menzies NW, Kopittke PM (2018) Selection for rapid germination and emergence may improve wheat seedling establishment in the presence of soil surface crusts. Plant and Soil, 426: 227-239.

Dang YP, Christopher JT, Dalal RC (2016) Genetic diversity in barley and wheat for tolerance to soil constraints. Agronomy *6*(4), 55; doi:10.3390/agronomy6040055

Dang YP, Dalal RC, Routley R, Schwenke GD & Daniells I (2006) Subsoil constraints to grain production in the cropping soils of the north-eastern region of Australia: An overview. Australian Journal of Experimental Agriculture, 46, 19-35

Dang YP, Dalal RC, Buck SR, Harms B, Kelly R, Hochman Z, Schwenke GD, Biggs AJW, Ferguson NJ & Norrish S (2010) Diagnosis, extent, impacts, and management of subsoil constraints in the northern grains cropping region of Australia. Australian Journal of Soil Research, 48, 105-119

Dang YP, Dalal RC, Mayer DG, McDonald M, Routley R, Schwenke GD, Buck SR, Daniells IG, Singh DK & Manning W (2008) High subsoil chloride concentrations reduce soil water extraction and crop yield on vertosols in north-eastern Australia. Australian Journal of Agricultural Research, 59, 321-330

Dang YP, Routley R, McDonald M, Dalal RC, Singh DK, Orange D & Mann M (2006) Subsoil constraints in vertosols: Crop water use, nutrient concentration, and grain yields of bread wheat, durum wheat, barley, chickpea, and canola. Australian Journal of Agricultural Research, 57, 983-998

Dalal R, So B & Blasi M (2002) High sodium levels in subsoil limits yield and water use in marginal cropping areas; Grains Research & Development Corporation, Final Report DNR 6, 2002

Hochman Z, Probert M, Dalgliesh NP (2004) Developing testable hypotheses on the impacts of sub-soil constraints on crops and croplands using the cropping systems simulator APSIM. In 'Proceedings of the 4th International Crop Science Congress, 26 Sep – 1 Oct 2004, Brisbane, Australia' (Eds. T

Fischer, N Turner, J Angus, L McIntyre, M Robertson, A Borrell).http://www.cropscience.org.au/icsc2004/poster/1/3/1/1013_hochmanz.htm

Liu CY, Paull JG & Rathjen AJ (2000) Shoot mineral composition and yield of wheat genotypes grown on a sodic and non-sodic soil. Australian Journal of Experimental Agriculture, 40, 69-78

Nuttall JG Armstrong RD& Connor DJ (2003) Evaluating physio-chemical constraints of calcarosols on wheat yield in Victorian southern Mallee. Australian Journal Agricultural Research, 54, 487-498

Nuttall JG & Armstrong RD (2010) Impact of subsoil physicochemical constraints on crops grown in the Wimmera and Mallee is reduced during dry seasonal conditions. Australian Journal of Soil Research, 48, 125-139

Munns R & James RA (2003) Screening methods for salinity tolerance: A case study with tetraploid wheat. Plant and Soil, 253, 201-218

Munns R, Gardner PA, Tonnet ML & Rawson H (1988) Growth and development in NaCl-treated plants. Ii. Do Na or Cl-concentrations in dividing or expanding tissues determine growth in barley? Functional Plant Biology, 15, 529-540

Rayment GE& Lyons DJ (2011) Soil chemical methods: Australasia. CSIRO publishing.: 2011; Vol. 3.

Rengasamy P (2002) Transient salinity and subsoil constraints to dryland farming in Australian sodic soil: An overview. Australian Journal of Experimental Agriculture, 42 (3), 351-361

Reuter DJ, Robinson JB& Dutkiewicz C (1997) Plant analysis: An interpretation manual. CSIRO Publishing: Melbourne

Sadras V, Baldock J, Roget D, Rodriguez D (2003) Measuring and modelling yield and water budget components of wheat crops in coarse-textured soils with chemical constraints. Field Crops Research 84, 241–260

Shaw R (1997) Salinity and sodicity. In Sustainable crop production in the sub-tropics: An Australian perspective pp 79-96.

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.

Contact details

Yash Dang
School of Agriculture and Food Sciences
The University of Queensland
Ph: 0427 602 099
Email: y.dang@uq.edu.au

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

® Registered trademark

Common sowthistle – knockdown and double knock control in fallow

Richard Daniel, Linda Bailey, Denielle Kilby, Branko Duric, Richard Black and Lawrie Price, Northern Grower Alliance

Key words

common sowthistle, knockdown, double knock, fallow, *Sonchus oleraceus*

GRDC code

NGA00004: GRDC grower solutions for northern NSW and southern Qld

Take home messages

- Current no effective alternatives to glyphosate for consistent one-pass knockdown control of common sowthistle
- Control levels from all strategies improved on seedling to rosette weed stages compared to later growth stage application
- A range of options provide effective control of seedling to rosette staged common sowthistle when followed with a paraquat 2nd knock application
- The double knock program of glyphosate + 2,4-D followed by paraquat for flaxleaf fleabane also provides consistent management of common sowthistle
- Double knocks of Basta® followed by paraquat have provided the most consistent common sowthistle control, but may only be appropriate in sensitive areas or in optical spray situations due to cost
- Sharpen® as a 2nd knock option has provided similar levels of common sowthistle control to paraquat at 1.6-2.4 L/ha

Background

Management of common sowthistle (*Sonchus oleraceus*) has increased in difficulty over the last 10-15 years across most of the grain growing areas of northern NSW and southern Qld. The reasons for this are varied but include: the weed appears to have adapted to emergence at any time of the year, the seed is easily wind dispersed with reinfestation of 'clean paddocks' a constant challenge, and glyphosate tolerance and resistance levels have continued to increase.

It is clear that the industry can no longer rely on applications of glyphosate alone for common sowthistle control in fallow. The project activity undertaken during 2016 to 2018 has been to screen alternative herbicides for potential as standalone options on small weed stages but more likely as 1st knock applications in a double knock herbicide program. A double knock approach is where two different weed management strategies are employed in a sequential fashion to achieve a high level of weed control.

Approach

Two distinct series of knockdown trials have been conducted:

1. **Evaluation of alternatives to glyphosate for use as 1st knock.** The focus of this work was to identify whether existing fallow herbicide registrations may provide a viable alternative to glyphosate, either when applied alone or as part of a double knock strategy. In 2016 and 2017, paraquat was applied as the 2nd knock treatment. In 2018, a mixture of paraquat (Gramoxone® 250) + saflufenacil (Sharpen®) was applied.
2. **Evaluation of alternatives for use as 2nd knock**. The focus of this activity was to screen for alternatives to paraquat for use as a 2nd knock treatment in an attempt to improve the

consistency of double knock control but also to reduce the high level of resistance selection pressure on paraquat.

Results to date

1. Evaluation of alternatives to glyphosate for use as 1st knock

Initial work evaluated a range of tank mixtures with glyphosate. However, unless marginal control was achieved from the glyphosate component (either a marginal rate under prevailing conditions or weeds exhibiting glyphosate resistance) the risk was that all treatments provided complete control as 1st knocks. Subsequent activity in 2016-2018 evaluated the majority of options in the absence of glyphosate. A total of 24 different 1st knock approaches have been evaluated. A range of chemistry has been evaluated with Group I chemistry such as Tordon™, Amicide® 625 and Starane™ Advanced providing useful activity. Table 1 shows the results from the most consistent 1st knock treatments. All listed treatments were evaluated together in six trials.

Table 1. Summary of efficacy from 1st knock applications alone on <u>seedling to rosette</u> staged common sowthistle 2016-2017, assessed ~five weeks after application (range 20-64 days)

1st knock treatment	% Control (1st knock alone)		Comparison to Glyphosate CT 1.0 L/ha (applied alone)	
	Mean 6 trials	Range	Significantly POORER control	Significantly IMPROVED control
Glyphosate CT 1 L/ha (450 g/L glyphosate)	86	73-99	NA	NA
Glyphosate CT 2 L/ha (450 g/L glyphosate)	96	92-100	-	2 trials
*Tordon™ 75-D 1 L/ha (300 g/L 2,4-D + 75 g/L picloram)	91	75-99	1 trial	2 trials
*FallowBoss™ Tordon™ 1 L/ha (300 g/L 2,4-D + 75 g/L picloram + 7.5g/L aminopyralid)	94	91-100	1 trial	2 trials
Starane™ Advanced 0.6 L/ha (333g/L fluroxypyr)	84	70-99	2 trials	-
Amicide® 625 1.8 L/ha (625 g/L 2,4-D amine) + Hasten 1%	94	82-100	1 trial	2 trials

*Note: Tordon™ 75-D and FallowBoss are both registered for use in fallow at a rate of 1L, but sowthistle is not separately listed as a weed controlled under this use pattern. Lower rates of both products are registered for use in wheat and sowthistle is listed as a weed controlled at these lower rates.

