BREEZA
NEW SOUTH WALES
FRIDAY 2ND MARCH, 2018

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

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GRDC Welcome

Welcome to the 2018 GRDC Grains Research Updates

Ensuring growers, advisors and industry stakeholders are informed about the latest research and development outcomes in their quest to improve on-farm profitability is a key role of the annual Grains Research and Development Corporation (GRDC) Updates.

As an industry we face new challenges in terms of climate variability, technology and market conditions, so it is important for all of us to have up-to-date knowledge to make informed decisions and drive practice change.

Last season, New South Wales and Queensland grain growers experienced everything from moisture stress, to heat stress, frosts and waterlogged paddocks. This highlights the importance of robust and rigorous research to help underpin profitability across a range of climatic and environmental conditions.

It also emphasises the value of GRDC investments into regional extension to equip growers and advisors with the information and support they need to make key farm management decisions.

For 25 years, the GRDC has been driving grains research capability and capacity with the understanding that the future of Australian grain growers' hinges on relevant, rigorous, innovative research that delivers genuine profitability gains.

Despite the challenges the grains industry remains confident about the future, willing to embrace new concepts, and keen to learn more about innovations and technology that bring cost efficiencies, promote sustainability and grow productivity.

The GRDC Updates deliver research direct to growers, agronomists and industry. This year the Updates will offer information from the latest research and development from short- and medium-term investments that address on-farm priority issues from farming systems, agronomy, soils, weeds to pests and diseases.

So I hope you enjoy the Updates and that the events provide a valuable opportunity for learning, knowledge sharing and networking. I encourage you to use these events to interact with GRDC staff and GRDC Northern Panel members, who are committed and passionate about your success and the future of the northern grains industry.

Jan Edwards

GRDC Senior Regional Manager North

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Breeza GRDC
Grains Research Update
Friday March 2nd, 2018

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 AM	**Welcome**	
9:10 AM	**Mining and farming - can they co-exist?**	*Angus Duddy (Grower & Nuffield scholar)*
9:40 AM	**The P story thus far – how much, when, how and with what expected benefit?**	*Mike Bell (QAAFI)*
10:10 AM	**What's new in grain storage?** ProFume® fumigations, fumigating large silos and latest trials on grain protectants	*Philip Burrill (DAF Qld)*
10:45 AM	**Morning tea**	
11:15 AM	**Tall sorghum types in irrigation yielding 15 t/ha & IT sorghum. What's happening, when and with what agronomy?**	*Trevor Philp (Pacific Seeds)*
11:35 AM	**Sorghum and maize -** avoiding yield loss to heat at grain fill through agronomy and changing the sowing window	*Loretta Serafin (NSW DPI)*
11:55 AM	**Sunflower agronomy** - manipulating the crop for the best yield and oil content outcomes. Which leaves contribute the most to yield and oil?	*Loretta Serafin (NSW DPI)*
12:20 PM	**Soil water, risk management and sowing decisions on the Liverpool Plains.** Using knowledge about soil water to make better decisions on crop type, variety, population, nutrition, sowing date and row spacing in sorghum	*Daniel Rodriguez (QAAFI)*
12:55 PM	**Lunch**	
1:45 PM	**Chickpea: temperature and other factors affect flowering, pod set and yield**	*Andrew Verrell (NSW DPI)*
2:10 PM	**Chickpea water use efficiency**	*Kerry McKenzie (DAF Qld)*
2:35 PM	**Setting the farm up for broadband connectivity**	*Nick Gillingham (Keytah)*
3:05 PM	**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
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Assessing the viability of agriculture and energy's co-existence model

Angus Duddy

Key words

agriculture, energy, co-existence model, mining

Call to action/take home messages

The study focused on key considerations and constraints in managing the impact of extractive energy industries and agriculture co-existing in close environmental proximity to each other. The challenge lies in managing the barriers to this co-existence including scientific, technological and social obstacles. Lessons from the United States and Canada shed light on various ways to foster a sustainable co-existence. These include; environmental bond legislation, extraction and reclamation processes, and increased communication of the values and interests of different industries. Ultimately, the goal is to initiate effective governance and adaptive management utilising a region-specific management technique.

Introduction

There is often an uneasy co-existence of the energy and agricultural industries, particularly in highly productive agricultural areas. The co-existence model is that resources and agricultural industries can operate together while maintaining and even enhancing the condition of natural, social/cultural, human and built assets in the region. This implies that all industries can be productive and profitable without exceeding sustainable limits of physical infrastructure, social systems or the environment (Collins, N. et al. 2013).

The challenge is to manage the various interests of different stakeholders and to overcome the scientific, technological and social barriers to achieve a suitable co-existence model. Facing this challenge is crucial as there is much at stake, including irreversible damage done to land and water.

Background

Prior to the recent scale back of the proposed coal mine in mid-2017, the Liverpool Plains region was one of the concentrated areas within Australia where the co-existence between extractive industries and agriculture was a topic of particular significance. This situation prompted this study.

Much of the argument for the development of the mines on the Liverpool Plains focused on the potential to provide employment and financial security to the region. Proponents of the mines argued that the mining industry and the local agricultural sector could continue to operate within close proximity to each other. This validity of this assumption was questioned by much of the local broadacre farming community who were concerned that the vast reserves of water held in underground alluvial aquifers would be disrupted by mining activities. The farmers argued that this water, a source for irrigation that sustains cropping activities and food production, provides the real financial security of the region.

The Liverpool Plains is also well known for its extremely high-quality soils that are capable of storing large amounts of plant available water, making the region a more reliable crop producing area than most other parts of the cropping belt.

Initially, the proposed mining projects sought to create a symbiotic relationship between the producer and the coal mining entities. As these projects moved through various levels of planning, potential impacts on the local environment and water reserves became clearer. Furthermore, there was evidence of a great lack of trust and confidence in government due process and in the companies developing the resource.

Objectives

Consideration of how mining and agriculture co-exist in other parts of the world can help to shed light on the viability of an agriculture and energy co-existence model in Australia. This study has focused on the assessment of the key considerations and constraints in managing the impact of extractive energy industries and agriculture coexisting in close environmental proximity to each other.

Lessons from the United States and Canada

Government legislative framework in Wyoming, United States

The state of Wyoming in the United States is heavily reliant on coal, oil and gas industries. Wyoming produces 39% of all of the coal mined in the U.S. The area was originally based on agriculture and is currently responsible for a large amount of high-value agricultural production including crops, livestock and poultry.

The Powder River Basin Resource Council was developed to assist landholders who were directly affected by energy development in Wyoming. Wyoming and Texas are somewhat unique as some landholders held their mineral rights as part of their original homesteading tenure, and holders can negotiate with coal and oil companies for the right for surface access arrangements through state process. One issue is that through a loophole there is provision for gas companies to access land without landholder consent. As the Coal Bed Methane (CBM) industry developed, landholders felt they had lost their voice, and in some situations landholders were host to 200+ CBM wells of which they had no control over their development.

Wyoming's situation, although not isolated, is interesting, as the social values that are held by the landholders are derived from a long history associated with early homesteading. The landholder is nearly always multigenerational, with a strong intent to continue ranching into the future. Issues arise between the ranchers, the locals and the energy companies, with the ranchers becoming the target of public and mining company campaigns, that they are impeding the flow of mining royalties into the community. The contribution of coal to the state of Wyoming is in excess of US $1 billion per annum. Agriculture in Wyoming is in the situation that the support generated by the general population is proportional to its contribution to state revenue. This makes it hard for agriculture to compete against the energy industry.

Government legislative framework does provide some regulation to this contentious relationship. In the U.S., the *Surface Mining Control and Reclamation Act 1977* requires that coal mining areas be restored to 'a condition capable of supporting the uses which it was capable of supporting prior to any mining.' This Act also requires mine operators to submit a mine reclamation plan prior to commencing extraction and also post a performance bond prior to development to ensure that funding will be available to complete this reclamation. The bond is not released to the mine operator until after the regulator has concluded that the reclamation is successful.

Commercial oil production in Alberta, Canada

ConocoPhillips Surmount II in Fort McMurray, Alberta is a commercial oil production site. The site has a total build value of over U.S. $10 billion and is designed to produce approximately 118,000 barrels of oil per day over its 40-year production lifespan. Steam-Assisted Gravity Drainage (SAGD) is used to remove the oil from deep below the surface. SAGD is the most commonly used method to recover oil in the Athabasca Oil Sands region. Two horizontal wells are directionally drilled from a central well pad. Steam travels from a nearby plant to the wells where it heats the oil to a temperature at which it can flow by gravity into the producing well. The process of steam injection and oil production happens continuously and simultaneously. The resulting oil and condensed steam emulsion is piped from the producing well to the plant where it is separated and treated. 90% of the water is recycled. In a process which uses 2.5 barrels of water to produce one barrel of oil, a 90% recycle rate is crucial to maintain environmental integrity.

ConocoPhillips has stated that it is totally committed to the complete reclamation of the nearly one square mile of land that the project site resides on. However, there will be unavoidable impacts. The Directorate General for Internal Polices Policy Department stated

"An unavoidable impact of shale gas and tight oil extraction is a high land occupation due to drilling pads, parking and manoeuvring areas for trucks, equipment, gas processing and transporting facilities as well as access roads. Major possible impacts are air emissions of pollutants, groundwater contamination due to uncontrolled gas or fluid flows due to blowouts or spills, leaking fracturing fluid and uncontrolled waste water discharge."

The value of agriculture in Bluegrass County, Lexington, Kentucky, United States

In January 2013, the University of Kentucky was engaged to measure the influence of the agricultural cluster on the Fayette County economy. The paper found that historical nature of measuring agriculture in the county focused on production agriculture. However when the cluster was expanded to include the agricultural inputs, food processing, transport, communications, wholesale, retail and service industries, the real value was discovered. The findings were that one-in-nine jobs were directly linked to agriculture (16,676 in total) and that the cluster generated US $2.4 billion in output annually with a further $1.32 billion in additional income, profit and dividends.

The value of the industry is reflected in the Purchase of Development Rights Program. The program helps conserve the precious Bluegrass landscape by purchasing conservation easements on 50,000 acres in the Rural Service Area to secure a critical mass of protected farmland for general agriculture, equine and tourism industries. Essentially, a permanent agricultural land easement is created over the associated lands on a voluntary basis, whereby the landholder forgoes their right for development and leaves the land in agriculture for perpetuity.

Extraction and regeneration in Indiana, United States

The state of Indiana prides itself on the process of extraction and sustainable regeneration. Before mining begins, operators must plan for the replacement of topsoil after the coal has been removed. Details about the removal, storage, replacement and protection of the topsoil from wind and water erosion are listed in the mine operation plan. A 'Citizens Guide to Coal Mining and Reclamation in Indiana' states that topsoil is removed in a separate layer from areas to be mined and immediately replaced or stored at approved locations. Careful handling of the topsoil and subsoil is crucial for reclamation because this is the medium on which the success or failure of plant growth on the reclaimed site is determined.

Anson Family Farms in Indiana produces corn, soybean, storage, turkeys and cover cropping. Multiple acres of their farming land have been reclaimed from pillar and block and open cast mining. The results of the reclamation were outstanding.

Recommendations

The study focused on key considerations and constraints in managing the impact of extractive energy industries and agriculture co-existing in close environmental proximity to each other. It is clear that there must be an understanding of the true value of the agricultural and energy resources, as well as consideration of the societal effects.

The values that farmers hold with regards to the impact of the landscape as it changes during the mine development are not well communicated by the landholders to extraction companies. Better compensatory processes could be established in Australia if there was a better understanding between landholders and miners of their perceptions of land value. Examples from overseas have shown that community consultations and transparency in the development of projects have led to positive outcomes for all involved.

Co-existence of these industries also requires a legislative framework that accounts for the environmental, economic, social and cultural values. The overarching governmental framework differs in Australia to other parts of the world. One example of this is the environmental bond policy which puts necessary economic deterrents in place for mineral and petroleum companies to instigate best practice.

Environmental bonding is critical to produce positive outcomes with regards to sustainable energy extraction. It is crucial that the implications of environmental default are such that the financial viability of the operation would be jeopardised by a company's incompetence. In conjunction, negative measurable impacts to ground and surface water sources should negate any development proposal no matter its size or economic value.

Conclusion

It is unchallenged that agriculture and energy industries are closely interconnected, and the choices and actions made in one domain greatly affect the other. The challenge lies in managing the barriers to this co-existence, including scientific, technological and social obstacles. Ultimately, the goal is to initiate effective governance and adaptive management utilising a region-specific management technique.

The issue that underpinned all sites visited was that the sustainability of water resources is always compromised if energy extraction of any sort is undertaken close to water resources, either underground or on the surface.

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Contact details

Angus Duddy
929 Rossmar Park Road, Quirindi, NSW
Mb: 0400 369 723
Email: angusduddy@bigpond.com

The P story so far – an update on deep P research findings

Mike Bell[1], David Lester[2], Doug Sands[2], Rick Graham[3] and Graeme Schwenke[3]

[1] University of Queensland
[2] DAF Queensland
[3] NSW DPI

Key words

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

GRDC codes

UQ00063, UQ00078

Call to action/take home messages

Depletion of subsoil phosphorus (P) reserves and uncertainty over the benefits of starter P use led to a detailed examination of crop responses to P fertilisers in terms of rates, products and placement over the last 5-6 years. Trials have been conducted at 35 locations from central NSW to CQld. While large crop responses have been recorded at many locations, the impact of seasonal moisture availability (on yield potential and root activity), P placement (starter v deep P, band spacing, amount of soil disturbance), P rate, time of application and product choice will all impact on responsiveness. Residual availability of deep P has generally been excellent, although crop response may be limited by shortages of other nutrients (e.g. N). Data continues to be incorporated into the Deep P calculator to provide an indication of the economic returns from P investment. To access the Deep-P Calculator: http://www.armonline.com.au/deepp/

The trial program

There has been a staggered establishment of sites across the region since mid 2012, with a total of 30 experiments in UQ00063 by the 2016 winter crop season at locations indicated in Fig. 1. These trials consisted of rates of phosphorus (P) fertiliser (0 to 40 or 60 kg P/ha) applied in deep bands (at ~20cm depth), typically at band spacings of 50cm, along with an untilled Farmer Reference treatment. All main plots were then split to annual 'with' or 'without' starter P fertiliser applications at planting at rates ranging from 6 to 10 kg P/ha. Crop choice at each site was dependant on the crop in the surrounding paddock (e.g. crop mix in the establishment years are shown in Table 1), and the residual benefit of the different rates of applied P was tracked through subsequent growing seasons. After the 2017 winter crop harvest, some sites have produced 4 or 5 crops, while some of the newer sites were only in the first or second crop after the initial P application. An extension to UQ00063 will allow the residual value of these later sites in particular to be extended to at least 4 crop seasons, weather permitting, while some of the earlier sites will be in their 5^{th} to 7^{th} crop after P application.

At each site, efforts were made to initially address other potential nutrient limitations, identified by soil testing, by applying a basal application of N, K, S and/or Zn as appropriate. Additional N applications were needed to balance different N additions when the P rates were applied as MAP, but also in response to a likely increase in crop yield potential after overcoming the P constraints. Whilst this initial 'top up' ensured crop responses to applied P should be expressed, problems emerged in later years at some responsive sites, as the higher yield potentials in the plots where P deficiency had been overcome did not have enough N to deliver the higher yield potentials (i.e. P responses were constrained by lack of N). While mainly relevant to grain crops and not pulses such as chickpeas or mungbeans, this problem was often not evident until late in a growing season, or only from observations of sub-optimal grain protein content. That meant that remedial action could only be taken for the next crop in the cycle, and assessment of the residual P benefit may have been compromised in some crop seasons. An example of this is provided later in this paper.

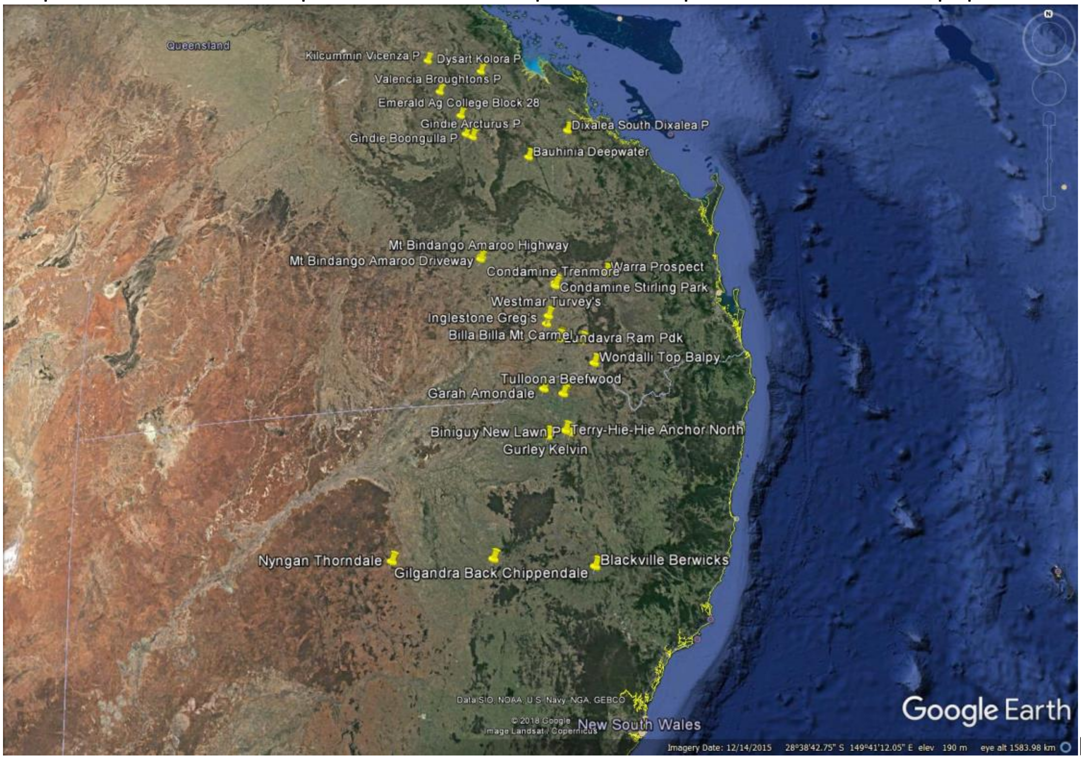

Figure 1. Location of the 30 P trials established from 2012-2017 under UQ00063.

The soil P tests for the 30 P trial sites in UQ00063 are shown in Table 1. Both Colwell and BSES P were higher in the 0-10cm layer than the 10-30cm layer, and BSES P was always at higher concentrations than Colwell P. Based on wheat critical soil test values for starter P responses, the median values would suggest a significant proportion of sites should have been P responsive. Similarly, we had hypothesized deep P responsive sites would have < 10 mg/kg Colwell P and <100 mg/kg BSES P in the 10-30cm layer, so most sites were predicted to respond to deep P.

Table 1. Median, maximum and minimum concentrations of Colwell and BSES P at sites sown to winter cereals (wheat and barley), chickpeas, grain sorghum or other species (sunflower and cotton) in the first year after fertiliser application.

	Colwell P (mg/kg)		BSES P (mg/kg)	
	0-10cm	10-30cm	0-10cm	10-30cm
Winter cereal sites (11)				
Median	19	6	66	18
Range	74-10	22-3	234-22	84-12
Chickpea sites (9)				
Median	17	4	29	12
Range	22-6	6-1	57-13	16-5
Sorghum sites (9)				
Median	14	3	71	15
Range	30-5	6-1	96-8	74-3
Other species (2 - Sunflower, cotton)				
Median	17	7	42	19
Range	19-15	9-4	47-37	30-8

An additional series of trials have been established since 2015 in core sites at Jandowae, Lundavra, Terry Hie Hie and Bellata under UQ00078, with these trials looking at placement strategies (rate*band spacing interactions, liquid v granular fertilisers, form of applied P, degree of soil disturbance/mixing, effect of co-location of different nutrients). Crop choice was again dependent on the host farm crop rotation.

Responses to starter P

Starter fertiliser applications were made at sowing – either by the trial operators with small plot equipment, or by the growers who turned starter fertiliser on and off in planned strip-plot designs. Unfortunately in the latter, starter was not always turned on and off as planned, so there was some loss of starter P contrasts at some trials. Overall, prior to the 2017 winter season (still being processed) there have been 42 site-years with starter P contrasts, split between wheat/barley (17), chickpeas (13) and sorghum (12), with crop responses assessed in relation to the initial pre-trial Colwell P concentration in the 0-10cm layer. To cope with differing yields between sites and seasons, responses were assessed on the basis of relative yield (Yield no starter/Yield with starter), with values <1.0 indicating that the crop responded to starter P application. Responses for each crop species are shown in Fig. 2 (a, b, c) for winter cereals, chickpeas and sorghum, respectively.

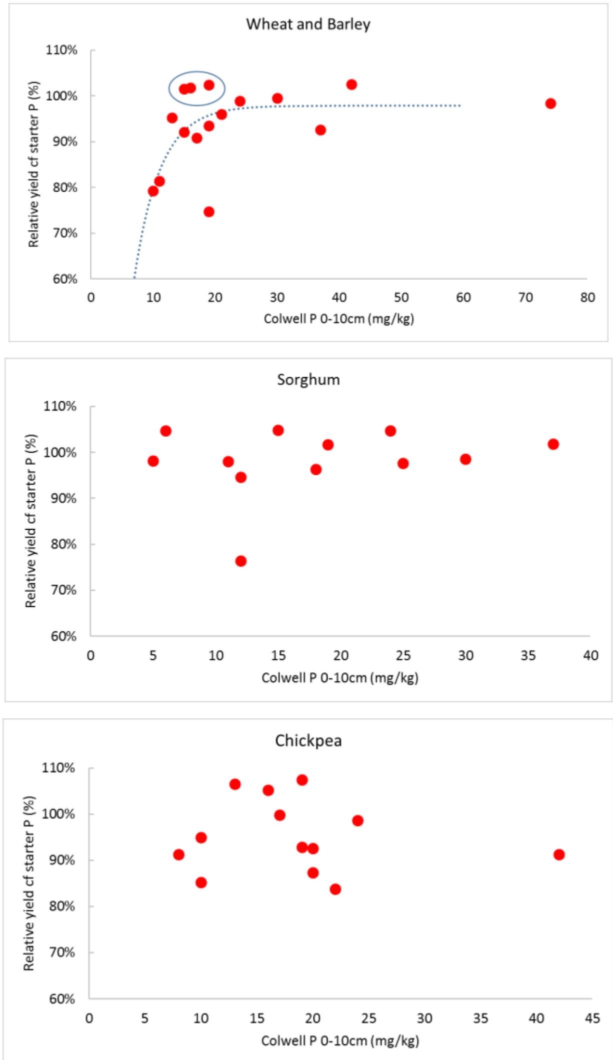

Figure 2. Response to starter P application in winter cereals, chickpea and sorghum crops grown in the UQ00063 trials. Points indicate the relative yield of the plots without starter fertiliser, compared to those where starter P was applied.