Basta® (200g/L glufosinate) at the rate of 3.75 L/ha was only included at two of the six trial sites in Table 2. It achieved complete control at one site and 99.9% at the second. Basta 3.75 L/ha significantly increased control to Glyphosate CT 1 L/ha at one of the two sites.

Mixtures of Group G herbicides (e.g. Sharpen – 700g/kg saflufenacil) with glyphosate were evaluated. They did not provide the consistency of control of treatments listed in Table 2, particularly when followed by paraquat.

A 2nd knock application of Gramoxone 250 (250g/L paraquat) was applied to all 1st knock treatments at a rate of 1.6 or 2.0 L/ha (depending on trial). Mean control from all treatments listed in Table 2 when double knocked was 99-100%. There was no significant difference in control between any of the treatments, in any trial.

Tables 2 and 3 show the results when targeting elongating staged common sowthistle. Table 2 shows the results from the 1st knock applications alone. Table 3 shows the same treatments when followed by a 2nd knock with Gramoxone at 1.6 or 2.4 L/ha (depending on trial).

Table 2. Summary of efficacy from 1st knock applications on elongating staged common sowthistle 2016-2017, assessed ~five weeks after 1st knock application (range 21-49 days)

1st knock treatment	**% Control (1st knock alone)**		**Comparison to Glyphosate CT 1.0 L/ha (applied alone)**	
	Mean 6 trials	**Range**	**Significantly POORER control**	**Significantly IMPROVED control**
Glyphosate CT 1 L/ha (450 g.a.i./L glyphosate)	60	40-84	NA	NA
Glyphosate CT 2 L/ha (450 g.a.i./L glyphosate)	70	35-97	-	4 trials
*Tordon 75-D 1 L/ha (300 g/L 2,4-D + 75 g/L picloram)	78	9-98	-	4 trials
*FallowBoss Tordon 1 L/ha (300 g/L 2,4-D + 75 g/L picloram + 7.5g/L aminopyralid)	77	18-100	-	5 trials
Starane Advanced 0.6 L/ha (333g/L fluroxypyr)	49	6-90	1 trial	2 trials
Amicide 625 1.8 L/ha (625 g/L 2,4-D amine) + Hasten 1%	80	35-100	-	4 trials
Basta 3.75 L/ha (200g/L glufosinate)	90	71-97	-	4 trials

*Note: Tordon™ 75-D and FallowBoss are both registered for use in fallow at a rate of 1L, but common sowthistle is not separately listed as a weed controlled under this use pattern. Lower rates of both products are registered for use in wheat and common sowthistle is listed as a weed controlled at these lower rates.

Table 3. Summary of efficacy from double knock applications on <u>elongating</u> staged common sowthistle 2016-2017, assessed ~five weeks after 1st knock application (range 21-49 days)

1st knock treatment	% control double knock		Comparison to Glyphosate CT 1.0 L/ha Double knocked with paraquat	
	Mean 6 trials	Range	Significantly POORER control	Significantly IMPROVED control
Glyphosate CT 1 L/ha (450 g.a.i./L glyphosate)	80	50-100	NA	NA
Glyphosate CT 2 L/ha (450 g.a.i./L glyphosate)	89	62-100	-	2 trials
*Tordon 75-D 1 L/ha (300 g/L 2,4-D + 75 g/L picloram)	97	82-100	-	3 trials
*FallowBoss Tordon 1 L/ha (300 g/L 2,4-D + 75 g/L picloram + 7.5g/L aminopyralid)	96	77-100	-	3 trials
Starane Advanced 0.6 L/ha (333g/L fluroxypyr)	86	56-100	-	-
Amicide 625 1.8 L/ha (625 g/L 2,4-D amine) + Hasten 1%	93	77-100	-	3 trials
Basta 3.75 L/ha (200g/L glufosinate)	99	97-100	-	3 trials

2nd knock applications of paraquat were applied at 7 to 19 days after the 1st knock

*Note: Tordon™ 75-D and FallowBoss are both registered for use in fallow at a rate of 1L, but sowthistle is not separately listed as a weed controlled under this use pattern. Lower rates of both crops are registered for use in wheat and sowthistle is listed as a weed controlled at these lower rates.

Key points: Alternative 1st knocks

Seedling to rosette

- Variable control with glyphosate alone. Improved control with increased glyphosate rates
- Group I (phenoxy) options generally provided good suppression but not consistent control
- Group I product differences were clearly evident from 1st knock applications alone
- **Consistent and high levels of control (99-100%) achieved when either glyphosate or the Group I options listed in Table 2 were double knocked with paraquat**
- Basta is encouraging, either alone or double knocked, but cost prohibitive for broadacre application

Elongating

- No treatment provided acceptable control when applied alone
- Overall most consistent suppression was achieved with Basta, however poorer control when applied alone than other options in two of six trials

- **Basta double knocked with paraquat was the most consistent option and should be considered for optical spray uses**
- Group I options were encouraging, but only when double knocked
- Starane Advanced at 0.6 L/ha provided the least suppression of the listed group I herbicides when applied alone or when double knocked with paraquat

2. Evaluation of alternatives for use as 2nd knock

Paraquat has been the key active ingredient used as the 2nd knock option and can provide effective management of a wide range of grass and broadleaf weeds. However, it is clear we require other options to use in this management window to:

1. Avoid the more rapid selection of paraquat resistance and
2. Provide options that may improve weed control in situations where paraquat efficacy is not adequate.

Table 4. Summary of efficacy from 2nd knock applications on common sowthistle 2017-2018, assessed ~five weeks after 2nd knock application

2nd knock treatment	% Control		Comparison to Gramoxone 1.6L/ha	
	Mean 8 trials	Range	Significantly POORER control	Significantly IMPROVED control
Untreated (1st knock only)	87	60-100	4 trials	-
*Gramoxone 250 0.8 L/ha (250g/L paraquat)	94	76-100	3 trials	1 trial
Gramoxone 250 1.6 L/ha (250g/L paraquat)	98	94-100	NA	NA
Gramoxone 250 2 L/ha (250g/L paraquat)	99	96-100	-	-
Gramoxone 250 2.4 L/ha (250g/L paraquat)	99	98-100	-	-
Sharpen 17 g/ha + (700g/kg Saflufenacil) Hasten 1%	100	98-100	-	1 trial
Sharpen 26 g/ha (700g/kg Saflufenacil) + Hasten 1%	99	97-100	-	1 trial

NB All treatments received the same 1st Knock application in each trial. The most common treatment was a mixture of glyphosate with 2,4-D amine, with the rates varying with the weed stage, environmental conditions and grower/adviser recommendations.

2nd knocks were targeted for application at ~7-14 days after the 1st knock. Mean interval was 11 days with a range of 7 to 19 days.

2 trials not included: 2016 trial excluded as Sharpen only evaluated at 34 g/ha. Final data not yet available from trial initiated 18/12/2018

*Label rates for Gramoxone are 1.2-2.4L/ha. 800 mL was included in trials as a 'failure rate'.

Key points: Alternative 2nd Knocks

- Evaluation in 2016 showed improved efficacy from Sharpen as a 2nd knock treatment compared to other group G options or Basta
- Sharpen performance has been more consistent when used in a 2nd knock application, with no regrowth evident in any of these trials
- Dose response to Gramoxone 250 was relatively flat from 1.6 – 2.4 L/ha but apparent in situations of marginal control
- Negligible dose response to Sharpen with similar performance to Gramoxone 250 at 1.6 – 2.4 L/ha

Conclusions

Inconsistent levels of control of common sowthistle with glyphosate alone are now commonplace. Results from these trials reinforce the need to use robust glyphosate rates, avoid spraying under stressed conditions and target small weed stages. There are no obvious direct replacements for glyphosate as a standalone knockdown option.

However, group I herbicides such as Tordon 75-D, FallowBoss Tordon and Amicide 625 have provided equivalent or improved control when followed by a paraquat double knock. For situations near sensitive crops or where cost isn't the major constraint (e.g. when applied via an optical sprayer), Basta has provided effective management when used as the 1st knock in a double knock strategy. Previous trial activity however showed inconsistent results on flaxleaf fleabane and a range of summer grass species when Basta was used as 1st knock in a double knock strategy.

Sharpen can be a very effective option on small common sowthistle but levels of regrowth are commercially concerning when used alone or in mixture with glyphosate. Results from this series of trials has also shown inconsistent double knock results when Sharpen + glyphosate is the 1st application.

In contrast, Sharpen has been very consistent when used as 2nd knock alternative to paraquat or in mixture with paraquat. Level of control from Sharpen at 17-26 g/ha has been at least equivalent to that achieved with paraquat at 1.6-2.4 L/ha. However, paraquat is a better option in mixed grass and broadleaf fallow situations.

Acknowledgements

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

NGA would particularly like to acknowledge the assistance from our trial co-operators during this series of trials.

Contact details

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

® Registered trademark
™ Trademark

Deep P update 2019 – Multi-year grain yield impacts and economic returns for southern Queensland cropping

David Lester[1], Mike Bell[2], James Hagan[1]

[1] Department of Agriculture and Fisheries, Toowoomba, Queensland 4350
[2] University of Queensland, Gatton Campus, Gatton, Queensland 4343

Key words

phosphorus, starter P, deep P, residual value, placement strategies

GRDC code

UQ00063

Take home messages

- You know your paddock variability for yield – use that to prepare a soil sampling program
- Look at the fertility and constraint status of the soil profiles
- For southern Queensland, placing phosphorus at depth has produced statistically significant yield responses in 26 out of 35 crop seasons. The cropping program has been dominated by winter crops at these sites (27 of 35 crop-seasons), with wheat and barley responding positively in all 15 site-years and chickpea in 6 out of 12 crop seasons. Sorghum has responded in 4 out of the 6 site-years. Whether these differences in response frequency relate to seasonal moisture availability, soil P status or inherent differences in the ability of crops to utilise deep P bands is being explored in other projects and additional experiments
- Effects of deep placed P on grain P concentration were small, so grain P removal (export) is primarily driven by crop yield
- It is still challenging to estimate what re-application timeframes for deep P re-application look like, given other nutrient limits and varying seasonal conditions, plus the lack of a method to directly account for fertiliser P recovery and export.

The trial program and experimental design

Field research as part of UQ00063 commenced in the winter of 2012. Since then a total of 12 sites across the eastern Downs (2), western Downs (8) and Maranoa (2) have been established. Experiments have generally consisted of rates of Phosphorus (P) applied in bands at ~20cm depth on spacings of 50cm, along with an untilled farmer reference treatment. Application rates at depth, range from 0 to 60 or 80 kg P/ha. Table 1 displays the structure of deep treatments used in the two experiments established in the Maranoa. Initial experiments in 2012 (4 sites) used triple superphosphate (TSP) as the P source for deep treatments while subsequent sites used monoammonium phosphate (MAP). Due to poor efficacy at higher soil pH values, the TSP sites where not continued from 2016. Effects on yield are reported separating the TSP and MAP site responses.

A basal nutrient application of nitrogen, sulfur and zinc was added to the deep application to balance the rates of N added as MAP and lower the risk of other nutrient limitations constraining P responses. Potassium was also applied at one location. A location on the eastern Downs that subsequently proved to be potassium limited is not reported as part of this summary. Full agronomic details for experiments are contained in Gentry and Grundy (2018).

All main plots were split to annual 'with' and 'without' starter P fertiliser applications at planting, to test for any interactions between starter P (standard practice) and deep P applications (i.e. were effects independent or could one application method substitute for the other). The choice of starter product and rate represented grower practice at each site. The crop sequence at each site was dependant on the local rotation, and the residual benefit of the different rates of deep P was tracked through subsequent growing seasons.

Table 1. Experimental treatments for Mt Bindango deep placed P sites (FR=Untilled Farmer Reference treatment– no P fertiliser applied)

Deep P treatment nutrient application rates (kg/ha)							
Treatment no	1	2	3	4	5	6	7
P rate (as Mono Ammonium Phosphate)	FR	0	10	20	30	40	60
N rate (from MAP and Urea)	-	40	40	40	40	40	40
Zn rate (Zinc Chelate)	-	2.0	2.0	2.0	2.0	2.0	2.0

Measurements of crop response typically comprised biomass cuts at physiological maturity, to determine crop growth response and nutrient acquisition, in addition to machine harvested grain yields. Grain was also analysed for nutrient composition to calculate nutrient export.

Yield effects of starter and deep P were determined using ANOVA (VSN International 2017).

A subsequent analysis investigated the potential impact of the deep tillage and basal nutrient (as a surrogate for ripping effect) using REML (VSN International 2017) comparing just the FR (untreated) and 0P treatments, with/without starter application. This approach considers all the yield data for the site year, but just focuses on those two treatments, and their potential interaction.

Effects of starter P, deep P and starter P x seep P interactions

Results are based on analysis of each crop as an individual year, with a table summarising the response frequency for the different winter or summer species (Table 2). "Winter cereals" combines mainly wheat crops with only 2 barley crops grown. Individual site analyses are shown in the appendix Table 1. The number of experiment-years for each crop varies as two locations did not have starter applied. Statistical significance for the starter treatment needs to be interpreted conservatively as the experimental design was only testing presence or absence of the fertiliser and so has limited the experimental ability to determine influence. It should be noted that while starter P responses are based on fresh applications in each crop season, deep P effects represent the average response across sites that have had up to five crop seasons after the application of deep P and the other basal nutrients.

Table 2. Summary of statistical significances ($p <= 0.05$) for southern Queensland sites to starter, deep or interactions for fertiliser P

	Starter responses	Deep	Starter x deep
Winter Cereals	11 of 14 crops	15 of 15 crops	3 of 15 crops
Chickpeas	2 of 11 crops	6 of 12 crops	2 of 11 crops
Sorghum	0 of 6 crops	4 of 6 crops	0 of 6 crops
Mungbean	1 of 2 crops	1 of 2 crops	0 of 2 crops

Summary of results

Winter cereals – wheat and barley

Winter cereals consistently responded to having both starter fertiliser applied at sowing and to application of deep P, with very few crops showing an interaction between starter and deep P. From the 3 sites where statistically significant interactions were recorded, only 1 result appeared to be a genuine interaction, with the others a product of unexplained data variability. These results then reduce fertiliser P management into two independent decisions for winter cereals in southern Queensland: one about starter fertiliser use, and the other for deep placement. Yield gain when starter P was applied averaged 210 kg/ha (7.6%) across all sites for wheat and barley, compared to no starter fertiliser.

Assuming P costs of $3.60/kg and typical starter-P rates of 6-12 kg/ha, applications represent a cost of approximately $20 - $40/ha. This cost is easily returned by the $84/ha from an average 210kg yield gain. At current prices, the response to starter provides a positive economic return to growers and so should be considered as a part of normal recommended practice. Grain prices would have to fall to below $200/t before this yield benefit would not add extra profit from 12kg of P, and below $100/t for 6kg/ha of starter P to not be profitable.

Deep P at 20 kg P/ha applied as either TSP or MAP has increased average grain yield at winter cereal sites by 9-13% (Table 3). Comparisons between TSP and MAP sites using cross-site statistical techniques, and in-field comparisons of P fertiliser choice are underway currently in UQ00078 to explore further the product choice options. With the MAP sites, increasing the deep P rate to 30 kg P/ha generated mean increases of 380 kg/ha (range 141-826) resulting in an additional 15% yield increase.