There is a relationship that can be developed for the winter cereal crops, although it is poorly defined due to the limited number of sites with very low Colwell P in the 0-10cm. That said, there seemed to be no real evidence of responses to starter P for Colwell P > 15-17 mg/kg – a value somewhat lower than the 20-23 mg/kg suggested from the recent national database analysis (R. Bell *et al.* 2013). More data is needed to better define this relationship.

Despite some quite significant responses to starter P in chickpea (up to 20% yield increases), there is no clear relationship to Colwell P in the 0-10cm layer – possibly because the variable sowing depths between sites and seasons may mean the 0-10cm layer is not always relevant to the developing crop (i.e. it may have been planted below 10 cm!). The data for sorghum shows almost no response to starter P at all, even when Colwell P in the top 10cm layer is very low. The one site where a significant response was recorded was south of Emerald in 2015.

We had intended to undertake separate analyses to look at starter P responses in the presence or absence of moderate-high rates of deep P, to gain some understanding as to whether ameliorating low subsoil P could eliminate the need for starter P – an effective diversion of the current P inputs in the cropping system from smaller annual starter P applications to occasional larger deep P applications. However, given the limited responses to starter P across all crops this has so far been inconclusive.

Responses to deep P

Deep P applications were made using either mono-calcium phosphate (TSP), or more commonly mono ammonium phosphate (MAP) with equilibration of the N inputs for the different rates using urea. The responses to deep P (Figure 3) have been assessed relative to the nil P treatments that received tillage and background nutrient inputs, so any yield increases are directly attributable to P addition only. Comparisons between the deep P treatments and the 'As is – Farmer Reference' condition were also made, with the relative performance of the deep P treatments generally greater than when benchmarked against the nil P, but responses in these instances could be due to soil disturbance, other background nutrients or the deep P input. There were 19 winter cereal and 19 chickpea site years of data, and 17 for sorghum, prior to the 2017 winter season.

As indicated in Figure 3 below, all crops responded to deep P when subsoil P (in the 10-30cm layer) was low. There are a range of responses to deep P for any given soil P concentration, which were due to a combination of other yield constraints (e.g. a lack of water!) or an ability to access P from relatively enriched topsoil layers (i.e. wet years). As an example, ignoring the red point which represented a trial with low N, failing to apply deep P resulted in yield penalties of 10-25% for a Colwell P of 2 mg/kg. It is difficult to make more definitive conclusions from the data at this stage (e.g. which species is the most responsive to deep P applications?), because the crops were grown on different sites, in different seasons with differing access to topsoil P, and with different deep P sources in some cases. For example, for sites where subsoil Colwell P was ≤5 mg/kg, the average yield loss due to low subsoil P from all site-years is 8% for wheat and chickpea crops but 13% for sorghum. It is impossible to tell whether this is because sorghum responds more to deep P than the other species, or because 90% of the sorghum crops were responding to deep P applied as MAP while for wheat and chickpea only 45-55% of the sites had MAP and the rest TSP.

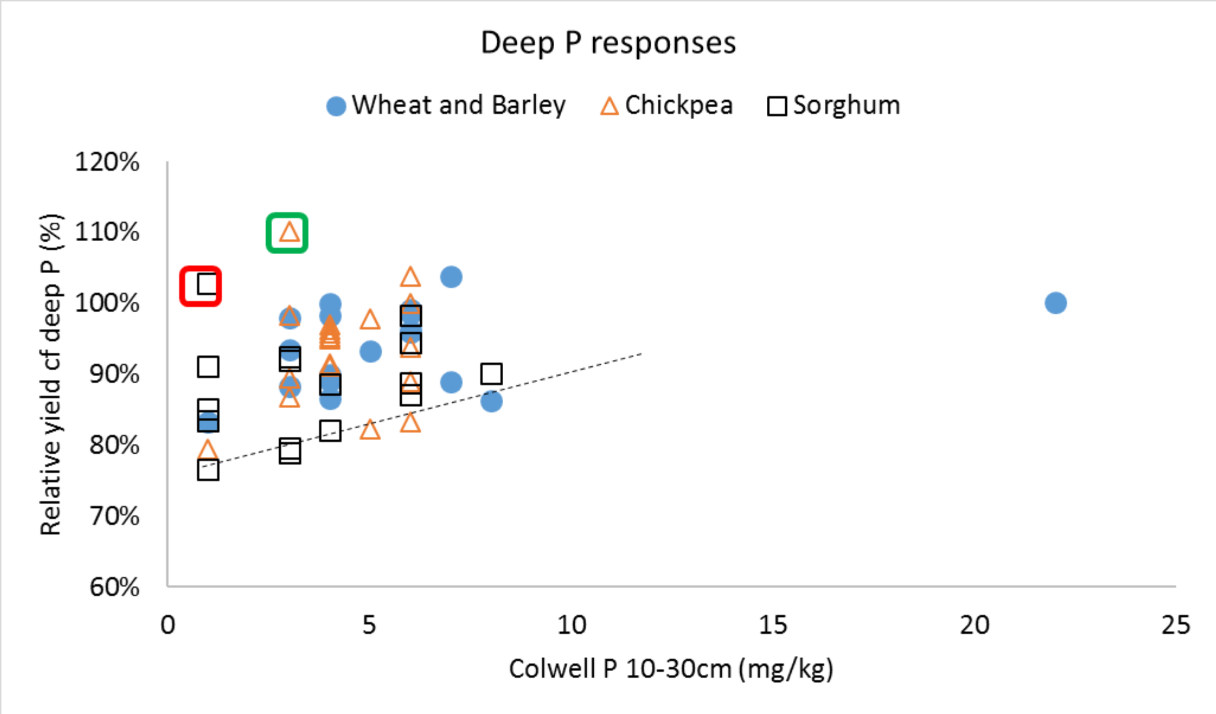

Figure 3. Response to deep P application in winter cereals, chickpea and sorghum crops grown in the UQ00063 trials. Points indicate the relative yield of the plots with starter fertiliser but no deep P, compared to those where starter P and deep P was applied, and represent both fresh and residual P responses. Points in the upper LHS of the curve (red and green squares) are where deep P was applied too close to the planting date, or where the site was N limited.

If we used the lower (more responsive) boundary of the trial data combined for all crop types (dashed line in Fig. 3) as an indicator of the potential crop responses to deep P in favourable seasons, this analysis would suggest that 90% of maximum yield potential (the value normally used to define a critical soil test concentration) will be achieved when Colwell P in the 10-30cm layer is ~10 mg P/kg. This agrees quite well with the original predictions at the beginning of this project in 2012.

Optimum application rates and residual value of applied P

To explore these effects we use case studies from 2 sites – one at Dysart (deep applied in Aug 2013, crop 4 harvested in 2017 winter) and the other at Wondalli (deep P applied in May 2013 and crop 4 harvested in 2017). Both sites were responsive to deep P, and responses are still evident in the 4th crop after application.

It is difficult to tell whether the P response is diminishing over time, or whether the rate required to reach P-unlimited yields is changing, due to other variables like seasonal conditions and N availability. In the first 3 crop years of sorghum, 20 kg P/ha was enough to reach maximum yields, but the P response was increasing all the way to the top rate (40 kg P/ha) in the chickpea crop in season 4. While this would suggest that the residual benefits of the lower P rates were diminishing by the 4th crop, this ignores the fact that yields of sorghum (crop 3, and to a lesser extent 2) were constrained by N availability, so the full potential P response may not have been able to be expressed. When a legume crop (chickpea) was grown in season 4, low N was less likely to be limiting crop performance, and the P response was very strong (and very profitable!). Further site-years with higher N inputs will help explore this response. However, to date the combination of tillage and deep P has produced an additional 700 kg/ha of sorghum in crop 1, 550 kg/ha of sorghum in crop 2, 450 kg/ha sorghum in year 3 and >850 kg/ha of chickpeas in year 4.

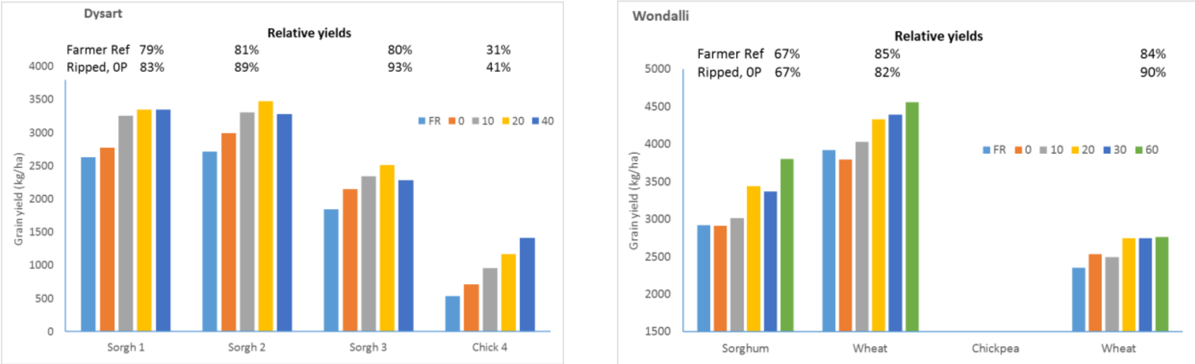

Figure 4. Grain yields at deep P sites at Dysart and Wondalli for the first 4 crop seasons after deep P application in 2013. Deep P was applied as MAP at rates ranging from 0 to 40 (Dysart) or 60 (Wondalli) kg P/ha, and each site had an unripped Farmer Reference (local practice) treatment as a benchmark.

There was no evidence of N limitations at Wondalli, although this site did lose its chickpea crop in season 3 due to the wet conditions in 2016. At this site, yields increased with increasing P rate up to 60 kg P/ha in the initial sorghum and subsequent wheat crops. However, while there were significant P responses in the 2017 wheat crop, there was no yield increase to rates >20 kg P/ha. The very dry seasonal conditions and water-limited yields in this season may have limited any response to higher P rates, so again, further site-years are needed to determine how long the residual effects last. To date, the combination of tillage and deep P has produced an additional 880 kg/ha of sorghum in crop 1, 650 kg/ha of wheat in crop 2 and 400 kg/ha of wheat in year 4.

When do I re-apply?

As more growers and advisors start deploying deep P strategies in their fields, this question is asked more frequently. Unfortunately there are no easy answers, other than the use of test strips with accurate yield monitoring. The amount of time and effort to effectively sample the subsoil layer to account for residual fertiliser bands, and assess the P bioavailability, would suggest soil sampling will not be the answer. Even a budgeting approach will not provide reasonable estimates. This is because, experimentally, we are unable to identify whether additional P uptake or removal by the crop accurately reflects fertiliser P recovery, as most crops are capable of proliferating roots in a P band and so can preferentially take P from the band while sparing P from the surrounding soil. We do not have any tracers that we can put into a P band to indicate fertiliser P recovery over a series of crop seasons, although Phil Moody and the group at DSITI are evaluating some options in the lab at present.

We are currently in year 1 of a 3 year extension to UQ00063 where we will continue to monitor a number of the more recently established sites as well as some of the longer term ones, and that may provide better estimates of the likely length of residual P benefits.

Products, placement strategies, timing

This remains an area of active research in both Qld and NSW under the co-funded UQ00078 GRDC project. Research has so far showed that

- There seems to be no advantage to be gained by using liquid v granular forms of MAP, as has been reported on the calcareous soils of the Eyre Peninsula in South Australia, and recent results from the NSWDPI site near Bellata have suggested the liquid MAP was actually inferior to the granular product.
- Studies have not been able to demonstrate an interaction between P rate and P band spacing (i.e. in band concentration), so the important thing is to get enough P into the subsoil layers in a

way that is practical but maximizes the chances of crop P recovery. Current recommendations for band spacings of 40-50cm therefore remain valid.

- To date, there has been no evidence of benefits of co-locating P and Zn in deep P bands, as there were suggestions that improved P uptake may limit Zn acquisition – possibly through a less extensive mycorrhizal network. However these effects have only been observed in sorghum crops in UQ00063, and as yet the specific P-Zn trial sites have not hosted a sorghum crop.
- The question of type of P fertiliser (MAP or TSP in particular) is currently the subject of trials sown in 2017 winter in NSW and in 2017/18 summer in Qld, and will also form a component of research conducted by a new postdoctoral appointment at UQ commencing in early 2018.
- Trials have also shown that there are no obvious negative impacts of combining MAP and KCl in deep bands in sites where both P and K are limiting, and that in this case, the root proliferation associated with the P band will encourage root activity and K uptake. Again, further work on the interaction between these products at different in-band concentrations and in different soil types will be undertaken by the UQ postdoctoral appointment from early 2018.
- Finally, trials are in the process of being established in Qld to explore the impact of amount of soil disturbance/mixing and the volume of soil enriched with P and K fertilisers on crop nutrient uptake. This will involve comparing discs, tynes and strip tilling units for their efficacy in making P available to the crop, and help to provide better guidance on the type of fertiliser rig required. A particularly interesting observation from this authors recent study tour to Europe and the UK has been the impact of voids/large pores on root branching and proliferation. This is illustrated in X-ray CT images produced in the University of Nottingham for maize and wheat (Fig. 5). Their results suggest that if the deep placement operation leaves large voids around the fertiliser bands and/or there is insufficient time and rain to allow profile reconsolidation, the chances of achieving the vigorous root proliferation needed to get good fertiliser uptake may not occur.

Conclusions

Research to better understand the effects of low subsoil P, agronomic strategies to overcome these limitations and the implications for fertiliser P management across northern cropping systems has come a long way. Rudimentary but functional diagnostic indicators of when to use starter and deep P fertilisers are becoming available, guidelines for effective application methods to address P limitations are developing, and economic assessments of the profitability of deep banding in a cropping system are showing strong returns in low P fields. Factors that limit deep P response include the availability of other nutrients (particularly N) and a lack of plant available water, both of which can restrict the achievement of higher yield potentials. The quantum of deep P response is also affected by seasonal conditions that impact on root activity in different parts of the soil profile, so obtaining benefits under some seasonal conditions will remain somewhat problematic. This risk is countered by the excellent residual value of deep P that is being documented in field trials, allowing the benefits of applications to occur across a rotational sequence rather than solely in the year of application.

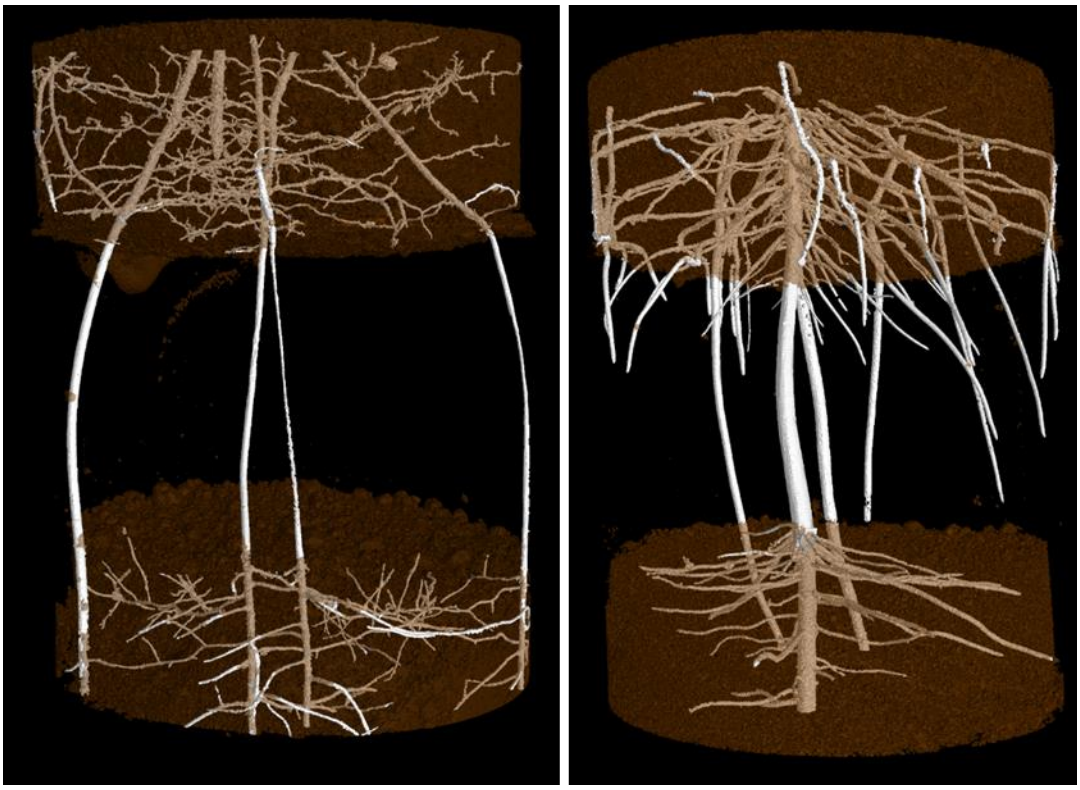

Figure 5. Impact of soil voids/air gaps on localized root branching in maize (left) and wheat (right). Image supplied by Prof Malcolm Bennett, University of Nottingham, and is reproduced from Morris et al (2017) Shaping Root Architecture. Current Biology, 27, R919–R930.

Acknowledgements

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Contact details

Prof Mike Bell
University of Queensland
Building 8117A, Gatton Campus, 4343
Ph: 07 5460 1140
Email: m.bell4@uq.edu.au

What's new in grain storage? – ProFume® fumigations, fumigating large silos and grain protectant update

Philip Burrill, Greg Daglish and Manoj Nayak, DAF Qld

Key words

grain fumigation, ProFume®, sulfuryl fluoride, storage pest control, large silo fumigation, fumigation recirculation, grain protectant insecticides

GRDC codes

PRB00001, PBCRC3036, PBCRC3150

Call to action/take home messages

- ProFume® (sulfuryl fluoride gas) applied by licenced fumigators to control storage pests in cereal grains, is valuable when rotated with phosphine fumigations to manage insect pest resistance.
- ProFume trials show that longer fumigation times of 7-10 days are required to control the full life cycle of storage pest insects when grain temperatures are below 25°C.
- In larger silos (150 – 2000 t) recirculating fumigation gases within the sealed silo using a small fan, helps ensures rapid, uniform distribution of phosphine, or ProFume (sulfuryl fluoride gas).
- Without recirculation during fumigation, it can take 2-5 days before the fumigant gas reaches all areas in a large silo, resulting in significant volumes of grain and insect pests being exposed to low amounts of gas.
- Seek good advice prior to applying any grain protectant treatment. Set up grain protectant spray application equipment to achieve good coverage and the correct dose rate.

Key storage management tools

Fumigations and strategic use of grain protectant insecticides are only two of the five key tools used to maintain grain quality and achieve reliable pest control results. Combined, they form the foundation of successful grain storage. Successful grain storage is crucial to a producer building a reputation as a reliable supplier of quality grain. Key aspects of successful grain storage are:

1. **Aeration**: correctly designed and managed, it provides cool grain temperatures and uniform grain moisture conditions. Aeration reduces problems with moulds and insect pests in storage, plus maintains grain quality attributes such as germination, pulse seed colour, oil quality and flour quality.
2. **Hygiene**: a good standard of storage facility hygiene is crucial in keeping background pest numbers to a minimum and reducing the risk of grain contamination.
3. **Monitoring**: monthly checking of grain in storage for insect pests (sieving / trapping) as well as checking grain quality and temperature. Keep a monthly storage record to record these details, including any grain treatments applied.
4. **Fumigation**: in Australia we now only have gases (fumigation) to deal with insect pest infestations in stored grain. To achieve effective fumigations the storage/silo must be sealable – gas-tight (AS2628) to hold the gas concentration for the required time.
5. **Grain protectants**: used on specific parcels of grain like planting seed held on farm, or bulk grain where potential grain buyers have agreed to its use, grain protectant sprays provide another line of defence against storage pests.

ProFume use in Australia

ProFume (sulfuryl fluoride gas) has only been available for use in Australia for a relatively short time (10 years). Phosphine fumigation products have been used to control grain pests for well over 50 years.

Initially registered and sold in Australia by Dow AgroSciences™, ProFume is now manufactured and supplied by Douglas Products™ based in America. A-Gas Rural® based in South Australia has the importing and distribution rights for ProFume. They also provide specialist product and safety training to licenced fumigators, allowing them to purchase and undertake ProFume fumigations.

One of the main drivers for use of ProFume is the continued development of phosphine resistance in storage pests over the past 30 plus years in Australia. Thankfully, for most grain producers, the current levels of phosphine resistance for most storage pest species still allows for complete control when fumigating in correctly sealed, gas-tight silos and when used as specified on the product label.

About 10 years ago one of the flat grain beetle species, known as the rusty grain beetle *(Cryptolestes ferrugineus)* developed a very high level of phosphine resistance at a number of eastern Australian sites. To control infestations of strongly resistant rusty grain beetles, most bulk handlers and a number of farm storage sites have been able to utilise ProFume.

Figure 1. Flat grain beetles, *Cryptolestes spp.*

When should I consider using ProFume?

- Phosphine fumigation failure. If live flat grain beetles *(Cryptolestes spp)* are found in grain after a well mananaged fumigation, consider using a ProFume fumigation.
- Fumigation resistance management. As for most Ag chemical use, aim for a rotation of products and active ingrediants to combat pests. If phosphine fumigations are often used for pest control at your grain storage facilities, consider a plan to use ProFume® every third year in rotation with phosphine.