Table 3. Winter cereal yield change summary for deep placed TSP or MAP at 20 kg P/ha (FR=Untilled Farmer Reference – no P fertiliser applied)

Deep P source	Number of crop-years	FR yield (kg/ha)	Average yield change with 20 kg P/ha deep	Range of responses with 20 kg P/ha deep
TSP	5	2426	+217 (9%)	+115-341
MAP	10	2522	+325 (13%)	+117-707

Chickpeas

Like the situation with winter cereals, chickpeas exhibited a low frequency of starter x deep P interactions, and again the two sites where these were significant were likely artefacts resulting from unexplained data variability. As outlined in Bell *et al.* (2016), chickpeas do not have an obligate requirement for starter application to set grain number (unlike cereal grain crops) and the very small number of responses to starter application (2 of 11 crops) is consistent with this (Table 2). However, there are situations where chickpeas were deep-sown into subsoils with very low available P, so the probability of starter P responses in these situations is greater.

The average chickpea yield without starter across all sites was 1747 kg/ha, compared to 1822 kg/ha with starter – a 75 kg/ha difference. Where that comparison was restricted to the two significant 'starter-responsive' sites, the yield increase from starter application averaged 300 kg/ha (1710 kg/ha without starter, 2010 kg/ha with).

At $800/t, even the overall average of 75 kg/ha increase in chickpea yield easily covers the cost of $20-40/ha of starter P, and the observed upper end responses would generate over $200 in additional profit for growers. To improve the reliability of starter P responses, growers should consider further on-farm experimentation – especially comparing responsiveness under deep sowing or normal sowing conditions.

It has been more difficult to make conclusive interpretations of deep P effects in chickpea crops in southern Queensland, with only half of the crops (6 from 12) showing statistically significant responses to deep P (Table 2).

Table 4. Chickpea yield change summary for deep placed TSP or MAP at 20 kg P/ha (FR=Untilled Farmer Reference – no P fertiliser applied)

Deep P source	Number of crop-years	FR yield (kg/ha)	Average yield change with 20 kg P/ha deep	Range of responses with 20 kg P/ha deep
TSP	7	2007	+56 (3%)	-172 to +249
MAP	5	1203	+133 (11%)	-144 to 535

The reasons for this more variable response are unclear, particularly in the light of the more consistent responses recorded in central Queensland. Dry matter responses to deep P were larger and more consistent than grain responses with an average increase of 500 kg/ha (10%). As harvest index for pulse crops is not relatively constant (compared to grass crops), this suggests that growth responses to P are not necessarily translating into yield responses. Further investigation into the relationship between P supply, biomass growth and establishment of grain yield in chickpea would appear to be needed to explain these interactions.

Sorghum

None of the sorghum crops grown in the current study period (2013-14 to 2017-18) recorded any statistical effect of starter application. Average grain yields without/with starter application also indicate a negligible effect (3404 kg/ha without vs 3376 kg/ha with). Warm soil conditions allowing rapid root expansion, combined with high potential evaporative loss in surface layers, may allow rapid early exploitation of P in the top soil layers but then limit the duration of access to the starter P band.

Deep P as MAP at 20 kg P/ha increased average grain yield from 3431 kg/ha in untreated plots by 311 kg/ha (Table 5). Application of 30 kg P/ha increased average yields slightly more with an average 372 kg/gain (11%, 319 – 514 kg/ha range). With only two crops on the TSP sites it is difficult to make much assessment on performance.

Table 5. Sorghum yield change summary for deep placed TSP or MAP at 20 kg P/ha (FR=Untilled Farmer Reference – no P fertiliser applied)

Deep P source	Number of crop-years	FR yield (kg/ha)	Average yield change with 20 kg P/ha deep	Range of responses with 20 kg P/ha deep
TSP	2	2924	69 (2%)	54 - 84
MAP	4	3431	311 (9%)	-44 – 517

Mungbean

The very limited set of mungbean data makes robust recommendations challenging. Like sorghum and chickpea, starter application showed negligible effects on mean yield (876 kg/ha without starter vs 908 kg/ha with starter). Similarly, deep P has provided only small average yield increases of 67 kg/ha for mean untreated yields of 837 kg/ha.

Economic assessment of deep P

As Deep-P involves large upfront costs (~$100/ha for 20kg P) it is important to identify how many crops it takes for this investment to be repaid, and how long this investment will continue to generate additional income. Of the 11 sites for deep P experiments in southern Queensland, 8 had repaid the investment in 20 kg/ha P and returned increased profit within 2 years and 5 of those had managed to do so in the first year. The 20 kg/ha P treatment at Jimbour West, which has had 5 crops between winter 2014 and winter 2018, has returned almost $800/ha in increased profit over this time period.

Potential tillage impacts on response with deep P

As outlined earlier, a contrast analysis just comparing the factorial effects of +/- starter and +/- deep rip plus basal nutrients was conducted. This approach focusses on these treatments inside the broader yield data for the site and crop in that year.

Results of this analysis indicate there was no substantial impact of deep tillage and basal application on their own, relative to current grower practice, with only 2 of the 35 crop seasons showing any statistically significant response.

Grain P concentrations with deep P treatment

Across the southern Queensland trial program, there were contrasting effects on grain P concentration between the grass and pulse species. For wheat and barley, 20 kg P/ha at depth increased grain P concentrations by an average of 150 mg P/kg (or 0.15 kg P/t). Grain P concentration in FR plots averaged 2260 mg P/kg (2.26 kg P/t) and with the 20 kg deep P/ha it increased to 2410 mg P/kg (2.41 kg P/t). At average grain yield for 20 kg P/ha applied deep, only an additional 1.1 kg P/ha leaves the paddock compared to the treatment without deep P.

Chickpea grain P concentrations showed greater responses to deep P applications, with 20 kg deep P/ha increasing grain P concentration by 330 mg P/kg (0.33 kg P/t). However, grain yield increases were smaller, so the change in P removed from the field with a 20 kg P/ha treatment was an increase of 1.2 kg P/ha, comparable to that of winter cereals.

The small differences in P removal rates with deep P application suggest that it will be difficult to use "cheque book" accounting to monitor depletion of deep placed P treatments. These data also suggest that while P applications can generate significant yield responses and improved profitability, they are also not having a large impact on crop P status. Grain P concentrations <2500-2900 mg P/kg are purported to indicate suboptimal crop P status in wheat, but even with a combination of deep P and starter P applications, average grain P concentrations still average only 2400 mg P/kg. These data therefore highlight the fact that once profile P becomes severely depleted, restoring soil P status with fertilizer applications will be a slow process that requires careful ongoing management.

Average additional P removal of ≈ 1.0-1.2 kg P/ha would appear to suggest an extended lifespan from a deep P application of 20 kg P/ha. However, it is unknown how residual fertiliser P availability will be impacted over time by chemical reactions that occur in the fertiliser band, and how those reactions might vary between soil types. Additional work to explore the chemistry of residual P availability is currently being conducted by a GRDC-funded postdoctoral fellow at University of Queensland.

Suggested on-farm research treatments

This field research was conducted under carefully managed experimental conditions. Before commencing a large-scale nutrient application program, growers are urged to appropriately soil test their fields to establish available nutrient concentrations in the surface and subsurface layers, and to identify the potential constraints to yield. They are then encouraged to evaluate the crop responses to fertiliser applications designed to address those yield constraints using an appropriate program of strip-trials and on-farm exploration to validate the diagnosis of nutrient constraints.

There are four suggested treatments to explore the effects of a deep P application before starting a larger program (Table 6):

1. Treatment 1 is current practice or "do nothing", which benchmarks current system performance;

2. Treatment 2 involves the physical tillage of soil to a depth or roughly 20-25 cm, which simulates the deep placement operation without any fertiliser application. While not a long-term solution, simply loosening soils can sometimes allow better root exploration of those profile layers and allow more efficient uptake of scarce soil P resources.
3. Treatment 3 is tillage with additional nitrogen. In many sites, nitrogen status is in equilibrium with the existing 'normal' yields from that field, and if deep P improves field yield potential, extra N has to be applied to achieve the higher yield target. Applying additional N alone in this treatment allows growers to separate responses from tillage, extra N, and extra N and P.
4. The last treatment is deep P application. Given that MAP is the most effective form of P, and soil Zn is often also low, an application of 100-150 kg/ha of an ammonium phosphate product with Zinc is typically used. Suggested rates for use in strip trials are 20-30 kg P/ha of an ammonium phosphate-based product. Placement of the P needs to be such that crops are going to be likely to access it. Plant roots must have a high probability of encountering the applied P early in the growth stage, so band spacings of 50 cm or less are suggested to maximise the chances of roots from each crop row encountering some of the applied nutrients.

Table 6. Suggested on-farm deep P treatments

Treatment	Rip (≈ 20-25 cm)	Deep N (≈ 30/50 kg N/ha)	Deep N+P+Zn (30/50 kg N/ha + 20/30 kg P/ha + Zn/ha)
1			
2	Y		
3	Y	Y	
4	Y	Y	Y

Treatments should be done in a way to make recording of yield response simple. The easiest strategies involve full-length field strips (ideally two or three header widths together) and also replicated several times within and across fields. Talking with precision ag practitioners, the minimum treated area to produce reliable yield estimates with harvester yield monitors is 1 ha in 5-6 header widths.

Acknowledgements

The research undertaken as part of project UQ00063 was made possible by the significant contributions of growers who host the field trials and the financial support of the GRDC. The authors would like to acknowledge these contributions and thank both groups for their continued support.

References

Bell, MJ, Lester, DW, Graham, R, Sands, D, Brooke, G (2016) Phosphorus and potassium nutrition. In 'GRDC Adviser Update - 2016. Goondiwindi', Mar 2016. (GRDC. Available at https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/past-update-proceedings/2016/grdc-grains-research-update-goondiwindi-2016

Gentry, J, Grundy, T (Eds) (2018) 'Queensland Grains Research - 2017-18 Regional Agronomy.' (Department of Agriculture and Fisheries (DAF): Brisbane, Qld). Available at https://publications.qld.gov.au/dataset/queensland-grains-research

VSN International (2017) 'Genstat for Windows 19th Edition.' (VSN International, Hemel Hempstead, UK)

Contact details

David Lester
Department of Agriculture and Fisheries
PO Box 2282 Toowoomba
Mb: 0428 100 538
Email: david.lester@daf.qld.gov.au

Supplementary Table 1. Individual site by statistical significance for starter, deep or interaction

Crop	Starter	Deep P	Starter * Deep P
Westmar - ANOVA			
2014 Wheat	*	***	n.s.
2015 Chickpea	n.s.	n.s.	n.s.
2016 Chickpea	n.s.	**	n.s.
Inglestone - ANOVA			
2013 Wheat	*	***	***
2014 Chickpea	**	**	n.s.
2015 Chickpea	n.s.	***	***
Lundavra #1 - ANOVA			
2013 Wheat	No Starter	*	No Starter
2014 Chickpea	n.s.	*	*
2015 Wheat	n.s.	***	n.s.
2016-17 Sorghum	n.s.	n.s.	n.s.
Lundavra #2 - ANOVA			
2013 Chickpea	No Starter	n.s.	No Starter
2014 Wheat	n.s.	*	*
2015-16 Sorghum	n.s.	***	n.s.
2016 Chickpea	n.s.	n.s.	n.s.
Wondalli - ANOVA			
2013-14 Sorghum	n.s.	***	n.s.
2015 Wheat	***	***	n.s.
2017 Wheat	***	*	n.s.
Condamine #1 - ANOVA			
2015-16 Sorghum	n.s.	n.s.	n.s.
2017-18 Mungbean	n.s.	n.s.	n.s.
Condamine #2 - ANOVA			
Crop	Starter	Deep P	Starter * Deep P
2014 Chickpea	n.s.	n.s.	n.s.
2015 Wheat	*	*	***
2017 Wheat	**	**	n.s.
2018 Wheat	**	***	n.s.
Mount Carmel - ANOVA			
2013-14 Sorghum	n.s.	**	n.s.
Jimbour West #1 - ANOVA			
2014 Barley	*	***	n.s.
2014-15 Mungbean	*	**	n.s.
2015-16 Sorghum	n.s.	*	n.s.
2017 Chickpea	*	***	n.s.
2018 Barley	**	***	n.s.
Mt Bindango #1 – ANOVA			
2016 Wheat	*	***	n.s.
2017 Wheat	*	**	n.s.
2018 Chickpea	n.s.	*	n.s.
Mt Bindango #2 – ANOVA			
2016 Chickpea	n.s.	n.s.	n.s.
2017 Wheat	n.s.	*	n.s.
2018 Chickpea	n.s.	n.s.	n.s.
n.s. = not significant, * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$			

Grower experience with Deep P

Tom Woods, "Billa Billa"

Key words

phosphorus, starter P, deep P, grower

Take home messages

- Application of deep P is a rare opportunity to utilise existing resources (land, equipment, moisture, present cropping options) to increase production
- My advice to other growers is to give it a go!

Demographics

Location: "Billa Billa", Goondiwindi, Queensland

Hectares: 14,000

Why?

- David Lester's research
- Age of cultivation
- Soil tests are low in P
- Yield targets were not being met

What rates?

- 100/120 kg starter
- 20 units P

When?

- Ideally after sorghum as it has a longer time for the soil to melt down with no fear of loss
- Can apply with urea on same pass with some risk of loss
- Can apply after chickpeas but there is less time for country to recover

How to apply?

- Tractor
- Implement
- Spacing
- Direction
- Depth (15cm to 25cm)

Costs

- Approximately $80 per ha for product
- Approximately $20 per ha for fuel, wages, wear and tear
- Total cost $100 per ha

Cost recovery

- With grain @ $300 per tonne, need an extra 1/3 tonne yield increase per ha over the life of the application

How often?

- Currently unanswered. Possibly 5 to 10 years

Unforeseen benefits and pitfalls

- Benefits - deep ripping, opening soil and breaking hard bands
- Pitfalls - application too wet or too late

Other cost comparisons

- Shire rates - No yield increase
- Chemical – No yield increase (sustains only)
- Camera spray – Reduces costs but no yield increase

Conclusion

Application of deep P is a rare opportunity to utilise existing resources (land, equipment, moisture, present cropping options) to increase production.

Contact details

Tom Woods
"Billa Billa"
Mob: 0428 718 884
Email: wtwoods@bigpond.com

Storing planting seed on farm - managing pests, maintaining quality

Philip Burrill, DAF Qld

Key words

planting seed storage, pest control for seed, planting seed germination and vigour, planting seed purity

GRDC code

PRB00001

Take home message

- Planting seed is the most valuable grain stored on farm. Each month check storages for pests and monitor grain temperatures
- Clearly identify / number each silo and keep up-to-date storage records
- Keep seed varieties pure. Clean out silos, augers and trucks to prevent contaminating seed with other varieties that have different maturities and disease resistant levels
- A cone-based silo, with aeration cooling, that is sealable when a fumigation is required, is the ideal farm seed storage. Locate silos in the shade or paint white to reduce seed temperatures
- Warm grain temperatures and higher seed moisture contents in storage are major causes of poor seed germination and vigour. Invest effort into achieving effective aeration cooling
- To minimise pest damage, apply a registered grain protectant treatment to seed at harvest time. When sieving and probe traps detect pests, fumigate with phosphine in a sealable silo.

The most valuable grain – planting seed

Planting seed is the most valuable grain you will ever store on farm. The consequences of allowing seed to deteriorate while in storage can be very costly. Poor crop establishment usually leads to reduced yield potential and problems with more in-crop weeds.

At times complete crop planting failures occur due to the use of seed that had low germination and vigour. Poor storage conditions such as warm grain temperatures, higher grain moisture content and damage by storage insects (weevils) can have a major impact on seed quality.

In dry times, the more common practice of planting deeper into soil moisture makes it critical we do our best to look after seed vigour quality during storage.

If possible, avoid keeping seed that has suffered weather damage prior to harvest, as seed viability falls more rapidly during its time in storage. Always test seed for germination and vigour well before planting time. Also check seed prior to harvest for the presence of smut / bunt diseases.

Seed storage silos and equipment

For bulk seed storage, aim to use a cone-based silo that is easy to clean / wash out, has aeration cooling fans fitted and is sealable so effective fumigations can be carried out when required.