Figure 2. ProFume

Key features of ProFume

- ProFume active ingredient is 998 g/kg sulfuryl fluoride. Each gas cylinder holds 56.7 kg.
- Only licenced fumigators with ProFume training can purchase and apply ProFume.
- Registered for use on cereal grains, NOT pulses or oilseeds.
- Requires a gas-tight (sealable silo) storage to hold the specified gas concentrations for the required time.
- Bulk grain treatment costs range from approx. $2-4/t excluding GST, depending on tonnage and travel.
- The 'eggs' of storage pests are usually the hardest life cycle stage to kill with ProFume. Longer fumigation times are required.
- Cooler grain temperatures below 25°C, typical for aerated grain, also require longer fumigation times.
- Fumigation time and grain temperature have the largest impact on successful pest control results with ProFume(see Figure 3).

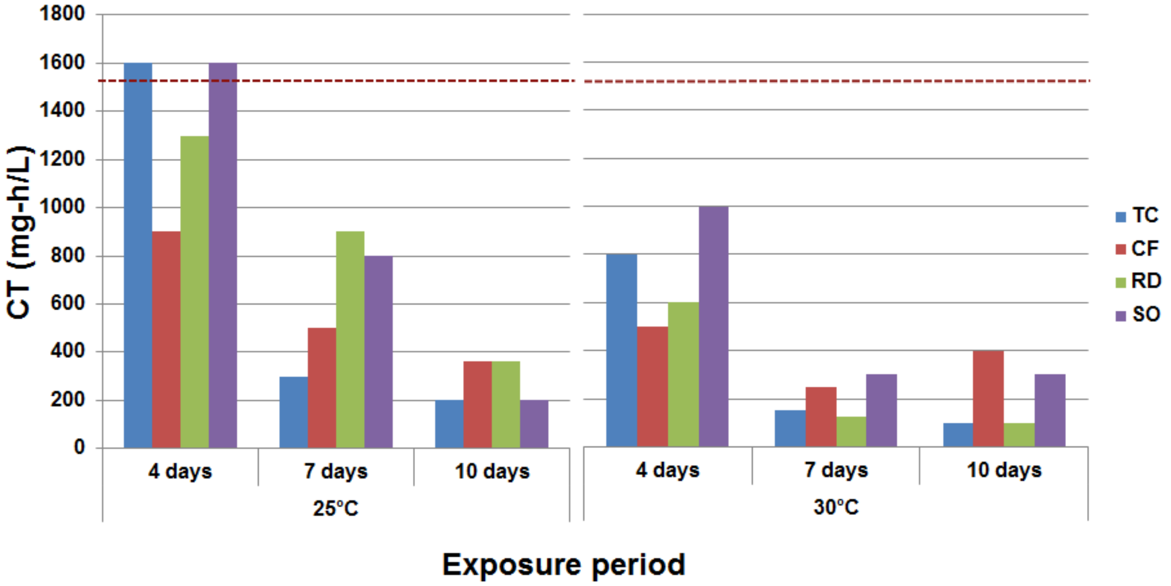

Figure 3. ProFume gas concentrations and time required at 25 and 30°C for complete control of the rust-red flour beetle (TC), rusty grain beetle (CF), lesser grain borer (RD) and rice weevil (SO) (Red dotted line is the 1500 CT limit for grain application)

Achieving reliable results and practical steps for ProFume fumigation

- Use only in gas-tight silos and storages. Pressure test silo, repair any leakage points.
- Avoid last minute, rushed 'short' fumigations. Longer fumigation times in a well-sealed storage provide effective pest control to all life cycle stages including the egg stage.
- Grain at temperatures below 25°C, fumigation times of 7-10 days would be recommended for effective pest control (see Figure 3).
- ProFume (sulfuryl fluoride) is a 'heavy' gas. Its' vapour density = 3.7 (air = 1). ProFume gas is typically applied into the top headspace of a silo. Discuss placement of a sealable fitting at the top of your silo with your licenced fumigator in preparation for fumigation.
- Recent field trials suggest that due to ProFume vapour density, there may be significant benefits to using recirculation during fumigation. This can reduce the tendency for this 'heavy gas' to fall and sit at much higher concentrations at the bottom of the silo or storage, leaving insects at the top exposed to much lower concentrations during fumigation.
- Follow all safety requirements as outlined by the licenced fumigator, including leaving fumigation warning signs and safety tape barriers in place. Aeration fans if fitted on storages simplify the venting requirements following fumigation. After venting and prior to grain movement, fumigators will test gas safety levels and 'clear' the grain. Keep copies of fumigation documentation.

Fumigation of larger silos (150 - 2000 t or greater)

The first step – ensure "gas-tight storage"

To control live insect pests in grain the only registered products in Australia are now a range of gases. Most often various phosphine fumigation products, and sometimes sulfuryl fluoride gas (ProFume). The controlled atmosphere method is also effective, using either carbon dioxide or nitrogen gas, but is mostly used for pest control in organic grains.

For any fumigation to be effective at controlling storage pests, the insects need to be exposed to a given gas concentration “C“, for a specified length of time “T”. If this “C x T” exposure requirement is not met during the fumigation, it is common to see survival of various insect life cycle stages. With these fumigation failures, live insect pests quickly appear in the grain within days or weeks.

This is why it is critical for Australian grain producers who store grain for more than a month, to have at least two or more sealable, gas-tight storages that meet the Australian silo sealing standard (AS2628).

A storage that is not gas-tight does not allow the fumigation “C x T” exposure level to be reached in all parts of a silo, large or small. Achieving reliable pest control results is not possible with gas leakage and air dilution. As well as not killing the pests, selection and development of resistant insect populations is the additional negative outcome of poor fumigation attempts.

To achieve effective fumigations, silos must be pressure tested to check they are sealed – gas-tight. This ensures they hold high gas concentrations for the required time to kill pests.

Checking a large silo is ready for fumigation – useful equipment for pressure testing

- Portable leaf blower, or small aeration fan, used to add air to silo for pressure tests. High volume, low pressure air is required. Standard air compressors are generally not suited to this task.
- 50 mm poly fitting, including a 50 mm shut-off value, fitted into external section of silo aeration ducting. Using this port to blow air into silo.
- Plastic tube manometer, or better, a digital manometer (e.g. Extech HD 755 Differential pressure manometer 0 – 0.5 psi). Aiming to measure within the range of 0-4 inches water gauge (w.g.) (0-1000 Pa).
- Spray bottle containing water & detergent, to check for leaks. Often you can hear or feel air leaks from large silos during the pressure test.

Pressure test – methods

New silos should be pressure tested by the silo supplier or manufacturer when completed on site. They should pass the Australian standard test (AS2628) to show they are sealable to a standard to allow for effective fumigations.

Sealable silos should then be pressure tested at least once a year to check for suitability for fumigations. Ideally pressure test when a silo is full of grain. This places grain pressure on all silo surfaces and outlets, which is the condition the silo is in when you are fumigating.

Pressure tests should not be conducted in the heat of the day, when the sun is heating the silo’s external steel surfaces and warming / expanding the air inside the silo. The pressure test results under these conditions are meaningless. Ideally test in the early morning before the silo is being warmed. A windy day is also difficult, as silo surfaces are pushed around. Hook up the digital manometer, or plastic tube manometer to the silo when the silo is fully sealed. This will quickly show if pressures inside the silo are stable. If stable, a reliable pressure test can be conducted to test the silo seal quality and for any leakage points.

For small silos the pressure tests can be carried out by using a short burst (5 – 15 seconds) from the small aeration fan fitted to the silo. For larger silos a portable leaf blower to push air into the silo via a fitted 50 mm port can be used to initially pressurise the silo for a test. The pressure decay (250-125 Pa) can be checked using one of three options - the silo’s oil bath relief valves, a length of 20 mm clear plastic tube in a “U” shape with water in it (manometer), or a digital manometer connected to the silo. See GRDC Fact Sheet: “Pressure testing sealable silos”. http://storedgrain.com.au/pressure-testing/

Common leakage points for large sealable silos

- Silo roof vents not sealing – maintenance or design problems.
- Silo grain fill point at top of silo not sealing – damaged rubber seals on lid, or sealing plate.
- Grain outload auger at base of silo – leaking seal plate.
- Bottom silo access manhole into silo - damaged seals, or poor design.
- Sealing plate covers for the aeration fan's intake, often poor design.
- External aeration fan ducting, or the aeration fan itself not well sealed.
- For all cone based silos, weight of grain in the silo can break the seal of the bottom outlet – poor design.

Fumigation recirculation – why is it important for fumigation of larger silos > 150 t

During fumigation, phosphine gas is typically liberated over 5-6 days from tablets or blankets that have been placed in the silo. This gas however only moves slowly, taking about 24 hours to travel 6m through grain.

If you are fumigating a medium to large silo (150 – 2000 t) the gas may take 2-5 days to reach all parts of the silo. In large silo fumigations this may result in some grain, at the furthest distance from tablets, only getting 6 days of phosphine gas instead of the required 10 days or longer exposure period. Six days is not enough time to kill all the life cycle stages of the pests.

One example of a typical phosphine fumigation required to kill all pests, is a minimum of 200 ppm phosphine gas concentration for at least 10 days. See horizontal blue line in Figure 4 below.

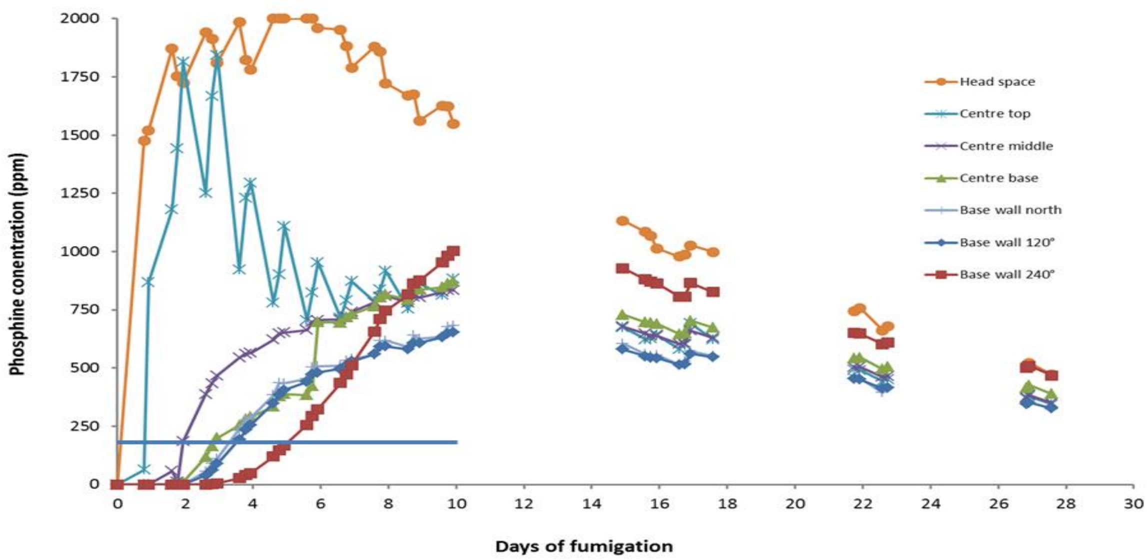

Figure 4. Phosphine gas concentrations at 7 points in a silo during fumigation of 1420 t of wheat. Phosphine blankets were placed in the silo headspace with no recirculation. It took as long as 5 days for all grain at the silo base to reached at least 200 ppm gas concentration.

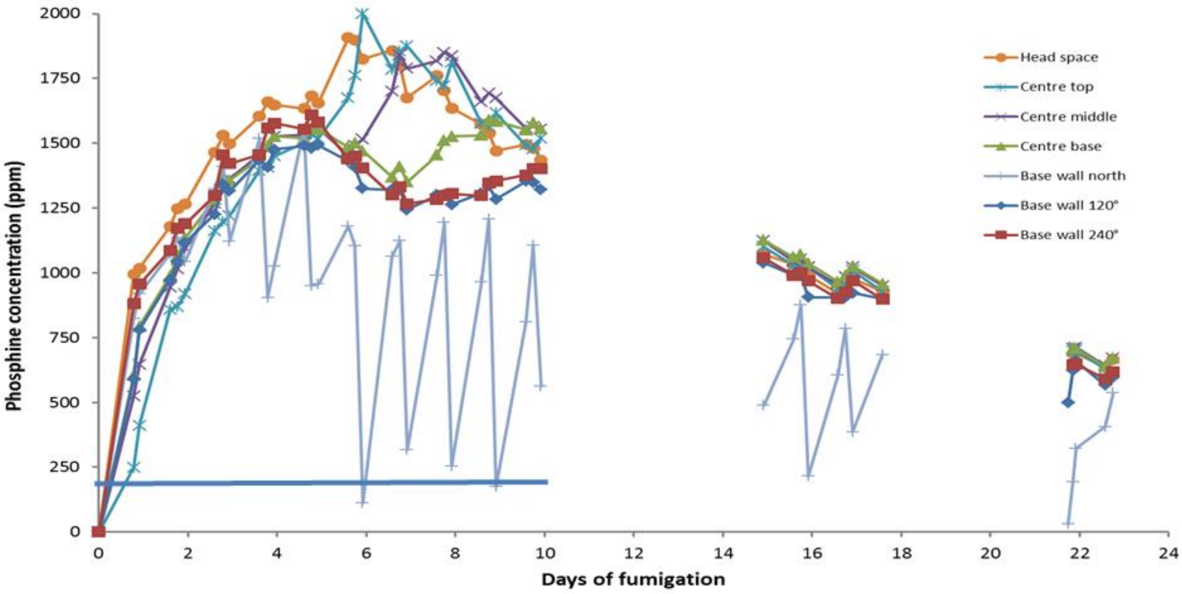

Figure 5. Phosphine gas concentations in a silo (1420 t wheat) where a small fan was used to draw gas from blankets in the silo headspace and pump it into the silo base via aeration ducts for the first 5 days of fumigation. Gas concentration in all areas of the silo reached over 800 ppm within the first 24 hrs.

Figure 6. A small fan (F370 – 0.37 kW) used during the first 5 days of fumigation to recirculate phosphine to give rapid uniform gas distribution in 1423 t wheat. See Figure 5.

Options for fumigation recirculation

- For all fumigation recirculation systems, the sealable silo needs to be gas – tight so there is no gas leakage during the fumigation. In Figure 4, "Base wall north" shows the impact of a leak at the silo manhole, causing large daily fluctuations in gas concentrations.
- Phosphine blankets or tablets can be placed in the 'silo headspace' along with a small fan connected to the headspace via 90 mm pipe plumbing coming down the silo wall from the

roof. Phosphine gas is drawn from the headspace and pumped into the base of the silo via both aeration ducts (see Figure 5).

- For ground level application of tablets or blankets, a sealable 'phosphine box' can be plumbed into this system, either a moveable box, or mounted permanently on each silo.
- Using a fan to force the phosphine gas movement around in silos during fumigation is generally recommended, rather than relying on a passive 'thermosiphon' approach. For medium and large silo fumigations, 150 t or greater, or silos storing smaller grain sizes (e.g. millets, canola, lentils etc.) that reduces air movement, fan force recirculation rather than thermosiphon is advised. Fan forced recirculation may also assist where the grain type (e.g. oilseeds) typically absorbs higher amounts of phosphine during fumigation.

Equipment for fumigation recirculation

- Sealable silo - gas tight, that passes a pressure test.
- Plumbing pipes (90 – 100 mm) from silo roof to ground level. Use quality pipe, fittings and seals that will ensure many years of safe, gas- tight fumigations.
- Small fan (e.g. Downfield F370 - 0.37 kW) to recirculate air. In most case this fan size will be suitable for both small & large silos. In trials (Fig. 4 & 5) this fan size provided a complete silo air change every 12 hours for the full silo holding 1420 t of wheat.
- Fittings for fan intake and outlet. Flexible hoses (50 – 100mm) couplings and gate valves.

Fumigation recirculation - operations

- Pressure test the silo to check for leaks.
- Follow all label directions and place tablets / blankets in the 'headspace' or 'phosphine box'.
- Run small recirculation fan for first 5 days of fumigation. Leave silo sealed for remaining days of fumigation exposure period as label requires (e.g. 7, 10, 20 days).

Notes

There are benefits to using the silo 'headspace' to locate the blankets or tablets. The large surface area of grain in the headspace provides safe, large easy access for liberated gas to penetrate and diffuse into the grain.

Licenced fumigators commonly choose to use 'gas' formulations of phosphine to undertake fumigations in large silos and other storage types, rather than using the solid phosphine formulations of blankets or tablets. An example is Cytec's ECO$_2$FUME® containing 20g/kg phosphine in carbon dioxide handled in 31 kg liquefied gas cylinders. While applying the full dose of phosphine gas on day one into a storage has benefits, in many cases the use of a recirculation systems is valuable to provide rapid, uniform gas concentration distribution throughout the storage.

Warning

Always seek advice from a suitably qualified professional before fitting fumigation recirculation systems to silos / storages. Some systems that are currently sold are not recommended because of unsafe design features. Phosphine is not only a toxic gas, but can be flammable and explosive if restricted in a small area, or used in a manner that causes gas concentrations to rise quickly to high levels. Follow label directions and seek advice.

Grain protectant sprays update

Warning

Grain protectant notes below 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.

When to use grain protectants

- Grain protectant sprays are not to be used to disinfest grain. When live insects are detected, fumigation in a sealed silo is required for effective control.
- Typically, protectant sprays are applied to clean cereal grain at harvest time as grain is augered into storages, providing storage pest protection for 3-9 months. Protectants are effective at controlling insects as they invade or emerge from eggs within grain during storage.
- With many domestic and export markets seeking grain supplies which are "pesticide residue free" (PRF), always talk to potential grain buyers / traders prior to applying grain protectant sprays.
- With the exception of some chlorpyriofs-methyl products in lupins in Victoria only, NO protectant sprays can be applied to pulses and oilseeds.

Common 'on-farm' uses for grain protectants

- Planting seed held on-farm – wheat, barley, oats.
- Grain held for an extended time in non-sealable storages (not suited for fumigation) and grain buyer has agreed to grain protectant use that is in line with directions for use on the registered product label.
- Grain held on-farm as feed for livestock with agreement from livestock agent or buyer and is in line with directions for use on the registered product label.

Grain protectant choices

Examples of two products, which include a partner product, to control the main storage pest species:

1. **Conserve Plus™ Grain Protector** – a.i. 100g/L spinosad, 100g/L s-methoprene. Used in combination with a compatible product such as chlorpyrifos-methyl (Reldan™), fenitrothion or deltamethrin

   For label and details on product use, see: http://www.conserveonfarm.com.au/en

   Recent key recommendations:

- Always add the OP partner to Conserve Plus so rice weevil (*Sitophilus oryzae*) is controlled.
- Spray equipment calibration and application care are critical to achieve correct dose and uniform coverage on grain.
- If treated grain is exposed to light, for example a semi open grain shed, cover the grain surface with a tarp or 80 - 90% shade cloth. Sunlight breaks down Conserve Plus over time
- Take care to read notes on the web site (above) and seek advice when purchasing Conserve Plus.

2. **K-Obiol® EC Combi**, synergised grain protectant – a.i. 50g/L deltamethrin, 400g/L piperonyl butoxide. Used in combination with an organophosate (OP) partner e.g. chlorpyrifos-methyl or fenitrothion.

   For label and details on product use, see: https://www.environmentalscience.bayer.com.au/K-Obiol/About%20K-Obiol

Key recommendations

- To control rice, maize and granary weevils (*Sitophilus spp.*) add a recommended partner (e.g. OP) to the tank mix.
- To ensure effective pest control and that MRL's are not exceeded, calibrate spray equipment and aim for even treatment / coverage on grain.
- Grower users are required to complete a brief (approx. 60 minutes) online training course to be an 'approved user' prior to purchase of K-Obiol® EC Combi. See above web site.

Insect resistant management

If possible, aim to rotate chemical active ingredients for storage pest control at your storage facility. An example, two years use of Conserve Plus™ product combination, followed by one or two years of K-Obiol® EC Combi.

Please read and follow all label recommendations and ensure that the product is registered for use in your state prior to application of any product.

Application for grain protectants

Grain protectant application requires care to achieve the correct dose and uniform grain coverage. This leads to effective pest control results and ensures MRL's are not exceeded. See Figure 7 below.

- Auger's grain transfer rate. Ensure you have good understanding of the grain flow rate, tonnes per hour, for the particular height the auger will be operating at.
- Calibrate your spray application unit with water and check appropriate nozzles and spray pressure are used to achieve the required application of 1 litre of spray mixture per tonne of grain.

Figure 7. Spray application equipment designed for good coverage by applying treatment at two points in the auger

Further information

GRDC booklet – Fumigating with Phosphine other fumigants and controlled atmospheres http://storedgrain.com.au/fumigating-with-phosphine-and-ca/

GRDC Fact sheet – Pressure testing sealable silos - http://storedgrain.com.au/pressure-testing/

A-Gas rural – ProFume® - https://www.agasaustralia.com/products-services/a-gas-rural-fumigation-supplies-services/products/profume/

GRDC video – Fumigation recirculation http://storedgrain.com.au/fumigation-recirculation/

Dow™ AgroSciences - Conserve Plus™ Grain Protector http://www.conserveonfarm.com.au/en

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

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Contact details

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

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Tall sorghum types in irrigation yielding 15 t/ha & IT sorghum. What's happening, when and with what agronomy?

Trevor Philp, Pacific Seeds

Contact details

Trevor Philp
Pacific Seeds
Mb: 0427 568 517
Email: trevor.philp@advantaseeds.com

Notes

Sorghum and maize – avoiding yield loss to heat at grain fill through agronomy and changing the sowing window

Loretta Serafin, Mark Hellyer, Annie Warren and Andrew Bishop, NSW DPI

Key words

grain sorghum, maize, time of sowing, hybrid selection, plant population, sowing depth

GRDC code

DAN00195 Tactical sorghum and maize agronomy in the Northern Region

Call to action/take home messages

Sorghum

- Sorghum emerged in 2017 at cold soil temperatures (~ 8°C at Breeza) but establishment percentages were low. The first time of sowing (TOS1) was 57% of the established population of the third time of sowing (TOS3).
- Plants were still emerging 47 days post sowing of the very early sowing time (TOS1).
- The very early and early sowing times (TOS 1 and 2) resulted in patchy, uneven plant stands which were more prone to weed competition.
- The very early and early sowing times did not achieve the target plant population of 50,000 plants/ha.
- Sowing deeper (~7-8 cm) resulted in higher establishment losses compared to the shallow sowing.
- There were differences in the establishment between hybrids, however these were often not consistent across sites and times of sowing.
- High quality seed; germination and vigour; is required to achieve the best results - especially under colder soil temperatures.

Maize

- Maize establishment in 2017 was delayed at TOS 1 and 2 by sowing into cold soil temperatures (~ 8°C and ~10°C at the Breeza site) but final plant populations were comparable to sowing into warmer soil temperatures.
- There was no difference in the establishment of the three hybrids in this experiment.

Introduction

Recent summer seasons have exposed dryland sorghum and maize crops in northern NSW to extreme climatic events of heat and moisture stress resulting in reduced grain yields, sometimes total crop failure and poor grain quality.

As a result, alternatives to the conventional sorghum and maize production systems are being sought. There is a need to move the critical stages of flowering and grain fill away from the late December/early January timeframe to avoid the high likelihood of extreme temperatures in this period.

In order to minimise the impact of these heat stress events, several tactics which growers could readily adopt into their current farming systems were evaluated in these experiments.

They were:

- To sow earlier, into soil temperatures lower than the current commercial recommendations of 16-18°C for sorghum and 12°C for maize.
- Develop new information on the tolerance of hybrids to cold sowing to assist in early sowing.
- Sow deeper into warmer, more stable soil temperatures.

Research methods

2017/18 season, experiments were sown in three dryland locations in northern NSW using a Monosem precision planter.

Establishment counts were conducted 5 - 7 days after sowing and then at weekly intervals until plant emergence had ceased. Days to flowering and plant cuts were taken at physiological maturity to provide biomass and harvest index information.

At the time of writing, the experiments had not yet reached harvest. However, all experimental sites will be harvested and grain yield and grain quality parameters measured.

Sorghum experiments

In the 2017/18 season three dryland experiment locations were conducted:

Sorghum		**Time of sowing (TOS) and date**			**Row spacing**
Region	**Location**	**TOS 1**	**TOS 2**	**TOS 3**	
Liverpool Plains	Liverpool Plains Field Station	10th August	28th August	21st September	1.0 m solid
Moree East	Gurley	2nd August	21st August	17th October	1.0 m solid
Moree West	Mallawa	1st August	24th August	18th Oct	1.5 m solid

The experiments included three factors:

1. Time of sowing

The time of sowing was determined based on target soil temperatures to capture very early sowing, early sowing and commercial standard. The soil temperature data used was measured at 8am Eastern Daylight Saving Time (EDST) at depths of 3 and 7 cm. Soil temperature loggers were used at each site. The targeted soil temperatures were:

a. Very early - 10°C

b. Early - 14°C

c. Conventional - 16-18°C

2. Seeding depth

Two seeding depths were included to evaluate if sowing deeper would provide warmer, more stable soil temperatures to improve crop establishment.

a. Shallow – 4 cm

b. Deep – 7-8 cm

3. Hybrid selection
    a. 9 hybrids: MR Buster, MR Apollo, 85G33, Cracka, Tiger, Agitator, Archer, HGS102, HGS114.

The sorghum experiments were sown targeting a plant population of 50,000 plants/ha.

Maize experiments

Three maize experiments were conducted in the 2017/18 season and included three factors:

Maize		Time of sowing (TOS) and date			Row spacing
Region	**Location**	**TOS 1**	**TOS 2**	**TOS 3**	
Liverpool Plains	Liverpool Plains field station	9th August	29th August	20th September	1.0 m solid
Moree East	Gurley	31st July	22nd August	17th October	1.0 m solid
Moree West	Mallawa	1st August	24th August	18th October	1.5 m solid

1. Time of sowing

The time of sowing (TOS) was based around target soil temperatures to simulate early sowing, commercial standard and late sowing. Soil temperature loggers were used at each site.

    a. Early - 10°C
    b. Conventional - 14°C
    c. Late - 16-18°C

2. Plant population – four target plant populations
    a. 15,000 plants/ha
    b. 30,000 plants/ha
    c. 45,000 plants/ha (Mallawa and Gurley only)
    d. 60,000 plants/ha
    e. 120,000 plants/ha (Breeza only)

3. Hybrid selection

Three hybrids were selected as examples of certain plant types. These plant types were either prolific (producing tillers with cobs), non-prolific multi cobbing (no tillers but potential for more than one cob on the main stem), non-prolific single cob with flex (where yield compensation is usually gained through a longer cob). Medium maturity hybrids were selected with a similar maturity or Corn Relative Maturity CRM.

The three hybrids used in these experiments were selected based on their differing plant types:

Hybrid	Plant type	CRM	End Use
Pioneer - 1467	Prolific - tillers with cobs	114	Silage and grain
Pioneer - 1756	Main stem, multiple cob	117	Processing (grit, feed, silage)
Pacific Seeds - 606IT	Main stem, single cob	114	Silage/ grain

Results

Sorghum

Time of sowing

Sorghum establishment was very slow for both TOS 1 and 2. There were no plants emerged until 30 days after sowing (DAS) for TOS 1 and 23 DAS for TOS 2. At the last establishment count, 47 DAS, the established plant population for TOS 1 was only 57% that of TOS 3. The targeted plant population of 5 plants/m^2 or 50,000 plants/ha was achieved by 23 DAS for TOS 3 only (Table 1).

Table 1. Sorghum plant establishment (plants/m^2) at Breeza research station (averaged across hybrids)

	Days after sowing (DAS)						
TOS	**5**	**14**	**23**	**30**	**37**	**42**	**47**
1	0.0	0.0	0.0	0.2		2.2	2.8
2	0.0	0.0	1.6	2.7	3.3	3.4	
3	0.0	4.2	5.4	4.9			

Sowing depth

There was a difference in soil temperature between the deep and shallow depths. On average across all sites, it was 0.6°C warmer at the deeper sowing depth.

At all three sites the plant establishment was better from the shallow sowing depth of 4-5 cm, compared to the deep sowing depth of 7-8 cm. This result was consistent across each of the sowing times, demonstrating that even under warm soil temperatures, there was still a reduction in establishment as a result of the deeper sowing depth. Seedbed moisture also needs to be considered as the soil dries out faster at the shallow depth. At the Breeza site only, an irrigation flush was applied prior to sowing to ensure even seed bed moisture. The temperatures at Breeza were lower compared to the other two sites.

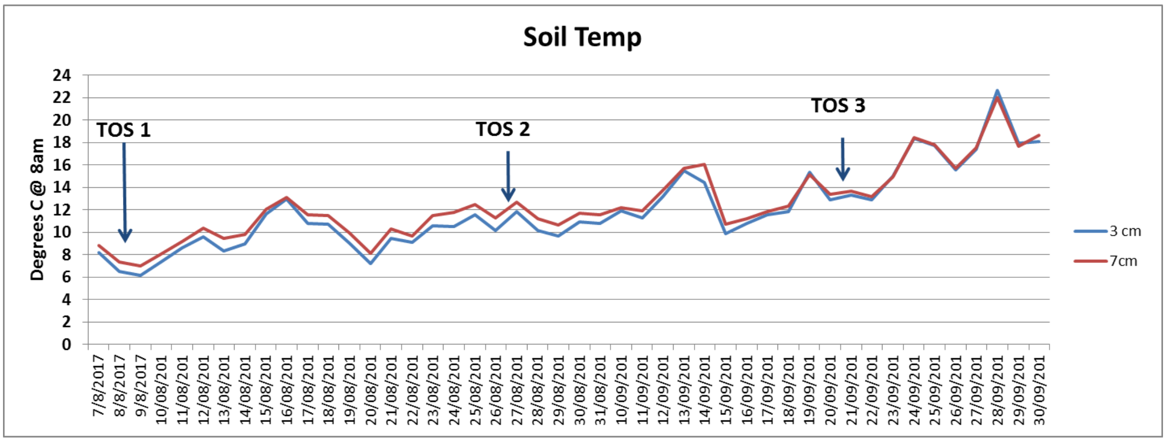


Figure 1. Soil temperatures at Breeza in 2017 (sowing dates indicated by arrows)

There was no statistical difference in the time taken to emerge based on the weekly assessments. The results from the Breeza site only are contained in Table 2.

Table 2. Impact of sowing depth on sorghum establishment (plants/m^2) at Breeza research station

		Days after sowing						
TOS	**Seed depth**	**5**	**14**	**23**	**30**	**37**	**42**	**47**
1	**Shallow**	0.0	0.0	0.0	0.2	-	2.5	3.0
	Deep	0.0	0.0	0.0	0.3	-	1.8	2.6
2	**Shallow**	0.0	0.0	2.3	2.8	3.7	3.8	-
	Deep	0.0	0.0	0.8	2.6	2.8	3.0	-
3	**Shallow**	0.0	4.5	5.6	4.8	-	-	-
	Deep	0.0	3.9	5.2	5.0	-	-	-

Hybrid selection

The nine sorghum hybrids used in these experiments established differently. The results were not always consistent across all three sites. The data from Breeza has been shown below (Figure 2) for a selection of four hybrids. Two hybrids, MR Buster and MR Apollo, from Pacific Seeds showed no variation between each other. In contrast, the two hybrids from Nuseed, Cracka and Tiger, behaved differently at the two colder sowing times, TOS 1 and TOS 2. Cracka established more plants and quicker than Tiger.

These are preliminary observations from this site which need to be considered in the context of seed quality e.g. germination and vigour differences could explain some or all of this variation. As such a pot trial is being conducted in unison with these field experiments to gather more detailed information on temperature, emergence and the influence of seed quality.

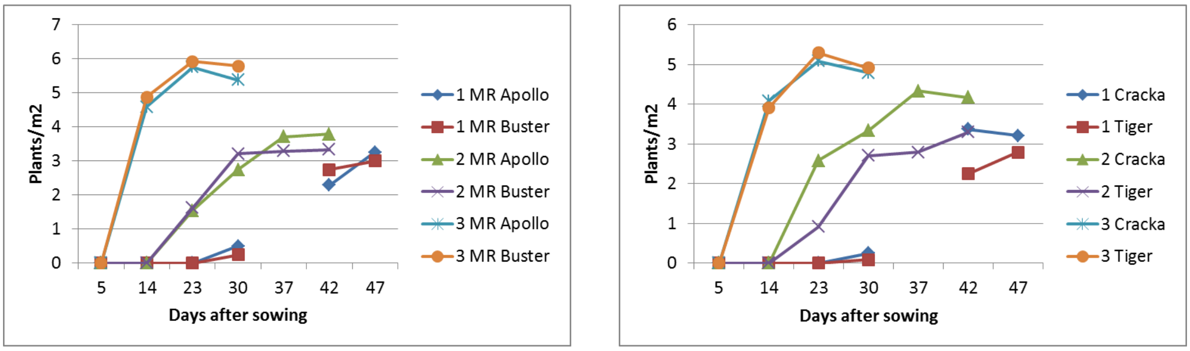
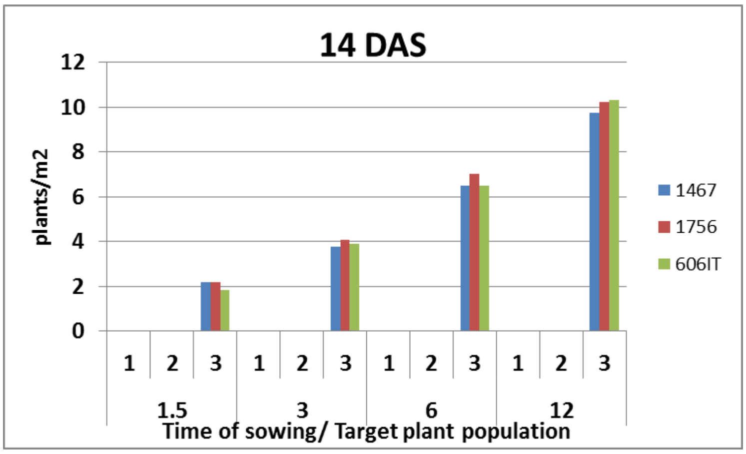


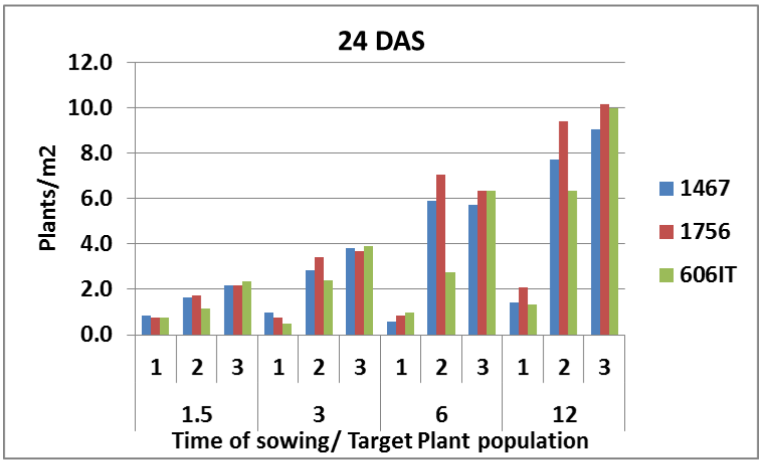
Figure 1. Plant establishment of varying sorghum hybrids at Breeza

Maize

Time of sowing

There were no plants emerged until 7 DAS from each of the three sowing times. TOS 3 emerged rapidly between 7 and 14 days post sowing to reach the target plant populations, with the exception of the highest population. There was a significant delay in plant establishment for TOS 1 and 2 until 24 DAS, at which point the established populations were not significantly different between the three times of sowing (Figure 3). Plants were still emerging at 30 DAS from TOS 1.





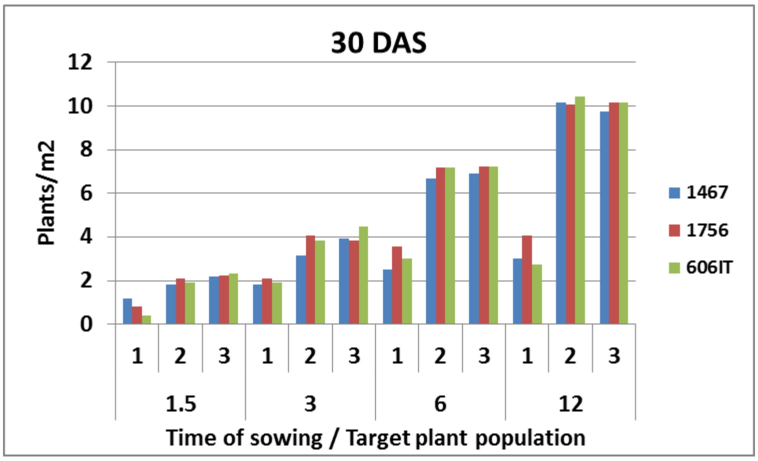


Figure 3. Maize establishment –clockwise from top left a) 14DAS, b) 24DAS, c) 30DAS

Hybrid selection

The three hybrids all established well within their target plant population categories. As such no major differences in hybrid populations were present by the last time of counting at 42 DAS.

Plant population

The final plant populations were higher than the targeted plant populations for the 15, 30 and 60,000 plants/ha populations. However, the 120,000 population was not achieved The final established population was 84,000 plants/ha averaged across treatments.

Discussion

At the time of writing, these 2017/18 season experiments had not yet been harvested so data relating to grain yield and quality was not available. This information will ultimately assist in the discussion of whether any of these tactics; hybrid selection or type, sowing depth, sowing time or plant population can assist growers to avoid the impact of heat at flowering and grain fill.

Sorghum

Grain sorghum was able to be established at much lower temperatures than is commercially recommended, however there are other issues to be considered before adopting this approach commercially.

1. Delayed/slow establishment

TOS 1 resulted in a much slower emergence than the industry standard of TOS 3. Plants were still emerging 7 weeks post sowing. The growth of plants in this first 4-6 weeks was substantially delayed by the cold conditions and some plant losses were seen. Overall, plants were observed to be small, pale coloured or purple and suffering from ill thrift.

2. Reduced establishment percentages

When comparing across the three times of sowing, it can be seen that final established populations for TOS 1 and 2 never reached the same levels as TOS 3. In essence this means a large wastage in terms of seed costs to a grower; seeds which were sown but never emerged.

3. Lack of uniformity in plant stands

Due to the slow and reduced establishment in TOS 1 and 2, the plant stands contained more gaps and irregular spacing compared to TOS 3. This led to additional opportunities for weeds to emerge in these gaps and makes crop management decisions more difficult if the plant maturity is staggered.

4. Weed control

The slow and patchy emergence which resulted from TOS 1 and 2 meant an opportunity for weeds to emerge in the gaps. While pre and post emergent herbicide options were incorporated in these experiments, weeds still needed to be controlled by chipping in the experimental plots to remove any confounding effects of weed competition.

Maize

The effects of the colder sowing were much less evident in maize than in sorghum. Based on current agronomic recommendations for a colder soil temperature for maize compared to sorghum, this result is not surprising.

Hybrid selection

The three hybrids were selected based on varying plant types. These three plant types are being used as indicators of the potential for maize to be manipulated to improve reliability and yield, particularly in the less favourable maize growing environments such as west of Moree.

The synchronisation of tassels and silks is critical to ensure seed set. Moisture stress and heat at flowering are two of the most important influences on these plant processes.

There are several different theories relating to plant types:

1. Plants with tillers allow more flexibility to respond to changing climatic conditions as the flowering time is spread over a longer period. Hence if poor seed set occurs on the primary stem cobs, then hopefully the tiller cobs can compensate.
2. Tillers use valuable moisture and nutrients and never contribute significantly to grain yield.

3. Plants with one cob only on the main stem have the greatest likelihood of producing the highest yield and quality (e.g. seed size)
4. Plants with multi cobbing properties allow for more of the top end yield potential to be captured in favourable seasons.

Conclusion

The inclusion of final plant, grain yield and quality data from the three trial sites will add significant information to allow interpretation of the value of these treatments. It is important to consider that this data is only from one season so additional years data will add to the value of this dataset.

Acknowledgements

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

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Contact details

Loretta Serafin
NSW Department of Primary Industries
4 Marsden Park Road Calala NSW 2340
Mb: 0427 311 819
Email: Loretta.serafin@dpi.nsw.gov.au

Sunflower agronomy – manipulating the crop for best yield and oil content outcomes. Which leaves contribute the most to yield and oil?

Loretta Serafin, Mark Hellyer and Neroli Graham, NSW DPI

Key words

sunflower, leaves, yield, oil content

GRDC code

DAN00197 Tactical crop agronomy for selected crops in the northern region (safflower, linseed, sunflower)

Call to action/take home messages

- The removal of all leaves from a sunflower plant at the start of flowering or at petal drop had the greatest impact on grain yield (80% and 65% respectively).
- Oil content was most affected (reduced by 13% compared to the control) by removing the top 2/3 of leaves at budding.
- Retaining the top 2/3 of sunflower leaves at budding, start of flowering and petal drop can prevent potential significant reductions in yield of 49, 40 and 35% respectively.
- Loss of the bottom one third of sunflower leaves did not affect grain yield or oil content at budding or the start of flowering.
- Based on the data obtained it is suggested that the middle 1/3 of leaves on a sunflower plant may contribute the most to grain yield.

Introduction

Sunflower plants have the ability to produce a large amount of leaf area; in the order of 2- 6,000 cm^2/plant, largely depending on soil moisture and plant nutrition. Maximising a sunflower crop's grain yield and oil content is paramount to ensure maximum economic returns. However, critical information on how many of and which leaves make the greatest contribution to grain yield and oil content has been missing.

Several factors such as hail, insect damage (e.g. heliothis or loopers) and diseases (e.g. alternaria and powdery mildew) have the potential to reduce leaf area. Insects and diseases can be managed through chemical application; however, we need to be able to confidently make decisions around which leaves to protect in order to obtain the best return on our investment in chemical and application costs.

Sunflowers have a growth and development scale similar to one of the Zadok based systems used in cereals. In sunflowers, the vegetative stages are given the preceding letter "V" and then the leaf number, e.g. V6 means the 6th leaf stage. The reproductive stages; from bud initiation are preceded by the letter "R". The reproductive stages are measured on a scale of 1 – 9.

Three growth stages are referred to in this paper:

1. R2: when the flower bud is 0.5-2.0 cm above the nearest leaf attached to the stem; commonly called budding or bud initiation
2. R5.1: the start of flowering
3. R6: when flowering is complete and the ray flowers (large petals surrounding the head) are wilting; commonly called petal drop.

Treatment timings were selected based on their importance in sunflower growth stages. Bud initiation is when the final leaf number is present and from this point onwards, leaves will continue to unfold and expand but no new leaves will be formed. A plant develops about 50% of its total leaf area by the start of head development and more than 75% by the start of flowering (Warmington, 1981). At bud initiation (R2), plants also make critical decisions on the maximum number of florets (and potential seed number) to be produced. Flowering (R5) is an important stage to ensure florets are fertilised to start the process of developing seeds (the hull and kernel) and R6 corresponds with the end of flowering and roughly the start of kernel development.

Previous research has found that in a plant's vegetative stages, most assimilates produced by photosynthesis are directed towards development of the plant's root system. While after bud initiation, the plant diverts assimilates towards the top of the plant for the developing head (Merrien, 1986). The retention of leaves is important, as a reduction in the photosynthetic area means a reduction in the amount of photosynthate available to the developing sunflower seeds.

Younger leaves, which are higher up the plant, have better access to light. As such there is also an age relationship to photosynthetic capacity. Therefore, bottom leaves, which senesce earlier are thought to have less impact on photosynthetic capacity, when compared to the middle and top leaves.

Since we are targeting higher yields and oil content, in this research we focused on leaf contribution at three of the reproductive growth stages; budding, flowering and petal drop.