Seed storages and equipment to maintain seed quality

- Clearly number each silo and keep up-to-date storage records of where each variety is stored. Also record monthly insect and temperature checks, etc. A blackboard painted section on the silo base is also helpful
- Bright reflective silo walls, or painted white walls will help reduce grain temperatures in the silo
- Locate seed silos in the shade if possible. e.g. south / east side of larger silos or sheds
- Aeration cooling is important. Operate fans using a good quality aeration auto-controller for best results
- Silo roof venting - a removable ‘chinaman’s hat’ vent fitted to the silo top fill point can provide effective venting for a silo while seed is stored under aeration cooling
- Good quality silo seals and design for effective fumigations when required. Silo should meet the AS2628 sealing standard when purchased new
- Silo hygiene – easy to clean or wash out the inside of silo to reduce contaminating a seed line with other grains or varieties. This also reduces carry over of insect pests in grain residues
- Have ladders on silos to provide access to the top of silos to take samples for seed quality testing, using a probe to measure grain temperature, checking for insects with probe traps, and undertaking fumigation activities
- Grain protectant treatments for storage pests or fungicide seed treatments – use spray equipment and augers that are easy to calibrate for accurate dosage and provide uniform coverage on seed
- Detecting insect pests – use an insect sieve, insect probe traps, a grain temperature probe, plus a storage note book or iPad to keep monthly records of pests found, seed treatments, etc

Figure 1. Seed silos fitted with aeration cooling and designed as sealable for fumigations

Managing pests and maintaining seed quality

Fumigations and use of grain protectant insecticides are only two of the five key tools used to maintain planting seed quality and achieve reliable insect pest control. Combining the five practices outlined below forms the foundation for successful seed storage.

Top five practices for successful seed storage

1. **Aeration**: Correctly designed and managed, it provides cool grain temperatures and uniform grain moisture conditions. Aeration reduces storage problems such as moulds and insect pests, plus helps maintain seed quality, germination and vigour.
2. **Hygiene**: A good standard of storage hygiene is crucial in keeping storage pest numbers to a minimum. Good hygiene for silos, augers and trucks reduces the risk of seed contamination.
3. **Monitoring**: To prevent serious damage, undertake monthly checking of seed in storage for insect pests (sieving / trapping) as well as checking grain quality and temperature. Keep monthly storage records, including any grain treatments applied.
4. **Fumigation**: In Australia, only fumigant gases (e.g. phosphine) are registered to deal with live insect pest infestations in stored grain. To achieve effective fumigations the storage/silo must be sealable – gas-tight to hold the gas concentration for the required time. Note – phosphine fumigations, used according to the label, does not damage seed germination.
5. **Grain protectants**: Grain protectant insecticide sprays provide another line of defence against storage pests. Prior to storage, treat cereal grain planting seed held on farm with a registered grain protectant. Use according to label directions.

Warning: Grain protectant notes do not apply to the grains industry in Western Australia where their use is restricted. In all cases, product labels are to be used to determine correct use patterns.

Figure 2. Rice weevil *Sitophilus oryzae,* a serious pest of stored seed

Figure 3. A probe trap and insect sieve used for regular grain inspections

Seed storage – cool and dry

Figures 4 and 5 below show the impact of storage temperatures (30°C and20°C) and grain moisture content (10, 12, 13, 14, 15% m.c.) over time on the germination viability of wheat seed.

Clearly, storing dry seed (10 – 12% mc), under cool conditions (15 – 20 °C), are worthwhile targets to aim for to maintain seed germination quality.

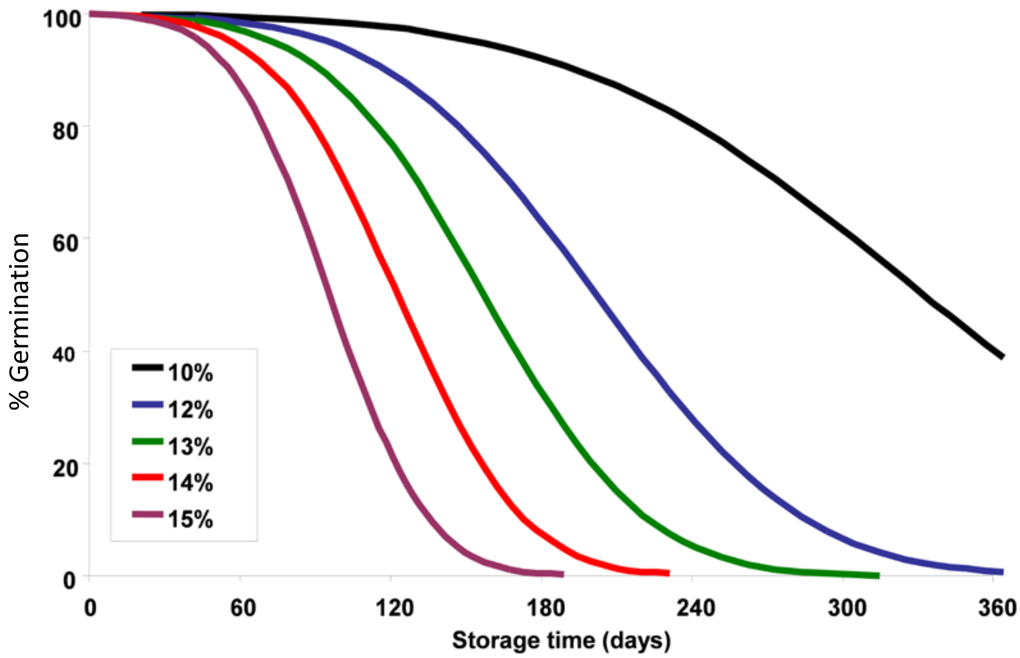

Figure 4. Influence of moisture contents (10 to 15%) on percentage germination of wheat stored at **30°C** *(Source CSIRO – SGRL)*

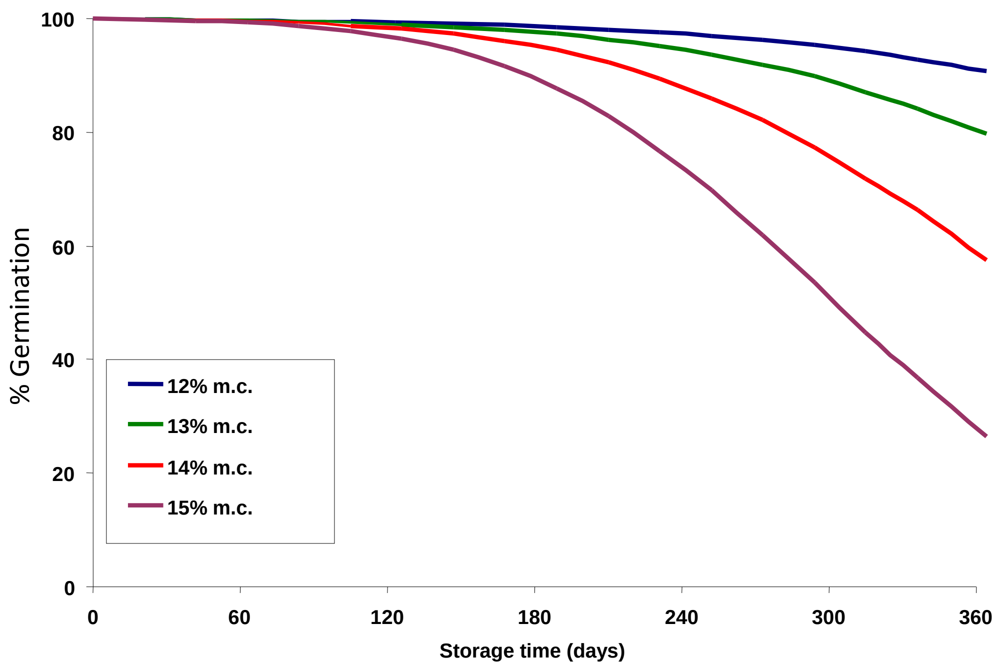

Figure 5. Influence of moisture content (12 to 15%) on percentage germination of wheat stored at **20°C** *(Source CSIRO – SGRL)*

Additional seed management strategies

Cool grain temperatures in storage and low moisture content seed are two critical factors for maintaining good seed germination and vigour quality. Aeration cooling systems play an important role.

Aeration research trials have shown it is feasible and that we should aim to achieve grain temperatures under 23 degrees Celsius in summer and less than 15 degrees in winter.

To monitor seed / grain temperatures in storage, use a hand held temperature probe, or fixed cables inside silos such as OPI™ grain cables http://www.advancedgrainmanagement.com/products/ . Be aware that some cables with sensors measuring both temperature and relative humidity may suffer damage to the relative humidity sensor following a phosphine fumigation. Phosphine gas is corrosive and will damage exposed electrical components.

A typical phosphine fumigation to kill all storage pests, needs to achieve a minimum of 200 ppm phosphine gas concentration for at least 10 days. This will only be achieved in a well-sealed silo.