Research methods

A series of five experiments were conducted between the 2014/2015 and 2016/2017 seasons in northern New South Wales. The single site/year experiments were conducted at "Boonery Park" (Curlewis) in 2016/2017, "Kyntyre" (Gurley) in 2015/2016, "Parraweena" (Blackville) in 2016/2017 and "Windy Station" (Pine Ridge) in both 2014/2015 and 2015/2016.

Each site/year experiment was designed as a randomised complete block design with three replicates. The monounsaturated hybrid Ausigold 62 was used in each of the experiments. Plots were sown with a Monosem precision planter and harvested with a KEW small plot header.

Grain yield (t/ha), oil content (%), oil yield (kg/ha), plant height (cm), test weight (kg/hL), thousand seed weight (g), head arc length (cm) and head diameter (cm) were measured at a selection of the single site/year experiments.

Twelve leaf removal treatments were used across each of the trials. These were targeted at 3 key growth stages; budding (R2), start of flowering (R5.1) and petal drop (R6). Each experiment included a control treatment where all leaves remained in-tact plus eleven leaf removal treatments which involved removing 10 leaves from various parts of the plant, e.g. top, middle or bottom and referred to as top 1/3, middle 1/3 or bottom 1/3.

As sunflower plants typically produce between 30-40 leaves, the 10 leaves removed were equivalent to removing around 1/3 of plant leaves. Treatments were a combination of growth stage and the section on the plant where the leaves were removed from, e.g. the bud 2/3 treatment had the top 20 leaves removed at budding. The treatments were imposed by cutting off the leaf with secateurs, but leaving the leaf petiole (leaf stem) in-tact.

Results

The final grain yield and oil content varied significantly between the five site/years. Grain yields when averaged across the leaf removal treatments ranged from over 1 t/ha at "Windy Station" in each year, to a low of 0.22 t/ha at "Boonery Park" in 2016/2017 (Table 1). However, when plant material was removed from the bottom third of leaves at budding in 2014/2015 at "Windy Station" the yield exceeded 2.0 t/ha.

When averaged across treatments, oil content of the harvested seed was highest at "Windy Station" and "Kyntyre" in 2015/2016 with 42.7 %, while the other three trial sites/years were below the accepted grain receival standard of 40 % (Table 1).

The difference in seed yields and oil content between sites/years was due in part to variable environmental conditions, over the three years.

Table 1. Seed yield at 9 % moisture (t/ha) and oil content (%) for the five site/years when averaged for leaf loss treatments at three growth stages.

Site/Year	Year	Grain Yield (t/ha)	Oil Content (%)
Windy Station	2014/2015	1.04	39.6
Kyntyre	2015/2016	0.23	42.7
Windy Station	2015/2016	1.05	42.7
Parraweena	2016/2017	0.63	39.8
Boonery Park	2016/2017	0.22	37.1
l.s.d. $_{(P=0.05)}$		0.3	2.0

The leaf removal treatments affected grain yield, oil content, grain quality and plant characteristics within the five sunflower experiments.

At the budding stage, the reduction in yield corresponded to the number of leaves removed. Removing 1/3 of leaves reduced yields by 17%, removing the top 2/3 of leaves reduced yields by 49% and removing all the leaves reduced yields by 71%. There was no impact on grain yield when the bottom 1/3 of leaves were removed during this stage of development

At budding, the impact of leaf loss on oil content was only apparent when 2/3 of the leaves were removed. This resulted in a 13 % loss in oil content and a reduction in oil levels from 41.4 % in the control, to 37.4 % (Table 2)

Removing leaves at the start of flowering resulted in a 40% yield loss when the top 2/3 of leaves were removed and an 80 % yield loss when all leaves were removed. There was no impact on yield when the top or bottom third of leaves were removed at the start of flowering.

The impact of removing the bottom 1/3, top 1/3 and top 2/3 of leaves on oil content was negligible, (>1 %) when compared to the control (Table 2). In contrast, removing all leaves reduced oil content by 9 % (Table 2).

When the leaves were removed at the petal drop growth stage, the impacts on grain yield had started to diminish compared to the start of flowering, but were still very large. Similar to the start of the flowering growth stage, removing the top 1/3 of leaves at petal drop did not impact on grain yield. There was significant loss in yield when the top 2/3 or all leaf matter was removed, with 35 % and 65 % losses respectively.

When all of the leaf material was removed at petal drop, the oil content was 39.3 %, which was lower than the receival standard of 40 %, as well as 5 % less than the control (41.4 %) (Table 2).

There were additional impacts on grain quality resulting from the defoliation treatments. Test weight was reduced by removing the bottom 1/3 of leaves at budding and by removing all of the leaves at both the start of flowering and petal drop stages. However, all treatments still remained well above the 32 kg/hl minimum trading standard (Table 2).

Thousand grain weights also showed a reduction of 22 - 24 % resulting from the total leaf defoliation treatments for each of the three growth stages (Table 2). There was no impact on thousand grain weight when the bottom 1/3 of leaves were removed at budding or flowering.

Table 2. Seed yield at 9 % moisture (t/ha), oil content (%), test weight (kg/HL) and thousand seed weight (g) for the five site/years for leaf loss treatments at three growth stages.

Treatment	Grain Yield (t/ha)	Oil Content (%)	Test weight (kg/HL)	Thousand grain weight (g)
Bud 1/3	0.75	41.8	39.6	40.4
Bud 2/3	0.46	37.4	38.8	37.9
Bud bottom 1/3	0.98	40.5	37.5	43.1
Bud Total	0.26	41.0	42.1	32.9
R5.1 1/3	0.89	41.5	39.0	39.8
R5.1 2/3	0.54	41.1	40.4	36.7
R5.1 bottom 1/3	0.90	40.8	40.1	42.3
R5.1 Total	0.18	37.7	36.6	33.8
R6 1/3	0.86	40.9	38.9	39.1
R6 2/3	0.58	41.3	39.0	37.8
R6 Total	0.32	39.3	36.6	33.6
Control	0.91	41.4	39.5	43.3
l.s.d $_{(P=0.05)}$	0.13	0.9	1.4	2.4

The removal of leaves also affected other plant characteristics such as head size, measured as head diameter and the length across the front arc. Head diameter was reduced to 9.5 cm and 5.3 cm, a reduction of 38 % and 65 % when defoliation occurred on the top third or bottom third of leaves at budding, respectively. Smaller head size occurred after loss of one third of leaf material. Head diameter reduction also occurred when defoliation occurred during seed development. The reduction in head diameter was smaller as the growth stages progressed (data not shown) towards plant maturity.

The only impact on plant height occurred when leaves were removed at budding, the earliest stage of growth, where either the top 2/3 or total leaves were removed. (data not shown).

Discussion

Defoliation through leaf removal mimics the effect of insect infestation, disease pressure or hail damage through the reduction in healthy leaf material. The reduction in leaf material can result in a reduction in energy production (and therefore stored energy sources) which may lead to reduced yield and oil contents, as well as impacting on grain quality and other plant characteristics.

The removal of plant material significantly decreased grain yield at each of the three growth stages, with the largest reduction resulting from total leaf loss at the start of flowering (80 % yield reduction).

The experiment did not include a treatment where the middle third of leaves were removed, so the impact of these leaves cannot be accurately reported. However, comparison of the losses resulting from the removal of the top 1/3 of leaves compared to the removal of the top 2/3 of leaf material, suggest that the middle 1/3 of leaves on the plant have the overall greatest impact on yield.

For example, the loss of the top third of plant material at budding resulted in yield loss of 0.16 t/ha or 17 %, while the loss of the top 2/3 of leaves at budding resulted in a 49% yield loss (Table 2). Therefore it could be suggested that the difference between these two treatments which was 32 %, could be attributed to the middle 1/3 of leaves.

Further removing the top 1/3 of leaves at the start of flowering or petal drop did not have a significant impact on yield, which adds to the evidence suggesting the top 1/3 of leaves do not contribute as much to yield.

As the amount of leaf material removed increased; from 1/3, 2/3 or all of the leaf material; the grain yield and oil content also reduced. At bud development, grain yield reduced by 17 % to 49 % to 71 %, compared to the control when 1/3, 2/3 or all leaf material was removed, respectively.

Increased intensity of leaf removal from one third to two-thirds' up to all leaf material resulted in increased yield and oil yield loss at each of the three timings of plant material removal. Early in bud development there was a reduction from 17 % to 49 % to 71 %, when compared to the control for one third, two-thirds', all leaf material, respectively. In addition, there was a similar trend in oil content when plant material was removed. When all leaves were removed from plants at each of the three stages, oil content was reduced when compared to the control (or no plant removal).

Grain test weight and thousand grain weight were also affected by leaf removal treatments; however the impact on test weight was not sufficient to result in an economic impact to growers by lowering the receival grade.

Head diameter and arc lengths were reduced when a higher proportion of leaf material was removed. Loss of all leaf material during bud formation reduced the size of the head diameter from 15.4 cm to 5.3 cm.

Conclusions

Leaf loss in sunflower crops can cause loss in yield and oil content. Loss of plant material could be caused by insect infestation, disease pressures or hail damage throughout the growing season. Any reduction in plant material has the potential to negatively impact carbohydrate production (through the loss of leaf material, for example) as well as energy stores (through losses in the stem and head of the plant).

The timing of leaf loss and the amount of leaves lost, markedly affects yield and oil content and also affects physical attributes such as plant height, head diameter and arc length.

The largest reductions in yield resulted from removal of all leaf material, however this is an unlikely event in most crop situations. It is more likely that a proportion of the leaves will be removed through disease, insect or environmental impacts.

Where management and maintenance of the leaves of a sunflower plant is possible (such as insect or disease management), the results of this research suggest that growers and advisors should be careful to maintain the middle 1/3 of leaves on the sunflower plant. Removing the top 1/3 of leaves had a significant impact on grain yield at the budding stage (17 % yield reduction), however, no impact was recorded when the top 1/3 of leaves were removed at the start of flowering or petal drop.

Oil content was mainly affected by the removal of the top 2/3 of leaves at the budding stage. Surprisingly, there was little impact on oil content from removal of the top 1/3 or 2/3 of leaves at the start of flowering or petal drop growth stages, which are closer to when oil content develops in the kernel. However, removal of all leaves (at both the start of flowering and petal drop) did have a major impact on reducing oil content by 9 % and 5 % respectively, in comparison to the control.

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Ridge. Thanks also to their advisors; Gavin McDouall, Jim Hunt and Peter McKenzie for their assistance with the sites. Thanks to Nuseed for supplying the Ausigold 62 seed utilised in the trials.

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Contact details

Ms Loretta Serafin
NSW Department of Primary Industries, Tamworth
4 Marsden Park Road, Calala, NSW, 2340
Mb: 0427 311 819
Email: Loretta.serafin@dpi.nsw.gov.au

Soil water, risk management and sowing decisions in the Liverpool Plains

Daniel Rodriguez and Peter de Voil, UQ/QAAFI

Key words

dryland cropping, APSIM modelling, seasonal climate forecasting, sowing decisions, soil water, risk, sorghum;,Liverpool Plains

GRDC code

UQ00074, UQ00075

Call to action/take home messages

- In sorghum, understanding how to match hybrids and management to site and expected seasonal conditions can increase yields by up to 60%.
- In environments yielding less than 5 t ha^{-1}, the highest treatment yields were observed with low tillering hybrids sown in solid configurations, and plant populations between 50 and 60k pl ha^{-1}.
- In environments yielding more than 5 t ha^{-1} plant density and the yield potential of the hybrid were the most important variables discriminating between low and high yields.
- When linked to APSIM, results showed that BOM's POAMA-2 forecasts showed higher skill than the SOI phase system. Based on this it is suggested that the SOI phase system shouldn't be used anymore.
- When current growers' practice was used as the baseline, information from linking APSIM sorghum and POAMA-2, could be used to increase average profits by 143 AU$ ha^{-1} and reduce or even eliminate down side risk. When the baseline for the comparison was a higher farmer investment strategy than normal practice, the actual value of the additional climate information was on average 17 AU$ ha^{-1}, which compares to the benefits derived from Australia's sorghum breeding over the last thirty years i.e. 2.1% per year, or 44 kg ha^{-1} $year^{-1}$. Clearly the largest value of these tools is in informing risk aversion in dryland cropping. Though no tools are available for growers as yet in the northern grains region. This should be considered a priority.

In rainfed cereal crops, yield gain over time has been the result of improvements in hybrids (G), improvements in management (M), improvements in the cropping system (CS), and their interactions (GxMxCS). Future improvements in growers practice need to focus on informing GxMxCS combinations that best fit site and expected seasonal conditions that maximise profits and minimise risks.

In Australia's northern grains region, climate variability presents growers with challenges, but also the opportunity to match hybrids and agronomy to match site, as well as prevailing and expected seasonal conditions. Water and nitrogen availability at planting together with expected in crop rainfall, all contribute to the final yield result. Some of these variables are known or could be known if measured before planting, others, e.g. seasonal climate forecasting, require specialised training packages for growers and advisers. Here we discuss growers' opportunities to inform how to match hybrid and agronomy to site and seasonal conditions at the time of sowing.

Over the last three years results from UQ00074 and UQ00075 demonstrated that the largest opportunity to manage stresses, increase profits and reduce risks in rainfed cropping, is to inform optimum combinations of hybrids and management options for specific sites and expected seasonal conditions. This is shown in Figure 1, which summarises results from on farm and on research station trials (n=15) run between 2014 and 2017 from the Liverpool Plains to Central Queensland. Trials consisted of combinations of hybrid i.e. most commercial hybrids, plant density, and row configuration. The combined dataset from NSW and Qld included results from more than 1960 individual plots.

Figure 1 shows that, (i) average site sorghum yields (x axis) varied between almost zero to more than 6t ha^{-1} (dry basis) across sites (environments); (ii) for any given yield environment (x axis) the yield difference between the highest and lowest treatment yield (y axis) i.e. obtained from the best and worst combination of hybrid and management, was up to 60% (Fig 1a); and (iii) that the yield differences between the best and worst combination of hybrid and management translated into a six-fold change in water use efficiency, from 2 to more than 12 kg mm^{-1} ha^{-1} (Fig 1b).

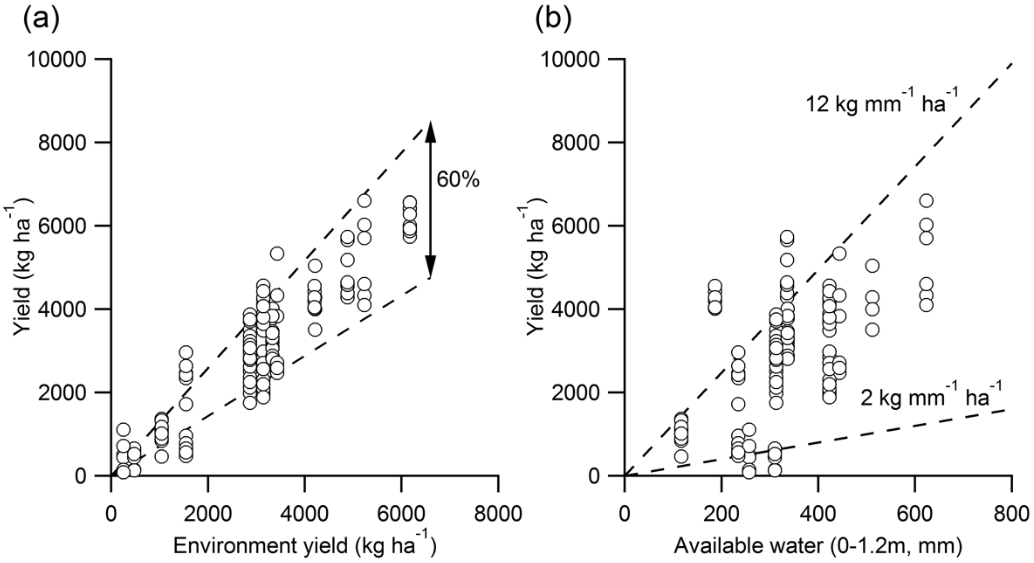

Figure 1. Treatment mean yield (y axis) versus environment yield (x axis) i.e. mean of site yield from all the treatments (a), and (b) relationship between treatment means and available water estimated as soil moisture at sowing (0-1.2m) plus in crop rainfall and added irrigation (if any).

Simple rules of thumb

The data in Figure 1 was further analysed to derive simple rules of thumb to help match hybrids and agronomy to expected yield environments. For the analysis, we only used data from sites that showed average yields larger than 2.5t ha^{-1}. The combined data set then was reduced to 488 treatment means i.e. combinations of hybrids, row configurations, densities, sites and seasons. The median yield for the data set was 5.3 t ha^{-1} with minimum and maximum treatment yields of 1.7 (rainfed) and 7 t ha^{-1}, respectively. Note that fully irrigated crops grown on research station trials at Gatton yielded over 12 t ha^{-1}.

Simple rules were then derived for higher yielding environments (sites with average yield higher than 5.3 t/ha), and lower yielding environments (sites that yielded less than 5.3 t/ha). The results of the analysis are shown in Figure 2.

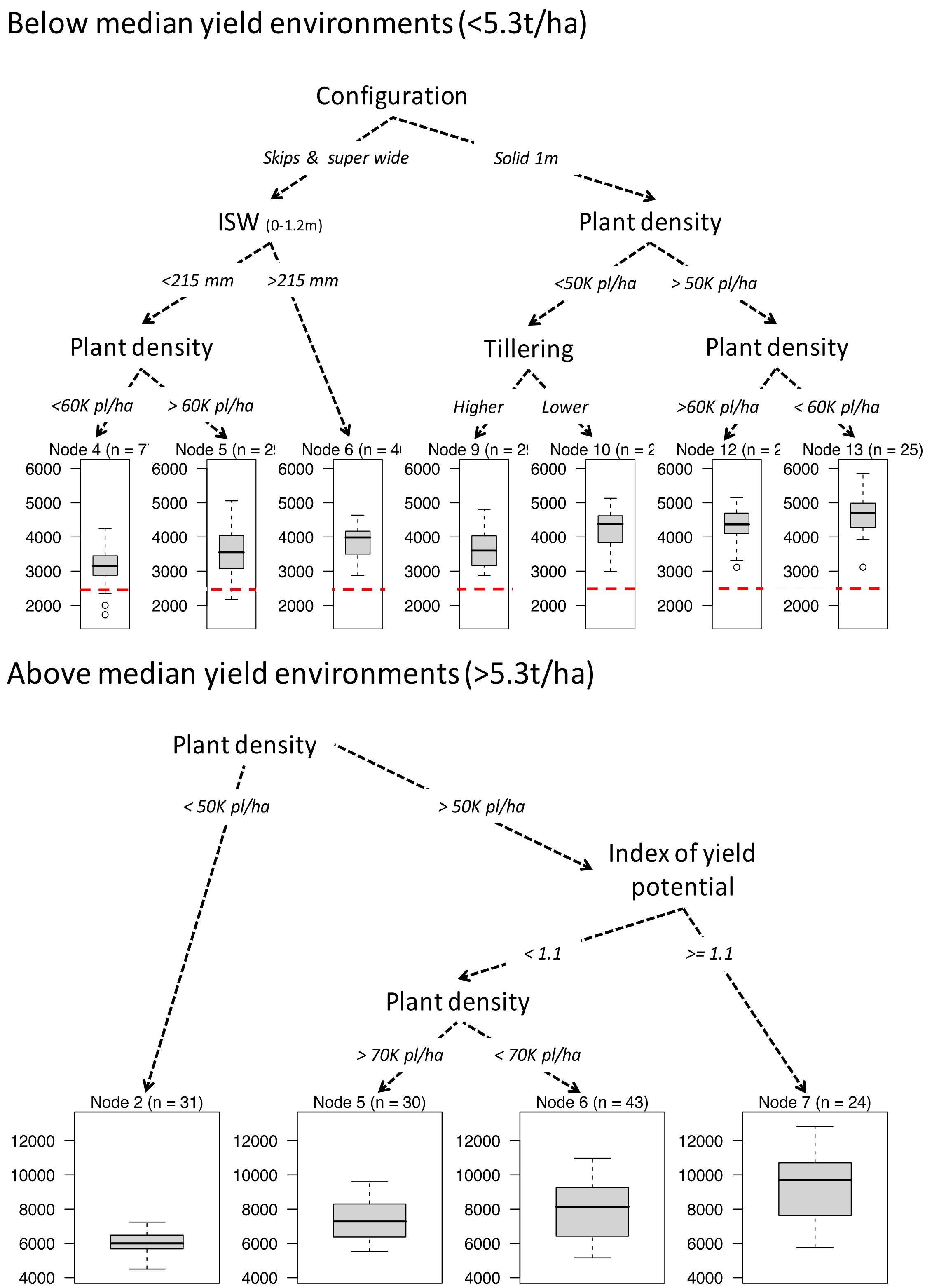

Figure 2. Simple rules of thumb from on-farm trials for below (top graph) and above (lower graph) median (5.3t/ha) yielding environments. The right-hand side of each graph shows the highest yielding hybrid and management combinations. While, the left-hand side of the graphs shows the lowest yielding combinations of hybrid and management for each environment. The dashed red line indicates a yield of 2.5t/ha. ISW = initial starting water (at sowing) as a % of PAWC; n = is the number of treatments included in each graph.

Figures 2 show the higher yielding combinations of hybrid and management to the right, and the lower yielding to the left. For example, for the lower yielding environments (i.e. below 5.3t ha^{-1}, top graph in Fig 2) the main variables separating low from high yielding treatments were row configuration, soil water at planting, plant density and hybrid tiller propensity. In these environments, the highest treatment yields were observed in solid configurations, and plant populations between 50 and 60k pl ha^{-1}. Even though the small variability in tillering among the tested hybrids, the difference between higher and lower tillering hybrids was about 1t ha^{-1}. This represented a yield increase from 3.5 using higher tillering to 4.5t ha^{-1} using lower tillering hybrids in dryer environments; and calls for low tillering or uniculm hybrids in dryer environments. The lowest yields were obtained with skip, double skip or super wide configurations and with less than 215mm of soil water at planting.