Planting seed held on farm should in most cases be treated with an insecticide 'grain protectant' at harvest time (not WA) to reduce storage pest insect problems. e.g. Conserve Plus™ with Reldan™.

For smut and bunt disease control, seek good advice on what fungicides to treat your planting seeds with. Some fungicides can shorten seedling coleoptile length. Spend time with your contract seed grader and understand exactly what they are doing with your planting seed. Only treat seed you will plant, as you cannot sell fungicide treated planting seed to any grain markets.

Further information

GRDC Fact Sheet – Saving weather damaged grain for seed:
http://storedgrain.com.au/saving-weather-damaged-grain-for-seed-grdc-fact-sheet-january-2011/

GRDC booklet – Aerating stored grain – Cooling or drying for quality control:
http://storedgrain.com.au/wp-content/uploads/2016/10/GRDC-Aeration-Book-2016_R2.pdf

Kondinin Research report: Planting seed treatments – armour against insects and diseases
https://www.farmingahead.com.au/edition/1000039/research-report-planting-seed-treatments

Dow™ AgroSciences - Conserve Plus™ Grain Protector:
http://www.dowagro.com/en-au/australia/product_finder/insecticides/conserve-plus

BAYER CropScience - K-Obiol® EC Combi
https://www.environmentalscience.bayer.com.au/K-Obiol/About%20K-Obiol

Acknowledgements

The authors acknowledge the RD&E support from GRDC. The authors would also like to thank DAF's Postharvest research team members, GRDC's national grain storage extension team, along with valued support from growers and industry collaborators.

Contact details

Philip Burrill
Department of Agriculture and Fisheries, AgriScience Qld.
Hermitage research facility, 604 Yangan road, Warwick Qld. 4370
Mb: 0427 696 500
Email: philip.burrill@daf.qld.gov.au

® Registered trademark
TM Trademark

Testing of farm-retained and carryover seed

Ken Cunliffe

Key words

germination, vigour, tetrazolium, purity, seed testing, seed quality

Take home messages

- Seed is the most valuable operational input even if it is low cost.
- A seed test and comprehensive seed analysis certificate can help avoid financial losses associated with a failed crop establishment.
- When seed testing, you have a right to a seed analysis certificate and ask for an interpretation if necessary.
- Seed is a living organism and needs an occasional health check. Multiple seed tests may be needed.
- Take samples that properly represent the entire seed lot and not just a single bag or the first take from the header.

Seed quality standards

Seed is just one of many operational inputs. On a per hectare basis seed is a low-cost item, but, poor seed quality can lead to massive opportunity costs on top of the losses from every other operational input.

Seed quality is essential as poor germination, or a lost season cannot be brought back! In some cases, farmers have also been left with significant weed problems that they never had previously from planting “cheap” seed.

It is also possible to face a law suit for infringing Plant Breeders Rights legislation where protected varieties are traded illegally for use as planting seed.

Plan your seed requirements early!

The Australian Seeds Federation (ASF) is the peak industry body for the Australian Seed Industry. Under the ASF Code of Practice, all seed for sale must be supported by a seed testing analysis certificate which must be made available on request. All Australian laboratories that are accredited by the International Seed Testing Association (ISTA) or National Association of Testing Authorities (NATA) to test seed follow the ISTA Rules for seed testing. As such, a seed analysis certificate is based on internationally prescribed test methods. That is the seed quality benchmark that all growers should subscribe to, when purchasing new, farm-retained or on farm carryover seed.

If seed is purchased from a reputable seed company or reseller, that seed will likely have a current seed analysis certificate that reports purity, germination, 1000 seed weight, tetrazolium, and possibly vigour results. A current seed analysis certificate should be no more than 12 months old from the date of sale. A grower should require no less and should be even more rigorous with retained or carryover seed.

Reputable seed suppliers endeavour to ensure that seed sold complies with acceptable quality standards. A seed analysis certificate should provide information about the supplier, the kind of seed, variety, lot identification, lot weight and test results. This is the purchaser’s assurance that the product in the bag is what it says it is and that it meets the standards stated.

Seed care

Seed is a fragile living organism. There are some important implications. A test report is very specific to a sample and is only representative of a moment in the history of a seed lot.

1. Adverse growing conditions through to harvest can markedly affect seed quality. For example, dry conditions at seed fill can lead to small seed that is not fully formed. Predation by sucking insects can leave almost invisible penetration points on the surface of the seed that will become infection sites for bacteria or fungi. Such seed may appear perfectly normal but will not perform.
2. Sometimes seed is harvested at a moisture content that is too high for safe storage and must be dried down. Excessive heating during the drying process kills or deteriorates seed rapidly.
3. Seed needs to be stored cool, dry and pest (rodents and insects) free. Conditions in on farm storage of seed can be quite variable – some being notoriously bad. If seed is to be stored on farm (even purchased seed), ensure that conditions are suitable – cool, dry and pest free.

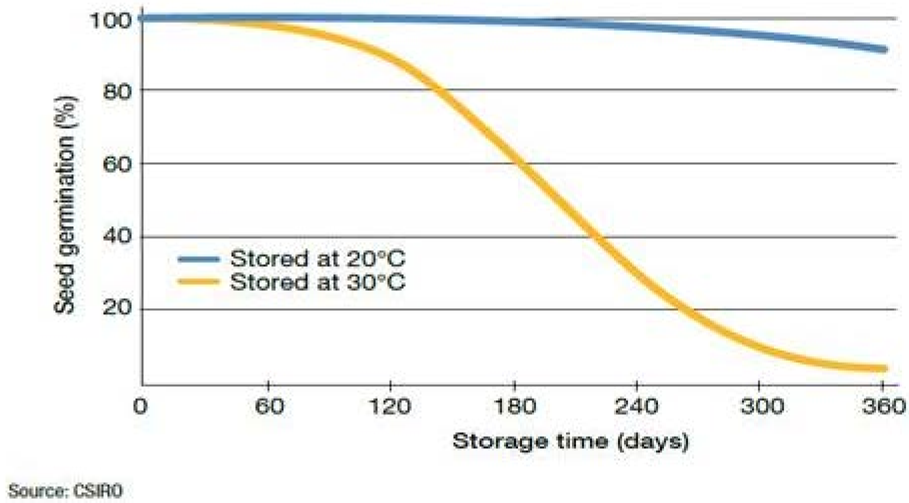

Figure 1. Influence of temperature on wheat germination stored at 12 percent moisture content (Source: CSIRO)

4. The impact of mechanical damage that comes from harvesting and handling seed should not be underestimated. It may appear sound on the surface but underneath there could be damage that renders that seed useless. Seed requires gentle harvesting and subsequent handling.
5. Chemical treatment, including fumigants, fungicides and insecticides, particularly with unapproved chemicals can damage seed and reduce viability. Only use products that are registered for use on seeds and refer to the label for any crop safety comments prior to use.
6. Unclean planting seed is a primary source of disease infection and the spread of unwanted weed seed or genetic mixing for subsequent crops.
7. Does farm-retained seed contain the required genetics? You cannot grow second generation hybrid seed and expect the same performance as the first generation. That is because first generation hybrid seed maximises heterogeneity. Subsequent generations become progressively inbred increasing the frequency of homozygous genes, which may be recessive, which leads to reduced performance and increased variability.

Seed testing is a valuable decision tool for farmers!

Whenever a laboratory receives a sample of seed for testing the results provided are only applicable to the sample that they receive. So, it is imperative that the sample provided is representative so that the results are applicable to the entire seed lot. The best way to achieve this is to combine subsamples from multiple access points to the entire seed lot. Seed samples should be securely contained (in a moisture proof container if a moisture test is required) and delivered to your laboratory as soon as possible. Never leave samples in a hot car.

Immediately after harvest a moisture test will indicate if further drying is necessary. This is important for both seed and grain. Germination and vigour tests can be used to determine the suitability of that harvest for seed. If the viability is questionable at harvest it will certainly be no better after a lengthy storage period in the lead up to planting time and it would be better to dispose of the crop to grain markets. While germination may be satisfactory, a poor vigour test may mean the same thing.

A purity test after harvest can help determine the presence of unwanted weed seeds and the grading losses necessary to bring the seed to a satisfactory standard. This test may also help to identify appropriate grading methods, such as screening, gravity separation or a combination. A post-grading purity test and 1000 seed weight test are useful in conjunction with germination or vigour tests to calculate optimum planting rates.