In the higher yielding environments (bottom graph in Fig 2) plant density and the yield potential of the hybrid were the most important variables discriminating between low and high yields. In these environments, the highest yields were observed with populations of more than 50k pl ha^{-1}, on hybrids showing high values for an index of yield potential. No lodging was observed in any of our trials, although lodging has been reported for high yielding hybrids and plots. Causes of lodging in sorghum are not clear, though have been associated to terminal stresses, weak/thin stems, and high yield potential crops (large panicles). The lowest yields in high yielding environments were observed with plant populations below 50k pl ha^{-1}.

Clearly our understanding of crop stress physiology indicates that in hindsight, optimum combinations of hybrid and management (for the past season) could be known. Obviously, our main problem is to predict relevant attributes of the season at the time of sowing, so that optimum GxM combinations could be informed. Even though contestable, outputs from seasonal climate forecasts and crop models could be used to inform optimum combinations of hybrids and management. I say contestable, because given the chaotic nature of the atmosphere, it is impossible to know exactly how it will evolve beyond a few days. Our only option is then to use probabilistic forecasts that give changes in the likelihood of the coming season to fall within a particular range of the historical climate records. A concept sometimes difficult to understand by those needing to inform "yes" or "no" type decisions, e.g. to plant or not to plant.

In our recent work we used seasonal climate forecast and crop models to test our capacity to answer *Can we inform optimum GxM combinations in sorghum?* Results showed that BOM's POAMA-2 forecasts showed higher skill than the SOI phase system. Actually, the SOI phase system appears to have significantly degraded and shouldn't be used anymore. We also found that the level of value in the skill of POAMA-2 depended on the baseline for the comparison: When current growers' practice was used as the baseline, linking APSIM sorghum and POAMA-2 increased average profits by 143 AU$ ha^{-1} and reduced or even eliminated down side risk. When the baseline for the comparison was a higher investment strategy, the actual value of the additional climate information was on average 17 AU$ ha^{-1}, which compares to the benefits derived from Australia's sorghum breeding over the last thirty years i.e. 2.1% per year, or 44 kg ha^{-1} $year^{-1}$.

These results indicate that even though the value of the additional climate information might seem small ($Value_{optSCF}$, in Table 1), its magnitude compares well with that derived from much larger and better funded breeding programs e.g. sorghum. This also shows that much larger benefits ($Value_{optS}$) could be realized when using this information in discussions with growers and advisers on benefits and risk from increasing investments in dryland cropping. Table 1 also answers the question '*What would be the value of having a hypotetical perfect seasonal climate forecast?'* ($Value_{PK}$ in Table 2). In Table 1, comparing $Value_{opts}$ i.e. reflecting the value of present skill in forecasting, and $Value_{PK}$ i.e. reflecting the value of a perfect forecast, shows that our present predictive capacity is about mid-way from what it could be if a perfect forecast would be available.

Table 1. Mean profits from a simulation using growers current practice and climatology (Growers), perfect knowledge (PK) i.e. optimized crop designs using climatology, optimized crop design using POAMA-2 (Optimised); and value i.e. mean changes in profit and down side risk i.e. likelihood of a profit lower than \$600 ha^{-1} for, growers current practice ($Value_f$). Optimized crop design using climatology 1981-2015 and ($Value_{optS}$) and a POAMA-2 seasonal climate forecast ($Value_{optSCF}$)).

	Soil type (PAWC)	Mean value to inform GxM with respect to a static management							
		Profit (\$ ha^{-1})					Down Side Risk (%)		
		Growers	Optimized	$Value_{optS}$	$Value_{optSCF}$	$Value_{PK}$	Growers	Optimized	$Value_{optS}$
Capella	High	1108	1260	152	3	335	0	0	No risk
	Medium	748	824	77	3	224	12	0	-100
	Low	544	600	56	4	219	68	62	-9
Dalby									
	High	1127	1337	210	13	353	0	0	No risk
	Medium	1048	1241	194	17	351	0	0	No risk
	Low	795	913	118	12	288	6	3	-50
Goondiwindi									
	High	866	1092	226	16	432	6	0	-100
	Medium	841	1011	170	63	345	3	0	-100
	Low	678	793	115	6	312	34	6	-82
Moree									
	High	1025	1226	202	23	406	0	0	No risk
	Medium	814	962	148	32	370	9	0	-100
	Low	373	427	54	19	210	89	86	-3.3

$Value_{optS}$ = difference in profit (\$ ha^{-1}) and down side risk (DSR), between simulation of current growers' hybrid by management combination ($Value_f$) and a static (every year the same) optimized hybrid by management combination.
$Value_{optSCF}$ = difference in profit (\$ ha^{-1}), between $Value_{optS}$ and the dynamically (every year different) optimized hybrid by management combination informed by the POAMA-2 seasonal climate forecasts.
$Value_{PK}$ = Value of having perfect knowledge i.e. optimum crop design using observed climatology.

APSIM simulations for the Liverpool plains

Given the large number of possible combinations of hybrid and management available to growers, together with the large diversity in sites and seasonal conditions, it would be impossible and too costly, for any experimental program, to comprehensively run trials to cover all possible combinations. This is where well tested crop simulation models like APSIM (www.apsim.info) are most useful. The Agricultural Production Systems sIMulator (APSIM) was developed in Australia, and is an internationally recognised as a highly advanced simulator of agricultural systems. APSIM contains a suite of modules which enable the simulation of systems that cover a range of plant, animal, soil, climate and management interactions. APSIM is undergoing continual development, with new capability added to regular releases of official versions. Its development and maintenance is underpinned by rigorous science and software engineering standards. A detailed description of APSIM sorghum is available from:

http://www.apsim.info/Documentation/Model,CropandSoil/CropModuleDocumentation/Sorghum.aspx

While results from model validation for a range of output variables e.g. biomass at flowering and maturity, leaf area at flowering, grain size, grain number and final yield are available from:

http://www.apsim.info/APSIM.Validation/Main.aspx

Here we used APSIM to answer the following questions:

1. What is the effect of starting soil water compared to sowing on a particular date?
2. Should we wait until the soil profile is full?
3. How much can we rely on summer in-crop rain?
4. What is the minimum plant available water at sowing to produce an economic yield (3.5 t ha^{-1}) sowing 50 – 70k plants ha^{-1}?

To answer these questions, we ran APSIM-sorghum, for climate and soils of Quirindi, Mullaley, Spring Ridge and Caroona in New South Wales (only Quirindi is shown here). Soil characteristics are described in Table 2. The model was run for fortnightly sowings from the 15th of September to the 15th of December; parameterised for MR-Buster, MR-Scorpio, MR-Taurus, MR-Apollo and G33; with three different levels of N fertilisation 50, 100, 200 kg ha^{-1}; four plant densities 3, 5, 7, and 9 pl m^{-2}; and assuming four soil moisture conditions at the time of sowing, 30, 50, 70 and 100% full. Simulated scenarios included running APSIM using long term climate records, i.e. observed rainfall (obs, in Figs. 3 and 4). To assess the value of soil moisture at sowing, we also modified the long climate records so that (i) there was no rain during the first 60 days after sowing (60 das, in Figs. 3 and 4); and (ii) no rain during the first 30 days after sowing (30 das, in Figs. 3 and 4). The idea of these scenarios was to quantify the significance of initial soil moisture on crop failures, yields and risks, to answer, What is the effect of starting soil water compared to sowing on a particular date? Here we just present results from the APSIM simulations at Quirindi, NSW with MR-Buster, at 7 pl m^{-2}, fertilised with 200 kg N ha^{-1}.

Figure 3 shows the likelihood of failed crops when sown fortnightly from 15 Sept to 15 Dec, on 30, 50, 70 and 100% of PAWC at sowing. Simulations are for the long-term climatology (blue), and assuming the case of no follow up rain for 30 and 60 days after sowing (red and green, respectively).

Table 2. Plant available water capacity and plant available water for sorghum

Location	Soil	$PAWC_{sorghum}$ (mm)
Quirindi, NSW	Grey black Vertosol (Breeza, APSoil 123)	264
Mullalley, NSW	Grey black Vertosol (Nombi, APSoil 1171)	252
Spring Ridge, NSW	Brown Vertosol (Bundella, APSoil 1168)	282
Caroona, NSW	Grey Vertosol (APSoil 1171)	135

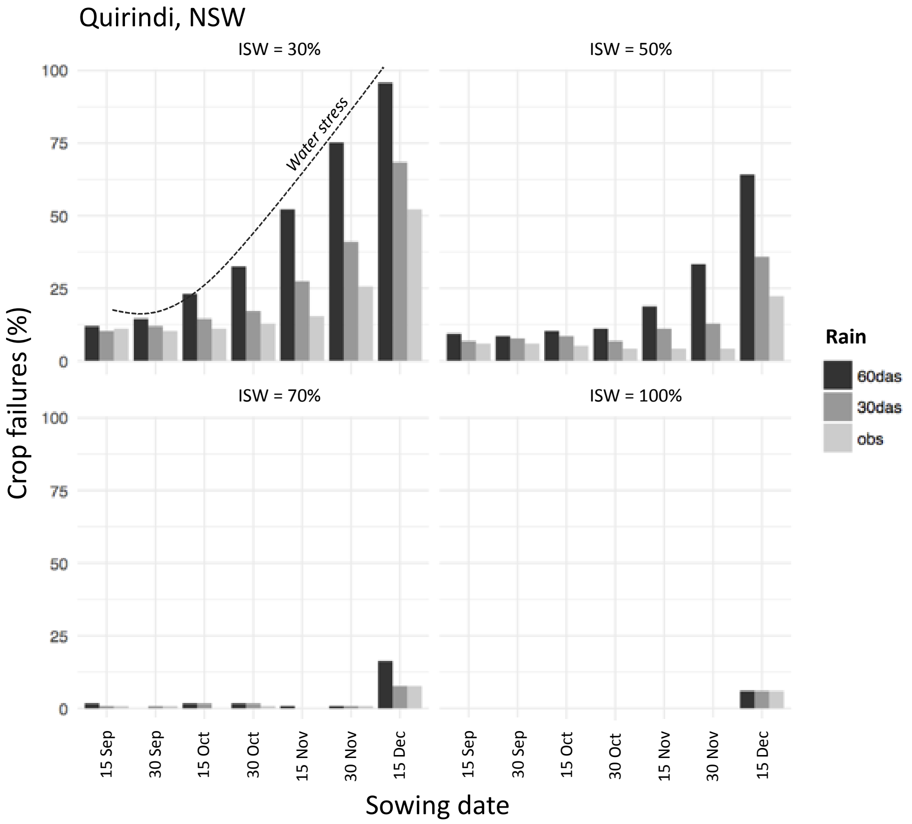

Figure 3. Likelihood of failed crops (MR-Buster, 7pl m^{-2}, 200kg N ha^{-1}), when sown fortnightly from 15 Sept to 15 Dec at Quirindi, NSW, on 30, 50, 70 and 100% of PAWC at sowing. Simulations are for the long-term climatology (light grey), and assuming no follow rain for 30 (grey) and 60 (dark grey) days after sowing. ISW = initial Starting Water (at sowing) as a % of PAWC.

Figure 3 shows that:

- Crop failures increased for the later sowings, particularly when followed by periods of 60 and 30 days of no rain after sowing. This is due to crops running out of water during periods of increasing temperatures and atmospheric demand. Sowing with more than ¾ full soil profiles prevent most of these losses, though yields are affected (see Figure 4). The increasing reliance on initial soil moisture with the later sowings is related to the fact that later sowings will grow during the hotter time of the year i.e. high atmospheric demand. It is important to note that there is increasing interest in the development of cold tolerance in sorghum cropping i.e. genetic + agronomic, which has shown yield, risk and cropping systems benefits in the Western Downs of Queensland. This is in response to increases in the frequency of heat stress and dry spells around flowering, our climate is not getting any colder!!. This year we planted a sorghum trial on the 5th of August at Warra Qld, with soil temperatures ca. 11°C. Even though five light frost before 6 leaves, the crop looked great, and was harvested on the week of the 8th of January, allowing a longer fallow into a double crop chickpea (talk to Wade Bidstrup, a farmer from Warra).

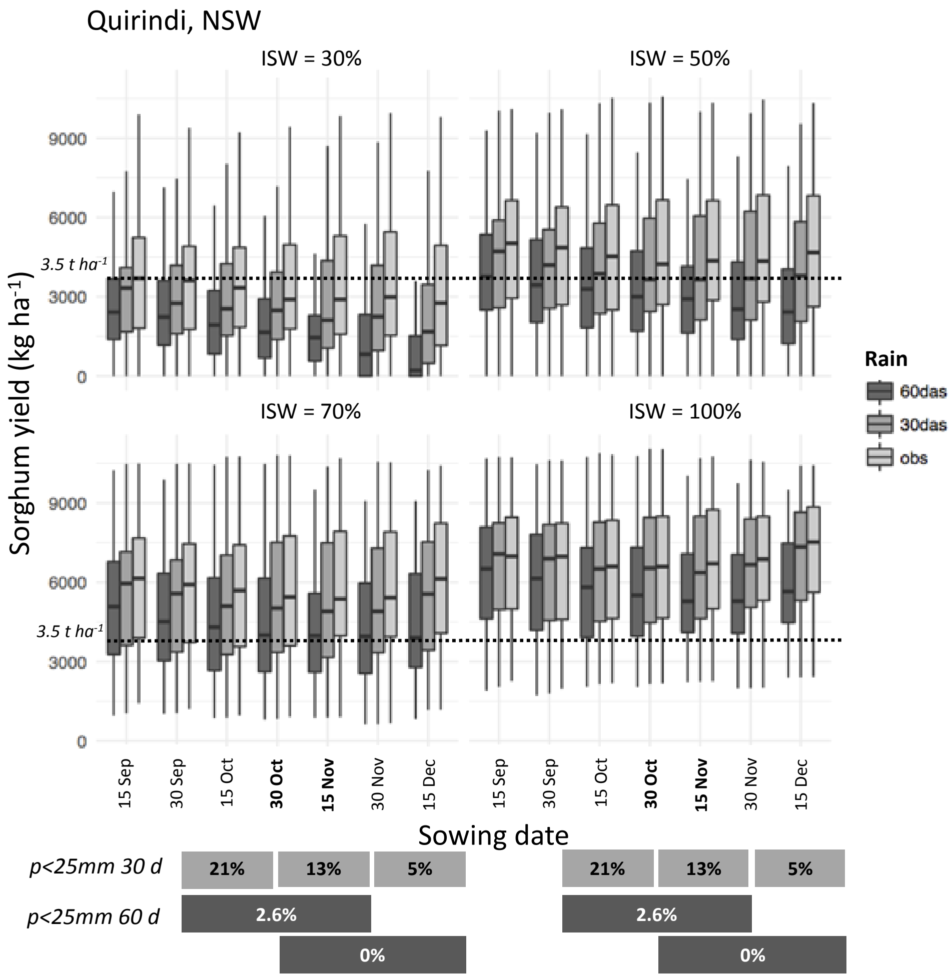

Figure 4. Box plots for simulated sorghum yields (MR-Buster, 7pl m^{-2}, 200kg N ha^{-1}), when sown fortnightly from 15 Sept to 15 December at Quirindi, NSW, on 30, 50, 70 and 100% of PAWC at sowing. Simulations are for the long-term climatology (light grey), and assuming no follow rain for 30 (grey) and 60 (dark grey) days after sowing. Dashed lines show a break even yields of 3.5 t ha^{-1} (p.c. B Manning). p<25mm 30 d and p<25mm 60 d indicate the likelihood of no significant rain (<25mm) after sowing for the next 30 (grey) and 60 (dark grey) days, for different planting windows. ISW = initial Starting Water (at sowing) as a % of PAWC

Figure 4 shows that:

- For Quirindi, irrespective of the planting time, there is around a 50% chance of economic yields if sowing on half full soils. Higher yields are more likely on early or late sowings. The likelihood of achieving economic yields dramatically increases with ¾ or full soil profiles, even if crops are followed by 30 or 60 day dry spells. The likelihood of dry spells after sowing is higher with the early planting at the end of September. The chance of a 30-day dry spell (defined as less than 25mm in 30 days), after a 30th Sep, is around 21%. This drops to 13% for sowings on the 30th of October, and down to 5% for sowings on 30th November. There is a 2.6% chance of a 60-day dry spell (defined as less than 25mm in 30 days) for plantings on the 30th of Sep, which drops zero for sowings on the 30th of Oct (Fig. 4).

APSIM simulations indicate that:

- What is the effect of starting soil water compared to sowing on a particular date? At Quirindi:
    - Starting soil moisture has a larger impact on the likelihood of crop failures and achieving economic yields than changes in sowing time.
    - The difference between sowing on 50 or 70% PAWC is that of gambling on a 50 – 50% chance of achieving an economic yield, versus a 75% likelihood.
    - The impact of a dry spell is larger on later planted crops than on early planted crops.
- Should we wait until the soil profile is full? At Quirindi:
    - Sowing early will minimise the likelihood of failed crops
    - Sowing on at least 70% of PAWC in early or late plantings will maximise the likelihood of economic yields.
- How much can we rely on summer in-crop rain? At Quirindi:
    - It is not just reliance on summer rainfall that should be growers' worry, but we need to understand that summer rainfall will be less efficient to translate into crop yield. This is because the crop will use more water to produce the same yield as an earlier planted crop. In addition, something we haven't investigated here, is the likelihood and yield of crops grown after an early or late planted sorghum.
- What is the minimum plant available water at sowing needed to produce an economic yield (3.5 t ha^{-1}) sowing 50 – 70k plants ha^{-1}?
    - The answer to this question is that it depends. It depends on whether we are talking about an early or a late planted crop.

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Contact details

A/Prof Daniel Rodriguez
UQ-QAAFI, The University of Queensland
203 Tor Street, Toowoomba, Qld
Mb: 0434 075 094
Email: d.rodriguez@uq.edu.au
Website: https://www.qld-fsr.info/
Twitter: @Queensland_FSR

The impact of wheat residue on air temperature in the canopy and phenology of chickpea in 2017

Andrew Verrell[1], Kathi Hertel[2], Brooke McAlister[2] and Matthew Grinter[1]

[1]NSW Department of Primary Industries, Tamworth
[2]NSW Department of Primary Industries, Narrabri

Key words

stubble, frost, temperature, radiant, phenology

GRDC code

DAN00965 Thermal responses of winter pulses

Call to action/take home messages

- Surface wheat residue increases the incidence and severity of radiant frosts.
- The average minimum surface temperature declines by -0.10^{0}C/ tonne of residue.
- High residue loads can change the thermal profile of the crop and lead to delays in the onset of flowering, podding and maturity in chickpeas.
- Inter-row sowing into standing residue (>30cm) led to less frosts and higher minimum temperatures in chickpeas.
- Some chilling tolerant chickpea lines flowered 3 to 11 days earlier than PBA HatTrick⊕ but this did not translate into earlier 1st pod dates.

Introduction

Chickpea productivity in the northern grains region (NGR) is constrained by several abiotic stresses (Whish *et al.* 2007) and temperature is one of the most important determinants of crop growth over a range of environments (Summerfield *et al.* 1980) and may limit chickpea yield (Basu *et al.* 2009).

The potential evaporative demand for water usually exceeds the water available to the crop and represents the greatest limitation to crop production in the northern grains region (NGR). Low-disturbance direct seeding into standing or flattened cereal stubble is the most effective practice to reduce the impact of water stress on chickpea crops. However, surface residues can cause an increase in radiant frost risk and may also affect the micro-climate of the crop canopy, with impact on floral initiation, pod set and seed development.

The impact of surface residue on air temperature in the canopy, phenology, biomass and grain yield of chickpea was explored in a series of experiments across the NGR in 2017.

Stubble effects on soil and air temperature

During the day, stubble reflects solar radiation. A bare, darker soil absorbs more solar radiation than a stubble-covered soil and warms up more readily. The stubble also acts as insulation as it contains a lot of air which is a poor conductor of heat. Finally, the stubble affects the moisture content of the soil. It takes more heat to warm up moist, stubble covered soil than dry, bare soil.

This causes soil temperature of a bare soil to be higher than stubble covered soil during the day (especially in the afternoon). At night, however, the bare soil loses more heat than stubble covered soil due to the lack of insulation (the air-filled stubble being a poorer heat conductor). This is especially noticeable when skies are clear. The air above the bare soil is therefore warmer during the night than the stubble covered soil, while the soil temperature differences become negligible. Therefore stubble cover may lead to a higher incidence of frost than bare soil.

Methods

A range of experiments were conducted at Rowena and Tamworth in 2017 (Table 1).

Table 1. Experiments, treatments and locations for 2017

Experiment	Tamworth	Rowena
Row orientation	North - South	East - West
Stubble loading	0, 3, 6, 12, 24 t/ha residue Chickpea, faba bean, field pea	0, 3, 6, 9, 12 t/ha residue 4 x chickpea genotypes
Stubble height	0, 10, 30, 50 cm Chickpea, faba bean, field pea	0, 5, 10, 17 cm 4 x chickpea genotypes
Chilling tolerance	Plus and minus residue 16 chilling tolerant chickpeas	Plus and minus residue 16 chilling tolerant chickpeas
Genotype screening	Plus and minus residue 20 selected chickpea lines	

In all of the stubble experiments, treatments were not invoked until just prior to sowing. This ensured there was no treatment effect on soil stored water at sowing. In the stubble loading experiments, residue was removed, bulked and weighed into treatment amounts and re-applied to the plots immediately post-sowing. In the stubble height experiments, treatments were cut using a small plot header the day before sowing. Stubble was stripped and captured at the back of the header for removal.

In all experiments, tiny tag temperature data loggers were used in selected treatments and plots. Sensors were placed at 0cm and 50cm above ground in-crop. Temperature was logged at 15minute intervals. Another Tiny Tag sensor was placed outside the crop area at 150cm above the ground to record ambient temperature at similar time intervals.

Detailed phenology was recorded on a daily basis. At physiological maturity, whole plant samples were taken for detailed plant component analysis and whole plots were harvested for grain yield.

Results

The 2017 growing season

The 2017 growing season has been one of the most difficult and extreme on record equivalent to the 1994 and 1982 seasons with record frost events and below average in-crop rain.