It is important to restate that if initial post-harvest testing indicates that seed is suitable for storage, then the seed should be stored under cool, dry and pest free conditions. Time is a tyranny for quality seed and if conditions are less than optimal, viability can decline very rapidly. I have tested seed that had a 90% germination prior to being loaded into a farm silo. With mid-summer temperatures well above 40°C and a silo in the full sun for just four weeks, the germination of seed on the western side of the silo was reduced to just over 40%. Deterioration can occur under any conditions simply because seed is a fragile living organism.

The reason that you need good quality, vigorous seed is so that you can achieve the optimal plant population of strong healthy plants in the paddock that give the best chance of maximising crop yield and at the same time providing for a uniform and easily managed crop. Seed quality is measurable via purity, germination and vigour tests. Under time pressure, a tetrazolium test can be used for viability in place of a germination and vigour test with caution and understanding the limitations of the test. Ideally these tests need to be carried out as close to planting as practicable.

A purity test delivers percentages of pure seed, inert matter and other seeds. Pure seed is as per a specific definition given by ISTA for the species. For example, wheat seed must be more than half of the original size. Thus, a broken seed is considered a pure seed if it is more than half the size of an entire seed. Inert matter consists of damaged seed that does not fit the definition for pure seed, straw, soil and other matter that will not grow. Other seeds include seeds of any other crop or weed species. These are listed on the certificate of analysis and should be carefully considered to avoid introducing unwanted weeds to your farm.

A germination test will report the percentages of normal, abnormal, fresh, hard and dead seeds.

1. **Normal** seedlings show the potential to develop into satisfactory plants when sown into good quality soil under favourable conditions of moisture, temperature and light.
2. **Abnormal** seedlings develop but are damaged, deformed or decayed to the point that they will not develop into normal healthy plants. Frequently these plants have the same negative effect on production as weeds.
3. **Fresh** seeds take up water but otherwise remain unchanged throughout the duration of the test. This may be because of dormancy, which could break at a later stage or they may never develop.

4. **Hard** seeds do not take up water for the entire duration of the test. They are considered dormant and may develop at a later stage.
5. **Dead** seeds decay and do not develop at all.

For the purposes of determining planting rates, only the normal seedlings should be considered. A germination test report will usually report a first and final normal seedling count. This may be used as a guide to vigour.

There are many different types of vigour test. In general, they report the ability of seeds to germinate and emerge from a specified depth of soil within a set time period and subject to specified conditions. Different vigour test types may impose a stress factor on the germinating seed, such as cold or high humidity. In general, the vigour result for high quality seed should be approximately the same as the normal percentage from a germination test. As with all laboratory tests, the laboratory that issued the certificate should be able to assist with interpretation. Vigour drops off more rapidly than germination. So, seeds which germinate well may not emerge well under adverse conditions.

A tetrazolium test is a rapid biochemical test for viability. Live seed tissue is stained red during the process. In order to be considered viable, all essential parts of the seed embryo must stain red. Viable seeds are expressed as a percentage. It is important to note that no distinction is made between normal, abnormal, viable hard and viable fresh seeds. The test does not account for dormancy. Your testing laboratory can assist with the interpretation of results.

Relationship between seed size and seed vigour test in canola

In the laboratory, there is no definite relationship between seed size and germination/vigour tests.

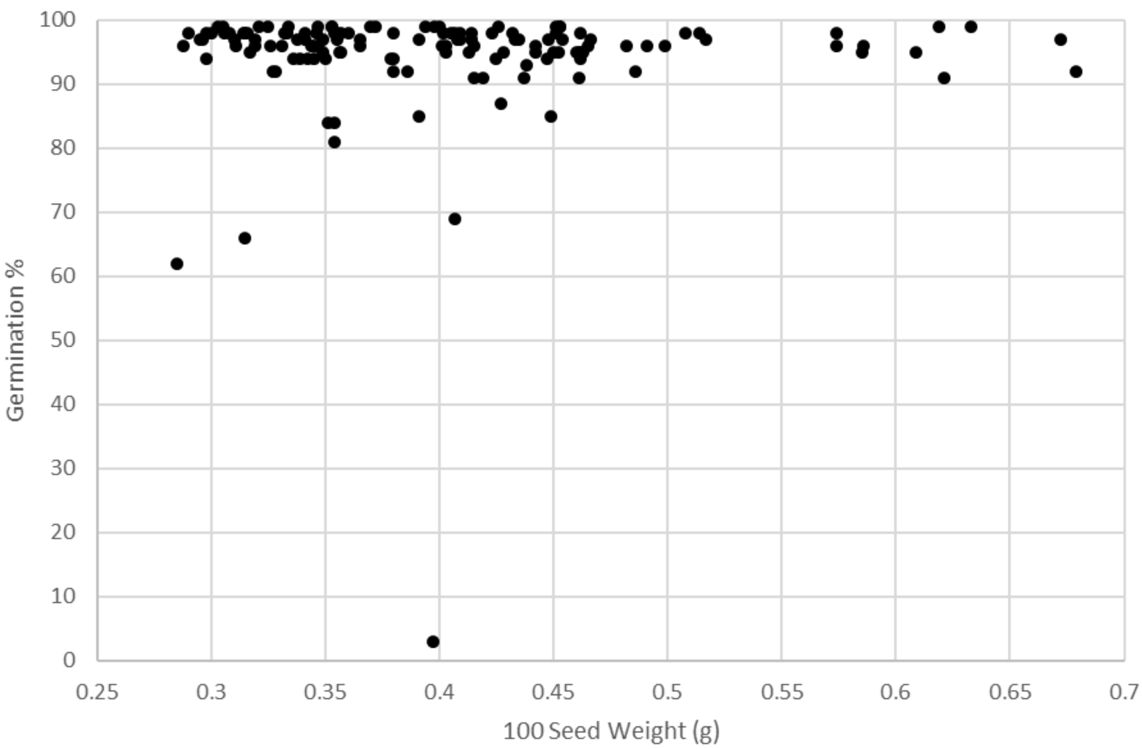

Figure 2. Canola: seed size vs germination %. Does larger seed size in canola mean better germination?

Although in the laboratory, there is no link between seed size and germination/vigour tests, research in the field by Rohan Brill from NSW DPI shows that there is a relationship between seed size and seed establishment in canola, especially under challenging conditions (e.g. deep sowing). For further information, please read Rohan's papers on page 59 of this link (Canola establishment - does seed size matter?) https://grdc.com.au/__data/assets/pdf_file/0021/186141/nsw-update-proceeding-2014-web-excl-industryinfo-pdf.pdf. Provided that you are able to obtain the variety that you want, purchasing or grading farmer-retained seed for larger seed size may perform better in the field than smaller seed where the germination and vigour are the same.

Conclusions

Irrespective of the origin of the seed that you plant it is worth securing a recent seed test certificate from a reputable laboratory to ensure that your seed is what you think it is and that it is fit for purpose.

Consider the cost of a crop failure that could arise after preparing your land, applying fertilizer and chemicals, irrigation water and the impact of sowing sub-standard or dead seed! While seed is a relatively low-cost input on a per hectare basis, it is an essential start that will set your paddock up for profit or loss.

Acknowledgements

Staff of AgEtal Pty Ltd Agricultural Testing laboratory

Australian Seed Federation

National Association of Testing Authorities (NATA)

International Seed Testing Association (ISTA)

Contact details

Ken Cunliffe
AgEtal Pty Ltd
Unit 9/24 Carroll Street, Wilsonton, QLD 4350
Ph: 07 46333223
Email: ken@agetal.com.au
www.agetal.com.au

KEY CONTACTS

NORTHERN REGION

TOOWOOMBA
214 Herries Street
TOOWOOMBA, QLD 4350
northern@grdc.com.au

APPLIED RESEARCH AND DEVELOPMENT GROUP

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

BUSINESS SUPPORT TEAM LEADER
Gillian Meppem
Gillian.Meppem@grdc.com.au
M: +61 4 0927 9328

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

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

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

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

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

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

GENETICS AND ENABLING TECHNOLOGIES GROUP

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

GROWER EXTENSION AND COMMUNICATIONS GROUP

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

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

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

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

BUSINESS AND COMMERCIAL GROUP

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