The Rowena site failed due to lack of soil moisture exacerbated by the high frost incidence. Nothing was recoverable. Table 2 shows the long term average (LTA) monthly rainfall and minimum screen temperatures and the monthly rainfall and average minimum temperature for Tamworth in 2016 and 2017.

Table 2. Long term average (LTA) monthly rainfall and minimum temperature and monthly rainfall and mean minimum temperature for 2016 and 2017 at Tamworth

Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall 2017 mm	125	19	124	22	61	49	20	21	10	90	64	39
Rainfall 2016 mm	100	1	22	5	61	169	29	83	133	76	12	97
LTA rainfall mm	85	67	49	42	44	49	46	46	48	58	66	72
Mean Min 2017 (°C)	19.6	18.5	15.3	9.2	6.3	3.5	-0.1	1.2	4.5	11.4	11.9	16.5
Mean Min 2016 (°C)	17.0	16.1	15.7	12.2	6.6	6.1	3.7	3.2	7.2	7.1	10.1	16.9
LTA min temp (°C)	17.4	17.1	14.8	10.6	6.7	4.1	2.9	3.7	6.1	9.9	13.1	16.0

Rainfall leading into the 2017 growing season was on par for the LTA, but July-September was below the cumulative LTA by 88mm. Rainfall in October saved these crops and resulted in average yields (Table 2).

The mean minimum temperatures started to dip below the LTA from April right through to September, with mean minimums for July, August and September being, -3.05, -2.52 and -1.58^{0}C colder than the LTA, respectively. The frost incidence at Tamworth in 2017 was unprecedented, with 49 screen frosts compared to 22 in 2016. Rowena experienced 26 screen frosts up to the 1st week in September when the crop failed.

At Tamworth, the extreme weather events led to complete death of ALL field pea blocks. This was through frost events followed by a wipe out due to bacterial blight infection.

Elevation and air temperature

Figure 1 shows the effect of slope on average minimum air temperature at ground level at the Tamworth site. Minimum temperature declined by - 0.22^{0}C per m drop in elevation measured on bare soil.

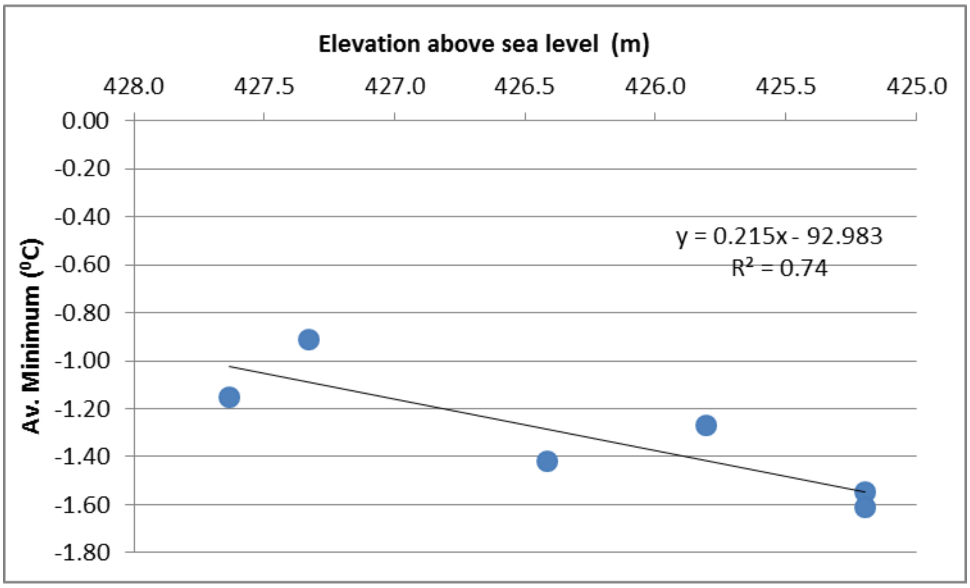

Figure 1. Effect of slope on average minimum temperature (7/7 – 8/8/2017) at ground level at the Tamworth Agricultural Institute (TAI)

Stubble loading effects on in-crop temperature

The effect of different amounts of wheat residue, flat on the ground, and its impact on the temperature profile of different pulse species was examined.

Table 3 shows the effect of residue loading on minimum temperature at the residue surface in chickpea at TAI.

The bare soil surface was on average, -1.0^{0}C colder than the minimum screen temperature. Both the average minimum and absolute minimum declined as the amount of surface residue increased, with the high residue loading (24 t/ha) -1.4^{0}C colder on average than bare soil. Frost incidence was similar across all residue level loadings, but there were 5 more ground frosts recorded compared to the screen temperature. The absolute minimum decreased with increasing residue load, with the high residue treatment reaching -7.5^{0}C compared to -6.4^{0}C on bare soil (see Table 3).

Table 3. The average minimum, absolute minimum and number of frosts (<0^{0}C) for a range of stubble loadings at the residue surface in chickpea compared to the screen temperatures at TAI (7th July to 8th August).

		Residue loading				
	Screen	Bare soil	3 tonne	6 tonne	12 tonne	24 tonne
Av. Min	0.5	-1.5	-1.9	-2.1	-2.2	-2.9
Abs. Min	-5.2	-6.4	-6.7	-6.9	-6.9	-7.5
No. Frosts	20	25	25	25	25	26

Table 4 contains data from the Rowena site prior to it succumbing to terminal drought. The temperature response to residue loading is the same here as at TAI. Average minimum temperature declined with increasing residue load, with a -1.2^{0}C difference between bare soil and 12 t/ha of residue.

Table 4. The average maximum and minimum, absolute minimum and number of frosts (<0^{0}C) for a range of stubble loadings at the residue surface in chickpea at Rowena (1st June to 10th August).

	0 tonne	3 tonne	6 tonne	9 tonne	12 tonne
Av. Max	10.3	10.5	10.4	10.4	10.3
Av. Min	0.4	0.1	-0.3	-0.4	-0.8
Abs. Min	-6.5	-7.2	-7.9	-7.6	-8.9
No. frosts	36	42	42	43	43

At Rowena, frost incidence rose with the addition of residue compared to bare soil, but was similar across residue loading treatments. Maximum temperatures did not vary across treatments.

Figure 2 shows the linear relationship between residue loading and average minimum surface temperature in chickpea.

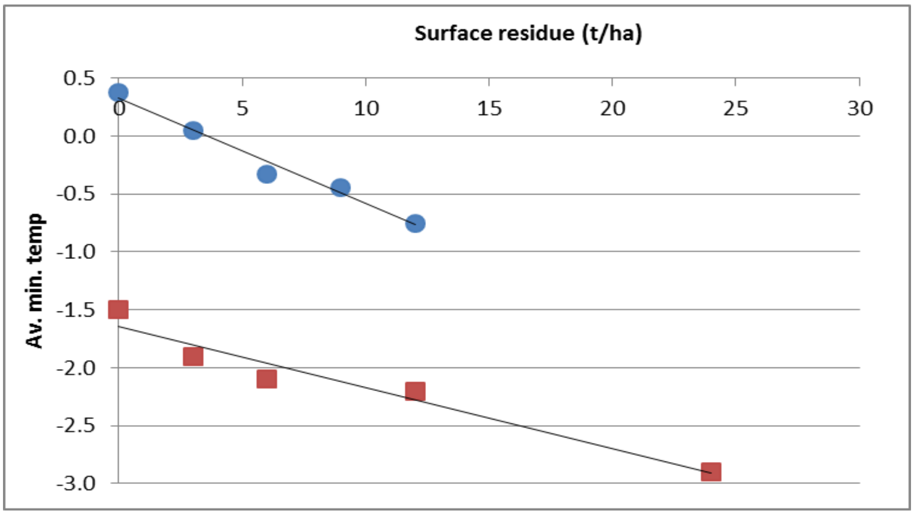

Figure 2. The effect of surface residue loading on average minimum temperature at the residue surface at Rowena (●) and TAI (■) in the chickpea crop

Both responses are linear but the steeper slope at Rowena would suggest that residue amount had a more significant impact on minimum temperature and frosting in 2017 than at TAI. Minimum temperature declined by -0.10 and -0.05 ^{0}C, per tonne of residue at Rowena and TAI, respectively.

Stubble height effects on in-crop temperature

Table 5 shows the effect of stubble height on temperature parameters at the soil surface on inter-row sown chickpea at TAI.

Table 5. The effect of residue height on absolute and average maximum and minimum temperature and number of frosts in chickpea at the soil surface at TAI (7th July to 20th September)

Parameter	Bare soil	10cm	30cm	50cm
Abs. Max	37.1	37.0	36.7	35.0
Av Max	25.5	25.3	24.9	23.5
Av Min	-0.8	-0.7	0.2	0.0
Abs. Min	-5.6	-5.4	-4.3	-4.9
No. frosts	51	51	41	42

There was no change in temperature parameters between the bare soil and 10cm high residue. Changes started occurring once residue reached 30cm high, with the average and absolute minimums rising 0.4^{0}C and 1.3^{0}C, respectively. There were 10 less frosts in the 30 and 50cm high residue treatments compared to bare soil. Average and absolute maximums were 2.0^{0}C cooler in the tall 50cm stubble treatment compared to bare soil (see table 5).

Stubble loading effects on phenology

The effect of surface residue loading on the time taken, recorded as days after sowing (DAS), to reach 20% flower, 1st pod, 50% pod and flowering cessation are shown in figure 3.

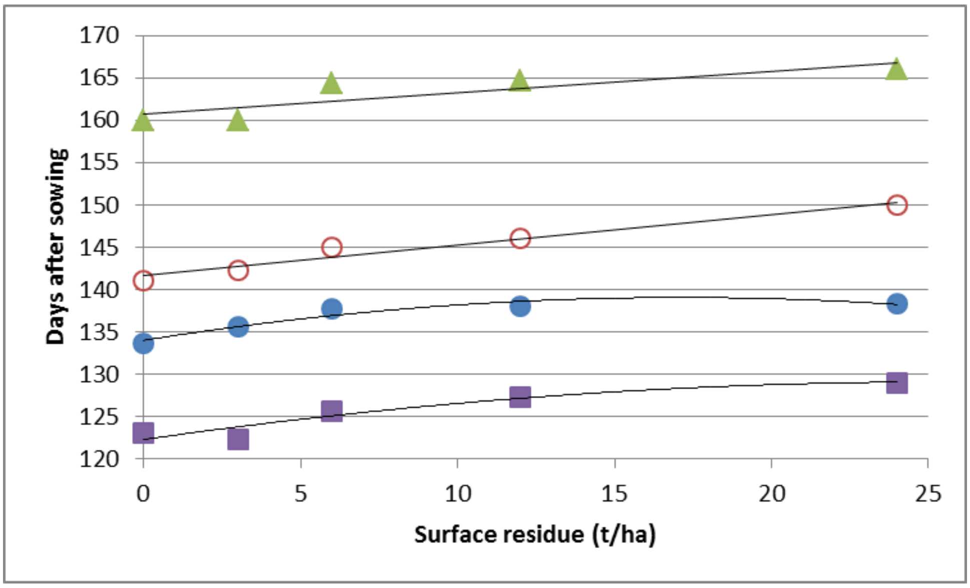

Figure 3. The effect of surface residue loading on the time taken (days after sowing) to reach 20% flower (■), 1st pod (●), 50% pod (○) and flowering cessation (Δ).

Across all parameters the time taken to reach these increased with increasing residue load on the surface. This effect was even more pronounced for 50% pod set and development and flowering cessation (Figure 3).

Assessment of chilling tolerant lines

Table 6 contains phenology data for selected lines from the chilling tolerance experiment at TAI.

Table 6. The effect of surface residue treatment on the time taken (days after sowing) to reach 1st flower, 50% flower and 1st pod for selected genotypes

		Days after sowing		
Stubble	Variety	1st Flower	50% Flower	1st Pod
Bare	CICA-1521	101	124	132
Flat residue	CICA-1521	104	126	132
Bare	PBA HatTrick⏀	110	126	132
Flat residue	PBA HatTrick⏀	115	126	137
Bare	CT-3	97	126	132
Flat residue	CT-3	118	129	137

In the bare soil treatment, genotypes reached 1^{st} flower 3 to 11 days earlier than in the flat residue treatments. The residue treatments delayed 50% flowering in the numbered lines, but not in PBA HatTrickⓟ, while the bare soil treatments led to earlier 1^{st} podding. CICA1521, a fixed line, is substantially earlier at flowering than PBA HatTrickⓟ, but similar in time to 1^{st} pod set. CT-3 is a new line with enhanced chilling tolerance which is evident from its earlier time to 1^{st} flowering, but this didn't translate into earlier pod set when compared to PBA HatTrickⓟ.

Conclusion

The 2017 season was unprecedented with record frost events coupled with below average in crop rainfall. The severe weather conditions led to the complete death of the field pea blocks at TAI, due to frost and bacterial blight. Terminal drought led to the eventual loss of the Rowena site.

The slope of cropping country can contribute to spatial variability in soil surface temperatures, with minimum temperatures declining by - 0.22^{0}C per m drop in elevation measured on bare soil.

Surface residue loading increased the severity of radiant frosts which impacted on all species. Field peas are the most susceptible, while faba bean and chickpea can tolerate some vegetative frosting. The number of frosts increased with residue loading, while the average minimum surface temperature declined by -0.10 ^{0}C, per tonne of residue.

Standing stubble led to changes in air temperature at the inter-row soil surface. There was no difference in temperature parameters between bare soil and 10cm high residue. Once residue was above 30cm average, absolute minimums rose by 0.4 to 1.3^{0}C and there were fewer frosts. Maximum temperatures were cooler by up to 2.0^{0}C.

Numbered lines assessed for chilling tolerance showed that they could flower 3 to 11 days earlier than PBA HatTrickⓟ, but this did not translate into earlier pod set. Post-harvest assessment will determine whether earlier flowering has led to more viable flowering and podding sites compared to PBA HatTrickⓟ.

In all cases, sowing chickpeas between standing wheat residue gave equivalent grain yield outcomes to the bare soil treatment.

This remains the preferred strategy to maximise fallow efficiency and grain yield.

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Contact details

Dr Andrew Verrell
NSW Department Primary Industries
Mb: 0429 422 150
Email: andrew.verrell@dpi.nsw.gov.au

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Preliminary data on phenology of Australian chickpea cultivars in the northern grain belt and prebreeding for heat avoidance traits

Angela L. Pattison, Helen Bramle and Richard Trethowan, University of Sydney

Key words

chickpea, phenology, heat, chilling, prebreeding

GRDC code

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Call to action/take home messages

- This research aims to identify chickpea traits and germplasm with superior tolerance to high temperatures and produce pre-breeding lines with improved productivity for the northern region. Results from this project will be published over the next few years.
- Results from contrasting 2016 and 2017 seasons in delayed sowing experiments were used to benchmark the phenological response of current and older cultivars to temperatures during flowering and podset.
- Approximately 1250 internationally-sourced lines (including both *Cicer arientinum* and wild relatives) are being screened for performance in the northern grain belt to select appropriate parents for pre-breeding for high yield under terminal heat stress. Earlier podding is one of several traits being targeted.

Introduction

Chickpea is rapidly growing in its importance as a winter legume crop in Australia. Research and pre-breeding in Australia is expanding in the areas of abiotic stress tolerance to build on gains in disease control over the past 40 years.

Terminal heat stress is one of the most widespread abiotic stressors in Australian cropping regions. There are several ways in which heat can reduce yield, which include death/sterility of reproductive tissues (Devasirvatham *et al.* 2013), reduced pod set, a reduction in the duration of developmental stages (Devasirvatham *et al.* 2012) and investment in heat-shock proteins (Jha *et al.* 2014). These factors are controlled by different genes and require different breeding strategies, but relevant traits could potentially be 'pyramided' into new pre-breeding lines to enhance the performance of chickpea in hot and dry seasons.

Compared to most other winter legumes, chickpea has a reputation as relatively tolerant to hot, dry conditions (Sadras *et al*. 2015). The temperatures required to sterilise flowers are relatively high (sustained >33°C daytime temperatures in sensitive genotypes – Devasirvatham *et al.* 2013) and are not usually persistent during the key weeks of pollination in September and October in the Australian grain belt. Conversely, temperatures which delay the onset of podding (average daily temperature of 15°C, termed "chilling temperatures" – Croser *et al.* 2003) are quite common, and delays in the commencement of podding of up to 35 days post flowering have been recorded in Mediteranean-type climates in Australia due to long periods of chilling temperatures (Berger *et al* 2004). Reduced pod set has been observed in mean temperatures up to 21°C (Berger *et al.* 2011). This has been attributed to a reduced ability of the pollen to grow through the style and fertilise the ovule under low temperatures, despite both pollen and ovule being fertile (Srinivasan *et al.* 1999; Clarke and Siddique 2004).

It has been argued that greater yield gains for Australian growers are possible by bringing the podding period earlier by a week in September (heat avoidance) rather than extending the podding period a week into November (heat tolerance), when moisture availability is usually also a significant constraint (Clarke *et al.* 2004). Several approaches to breeding for improved chilling tolerance have been attempted in Australia, including pollen screening utilising internationally-sourced *Cicer arientinum* germplasm, which resulted in early-podding cultivars Sonali and Rupali (Clarke *et al.* 2004), and screening wild relatives for chilling tolerance (Berger *et al.* 2011). It has been suggested that little genetic variation exists amongst domesticated chickpea to breed for chilling tolerance (Berger *et al.* 2011), however a difference of a few days in the onset of podding, though scientifically small when compared to wild *Cicer* species or other crops, can be economically large to a grower, particularly in seasons of terminal heat or drought stress (Berger *et al.* 2004).

The aim of this research is to investigate mechanisms for heat tolerance and avoidance, screen Australian and international germplasm for genetic sources of relevant traits, and incorporate these traits into pre-breeding lines which can be used for development of future Australian cultivars by breeders. The data presented in this paper are preliminary phenological results from a subset of lines to illustrate the potential to breed for chilling tolerance as a mechanism to increase the time available for podding in seasons/environments which experience terminal heat and drought stress.

Methods for preliminary results

A field experiment was conducted at the I. A. Watson Grains Research Institute, Narrabri (30.34°S; 149.76°E) in 2016 and 2017. Up to 76 chickpea genotypes were planted in two replicated plots (each plot 1.8 x 4 m). Data presented here is from a subset of lines representing released cultivars or publically available genotypes.

The experiment consisted of two sowing dates - a sowing date typical for the northern region and a later sowing when plants would be exposed to higher temperatures. Planting dates were 14 June and 29 July in 2016, and 31 May and 25 July in 2017. The experimental years provided two contrasting seasons: 2016 was dominated by high rainfall (529 mm Jun – Oct) and relatively cool September daytime temperatures, with large amounts of cloud associated with precipitation in the first few months of growth. In contrast, 2017 started with good stored moisture, but had less in-crop rainfall (135 mm Jun-Nov), with concurrent warmer days and cooler nights. Temperature profiles for the period before and during the reproductive phase are given in Figure 1.

Plots damaged by severe ascochyta infection in 2016 were excluded from the analysis and hence, the results for some cultivars represent data from single plots.

Phenology for the time of sowing (TOS) trial was recorded as the days after planting (DAP) that 50% of plants in the plot had produced its first flower or first pod. Growing degree days (GDD) was calculated by

$$[(T_{max} + T_{Min}) / 2] - T_{base}$$

Where T_{max} is the daily max temperature and T_{Min} is the daily minimum, unless the minimum dropped below T_{base} in which case T_{base} was used. A T_{base} of $0^{o}C$ was assumed (Soltani *et al*. 2006). Daily temperatures were measured by an on-site weather station.

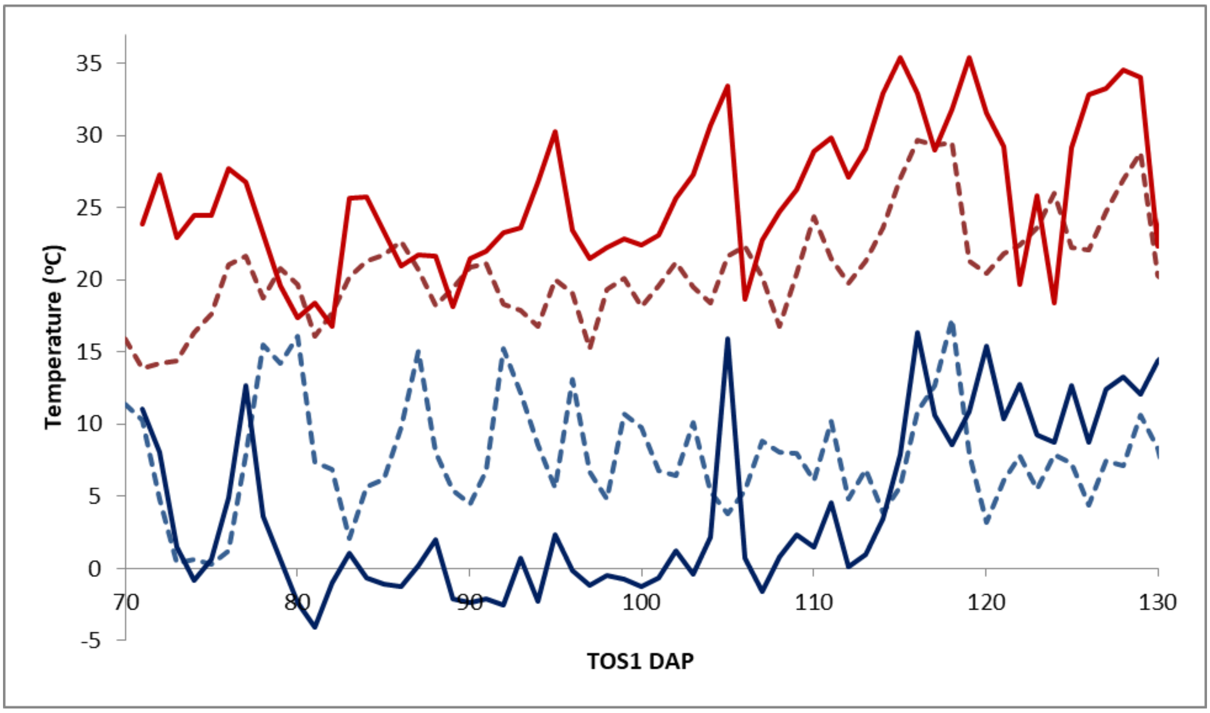

Figure 1. Temperature profiles for the two experimental seasons before and during the reproductive phase. Dotted lines = 2016 daily minimum and maximum temperatures; solid lines = 2017 daily minimum and maximum temperatures.

In addition, over 1000 genetically-diverse chickpea genotypes were obtained from the Australian Grains Genebank (AGG), plus a subset of 241 lines from the ICRISAT reference set were obtained via the Australian Centre for Plant Functional Genomics (Adelaide, South Australia). These sets included wild relatives of domesticated chickpea, wild-collected accessions of *Cicer arientinum*, and breeding lines/cultivars from a diverse range of growing environments around the world. All genotypes were sown in single 1.5m rows in 2016 in a netted bird-exclusion cage at Narrabri between the 18th and 27th July, with the late and long sowing period being due to high rainfall, which continued for most of the growing season. PBA HatTrick⏀ and PBA Slasher⏀ were included as comparators. Phenology was determined for plants within each 1.5m row as per TOS trial.

The data were analysed using the REML function I Genstat (version 17). Years, sowing dates and genotypes were considered fixed effects and row-column coordinates within sowing dates and seasons as random effects.

Preliminary results and discussion

The contrasting seasons provided interesting study years for the influence of temperature on phenology. DAP for flowering, podding and the flower-pod interval exhibited a significant interaction between genotype, year and TOS (P=0.036, P<0.001 and P<0.001 respectively). The range in flowering dates between genotypes for TOS1 was greater than the range in podding dates (Table 1). However, the range in flowering and podding dates within TOS2 were similar (approximately 12 days), but much narrower than TOS1. This suggests that either the warmer temperatures in TOS2 induced earlier pod set, or that cooler temperatures in TOS1 delayed pod set.

This data shows clear relationship between flowering and podding date, with 58-63% of the variance in podding date being explained by flowering date in regular sowings. Hence, selecting for earlier flowering will result in earlier podding. However, based on this data and considering only this set of genotypes, selecting for 1 day earlier podding will only bring forward podding by 0.31 days. Hence the economic value of selecting for earlier flowering/podding amongst this set of germplasm is quite low, considering that the range in flowering dates from which to select is only a couple of weeks.

Cultivars which had a flower-pod interval which was more than 2 weeks greater in TOS1 compared with TOS2 were Genesis 079, PBA Monarch⍉, PBA Pistol⍉, PBA Slasher⍉, PBA Striker⍉ and Sonali. These cultivars tended to have both earlier flowering and earlier podding times than other cultivars, and were the earliest in both TOS1 and TOS2.

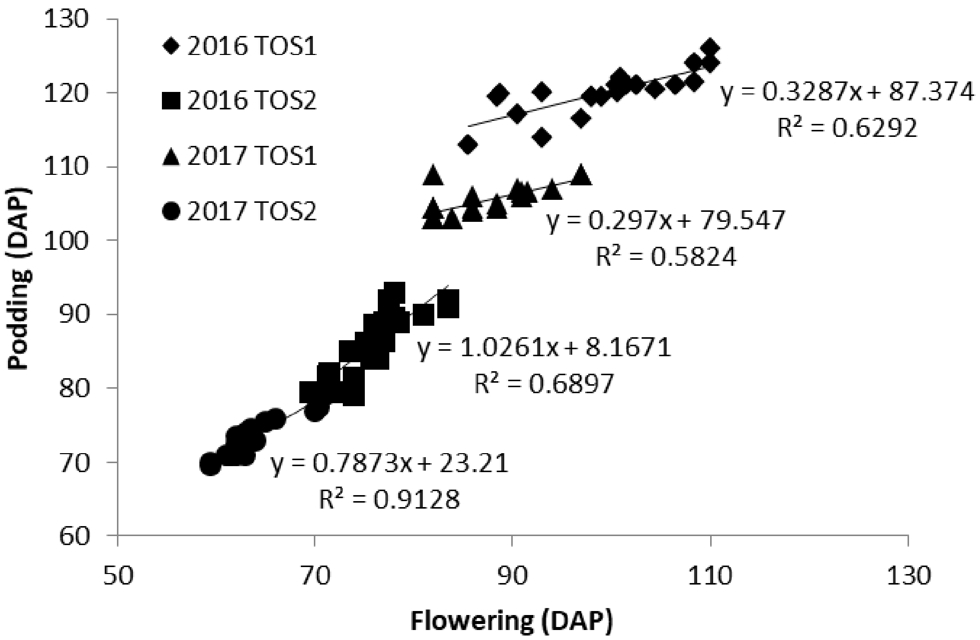

Figure 2. Correlations between the flowering and podding dates of genotypes in two contrasting seasons

The thermal time requirements to the commencement of the flowering and podding periods are given in Table 2. Earlier commencement of podding in 2017 cannot be explained by faster accumulation in thermal time. Commencement of podding in TOS1 was 207 GDD later in 2016 than 2017. This trend was also evident in TOS2, albeit to a lesser extent. Whilst the average daily temperatures (essentially what is used to calculate GDD where $T_{base} = 0^oC$) in both seasons were similar during the commencement and early reproductive stage (Figure 1), the daily maximums and minimums were quite different, and the amount of cloud was much higher in 2016 due to the large number of rainy days. It is possible that lower light intensity due to cloud cover had a significant influence on chickpea development. Note that irrigation was used to top up stored soil moisture in 2017 such that there was minimal to zero water stress during flowering and podding (no irrigation was required in 2016).

The shorter intervals between flowering and podding in TOS2 compared to TOS1 are also not explained by differences in GDD alone, with podding commencing 330 GDD earlier in TOS2 than TOS1 in 2016 and 246 GDD earlier in 2017. This lends support to the importance of considering daylength as well as temperature in delayed sowing trials (Sadras *et al*. 2015).

Table 1. Number of days between flowering and podding in heat stress trials at Narrabri in 2016 and 2017

	Flowering		Podding		Flower-pod interval	
	TOS1	**TOS2**	**TOS1**	**TOS2**	**TOS1**	**TOS2**
2016						
Amethyst	102	79	121	89	20	11
Flipperⓟ	105	77	121	89	16	12
Genesis 079	89	71	120	82	31	11
Genesis 090	101	76	120	84	19	8
Genesis Kalkee	107	77	121	87	15	10
Howzat	99	77	120	84	21	8
ICCV 05112	101	74	121	85	21	12
ICCV 05301	109	81	122	90	13	9
ICCV 05314	110	78	124	90	14	12
ICCV 06109	98	78	120	91	22	14
ICCV 98818	97	76	117	89	20	13
Jimbour	109	84	124	91	13	9
Kyabraⓟ	110	84	126	92	16	12
PBA HatTrickⓟ	98	75	120	86	22	11
PBA Monarchⓟ	93	72	120	82	27	11
PBA Pistolⓟ	93	74	114	79	21	5
PBA Slasherⓟ	91	72	117	80	27	8
PBA Strikerⓟ	89	74	120	82	31	8
Sonali	86	70	113	80	28	10
Tysonⓟ	103	78	121	93	19	15
Yorker	101	78	122	92	21	15
Range	*25*	*14*	*13*	*14*	*18*	*10*
Mean	*99*	*76*	*120*	*86*	*21*	*10*
2017						
Ambarⓟ	84	64	103	75	19	11
Amethyst	89	64	105	73	17	9
Genesis 079	82	62	103	73	21	11
Genesis 090	91	65	107	76	16	11
Genesis Kalkee	92	66	107	76	15	10
ICCV 05112	97	71	109	79	12	8
ICCV 05301	89	71	105	78	16	7
ICCV 05314	91	70	106	77	15	7
ICCV 06109	97	71	109	80	12	9
ICCV 98818	97	71	109	80	12	9
Jimbour	86	62	104	74	18	12
Kimberly Large	82	63	109	71	27	8
Kyabraⓟ	86	63	106	74	20	11
Neelamⓟ	91	63	107	73	17	10
PBA Boundaryⓟ	94	62	107	71	13	10

PBA HatTrick⦶	86	63	105	72	19	10
PBA Monarch⦶	82	64	105	74	23	11
PBA Pistol⦶	82	60	103	70	21	10
PBA Seamer⦶	82	62	103	71	21	9
PBA Slasher⦶	82	62	105	71	23	10
PBA Striker⦶	82	60	103	70	21	11
Sonali	82	61	105	71	23	10
Range	*15*	*12*	*6*	*11*	*15*	*5*
Mean	*87*	*64*	*106*	*74*	*18*	*10*
s.e.	*4.384*		*2.079*		*2.880*	

Podding for all genotypes in TOS2 began between 80 and 92 DAP in 2016 and 71 and 76 DAP in 2017. The mean flower-pod interval was 10 days in both 2016 and 2017 for this treatment, which was between 9 and 14 days shorter than TOS1. Given that it is not GDD alone which causes shorter flower-pod intervals in TOS2, two possible factors are proposed: longer daylength/greater incidence of solar radiation (Soltani and Sinclair, 2011), and/or a critical minimum temperature under which sporogenesis or pollenation cannot occur (Clarke and Siddique 2004). The large number of cloudy days in 2016 likely played a role in alteration of phenology.

Further field trials over the next few years will quantify the influence of these various factors, as well as growth rate, changes in canopy temperature using aerial remote sensing, model phenology relative to canopy temperature rather than weather station data, and quantify photothermal time rather than simply GDD. Another factor that warrants further research is that average daily temperature is not the best measure of chilling but rather temperatures after dawn (when pollen is released).

Table 2. Accumulated GDD up to the commencement of flowering and podding for the earliest genotypes in each treatment

	Flowering		**Podding**	
	TOS1	**TOS2**	**TOS1**	**TOS2**
2016	999	892	1374	1044
2017	940	729	1167	921

Of most value to prebreeding is that differences existed between genotypes, even amongst the fairly narrow genetic diversity found in current Australian cultivars. To expand this genetic range and seek lines with earlier podding capacity (and suitability to other climatic features of the Northern Grain Belt), the phenology and yield potential of a diverse range of chickpea genotypes were quantified at Narrabri (Figure 3). Heavy rains in June and July caused significant planting delays, such that the planting date was closer to TOS2 in 2016 and thus the discrimination between podding dates was anticipated to be small. Nevertheless, up to 6 days difference in podding date between PBA HatTrick⦶ and the earliest podding lines, and 7 days difference in the flower-pod interval, were observed. Podding dates of PBA Slasher⦶ and PBA HatTrick⦶ standards were 91 DAP and 85 DAP respectively, and flower-pod intervals were 15 days and 12 days respectively. This placed these lines (and by deduction most Australian cultivars) well within, but slightly earlier than average, the range of podding dates found in the diverse lines. It is anticipated that when sown within the optimum sowing window for chickpea there would be greater variation in podding dates and flower-pod interval, as experienced in the TOS1 trials.

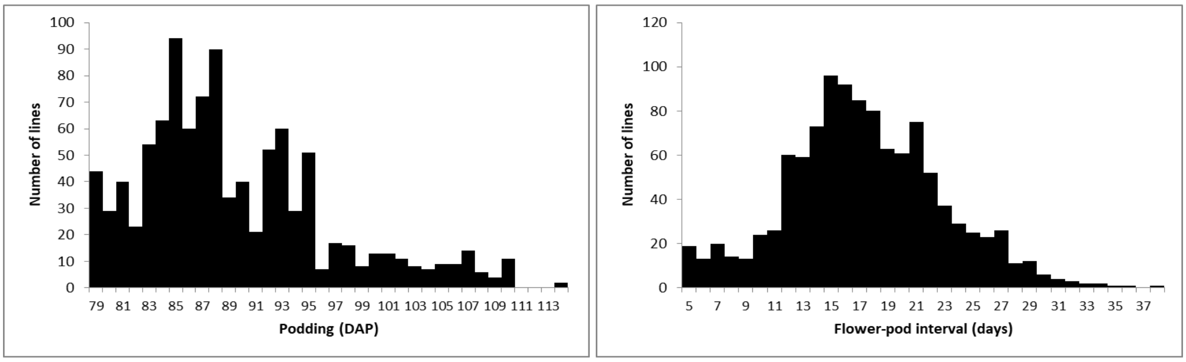

Figure 3. Histograms showing distribution of podding and flower-pod intervals amongst a range of >1000 diverse genotypes including closely related *Cicer* species and wild lines.

A subset of approximately 200 of the diverse lines from 2016 were increased in 2017 and will undergo field-based screening in 2018. Selection amongst diverse genotypes will be made for earlier podset as well as a host of other traits likely to lead to yield gains in the northern grain belt. The most promising lines will be crossed with high-yielding Australian cultivars and sent to the PBA chickpea breeding program at Tamworth for incorporation into future chickpea cultivars.

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Contact details

Angela Pattison
The University of Sydney
12656 Newell Hwy, Narrabri, NSW
Ph: (02) 6799 2253
Email: angela.pattison@sydney.edu.au

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Chickpea agronomy and water use with neutron moisture meters

Kerry McKenzie[1], RCN Rachaputi[2], Doug Sands[3]

[1] Queensland Department of Agriculture and Fisheries, Tor St Toowoomba
[2] Queensland Alliance for Agriculture and Food Innovation, University of Queensland Gatton
[3] Queensland Department of Agriculture and Fisheries, Emerald

Key words

chickpea, agronomy, row spacing, harvest index, water use

GRDC code

UQ00067

Call to action/take home messages

- Chickpea yields are maximised when planted on narrow rows (50cm and below).
- Avoid planting early and excessive biomass production.
- Aim to establish 20-30 plants/m^2 .
- Chickpeas will extract water from soils to 1.2m and below.
- Water Use Efficiency is improved by narrow rows; more water extracted and higher yields.

Background

The Queensland Pulse Agronomy Initiative planted its first chickpea trial in the 2013 winter, and with the next 2 years of trials our understanding of what drives yield improved, but also left many unanswered questions regarding crop physiology and how to best manage the crop to maximise yield.

The initial trials across southern Queensland confirmed that the latest release varieties such as PBA HatTrick⯑, PBA Boundary⯑ and the now released PBA Seamer⯑ (formerly CICA 0912) responded similarly to several agronomic factors:

- All maximised yields when planted at narrow row spacings with peak yields obtained when planted at row spacing of 25cm, however across several sites and years yields at 50cm were statistically the same as 25cm; yields then dropped when planted at wider spacings of 75cm and 100cm. This was observed in both low and high yielding environments (Figure).
- Plant population had less effect than did row spacing on final yields, with a flat response curve across 20, 30 and 40 plants/m^2, with a slight drop in yield at 10 plants/m^2. Hence it is recommended that planting rates remain at the current recommended rate of 20-30 plants established/m^2 for dryland plantings.
- There were no interactions that suggest any variety be planted at different populations for different row spacings. Planting early in the planting window had no grain yield benefit, however early plantings generated more biomass.
- Later plantings have mixed results for yield and biomass. It has been observed that harvest index (HI) improves with later plantings due to lower dry matter production (Figure 2) & (Table 1).

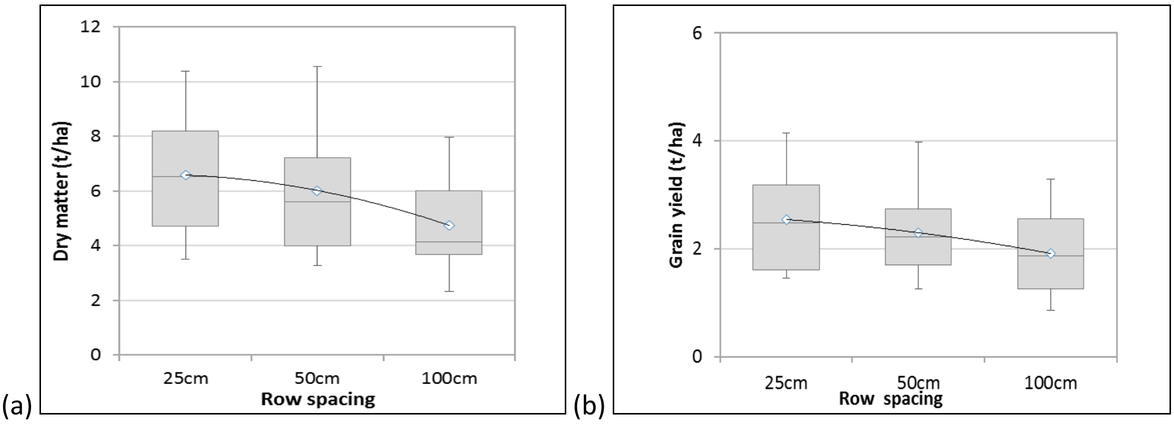

Figure 1. Summary of 12 chickpea sites from 2014 and 2015 [diamond marker indicates average across all sites and the trend line for the 3 row spacings]. (a) shows the effect of row spacing on dry matter production and (b) final grain yield. Row spacing has a larger effect on dry matter production than grain yield, however both trend lower as row spacing increases.

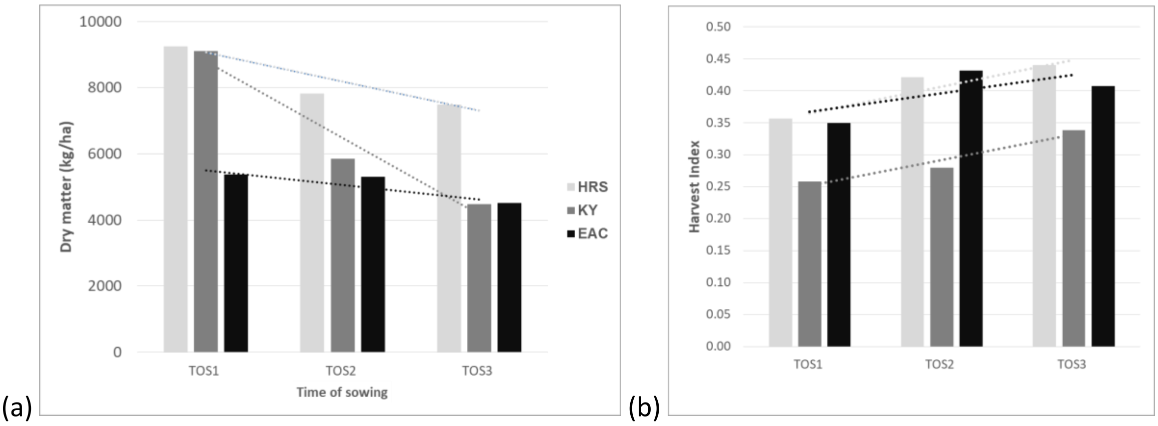

Figure 2. Time of Sowing (TOS) trials in 2015 at 3 sites; Hermitage [HRS], Kingaroy [KY] and Emerald [EAC]. All sites had a decreasing trend for dry matter production when planted later in the season (a). Harvest Index (HI) improves with later sowing dates as dry matter is reduced (b).

Table 1. Dry matter production and grain yield at Hermitage 2015 (relates to Figure 2).

Hermitage	**TOS 1 20/5**	**TOS 2 12/6**	**TOS 3 3/7**
Dry matter (t/ha)	9.250a	7.825b	7.492b
Grain Yield (t/ha)	3.3d	3.3d	3.3d

* Note that grain production in this trial was the same for all TOS even with high biomass in the early sowing

Combining dry matter and yield data across 10 sites over 3 years which includes trials sites at Emerald, Kingaroy, Warra, Dalby, Goondiwindi and Hermitage in Figure 3, indicates that chickpeas do not convert biomass to grain with the same efficiency as the production of dry matter increases. There is a very good straight line relationship up to 8t/ha dry matter and it plateaus after this, i.e. the highest yield potential crops do not fully meet their grain production potential. There could be many reasons for this including terminal droughts as a consequence of growing large biomass crops.

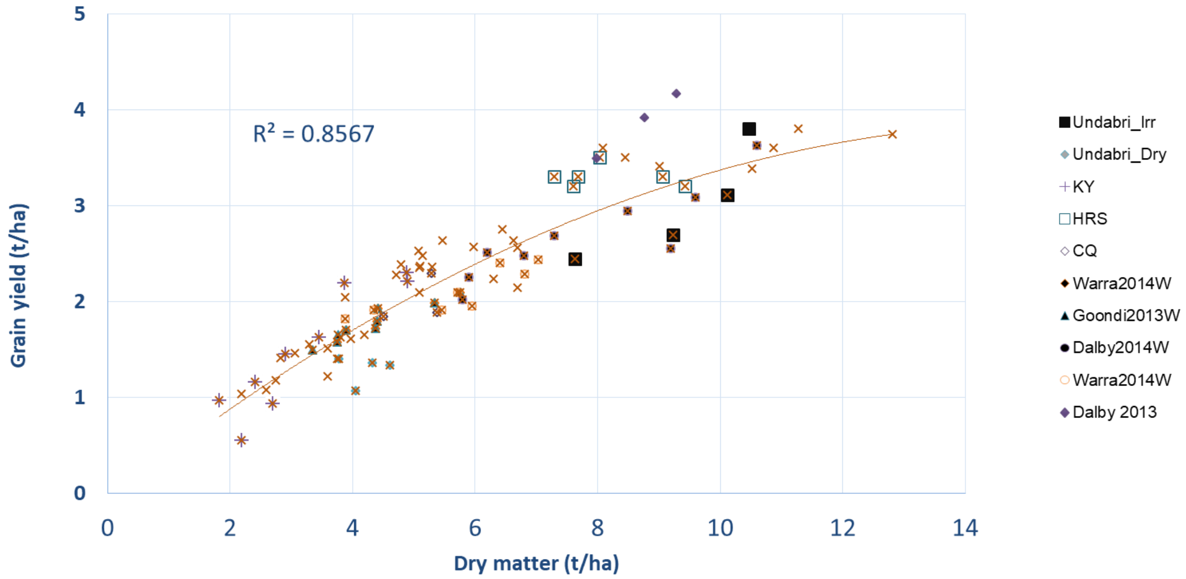

Figure 3. The relationship ship between dry matter production and grain for chickpea trials at 10 sites over 3 years

New directions

These findings have directed subsequent research questions in the Queensland Pulse Agronomy Initiative. The questions to be answered include; can harvest index be manipulated in chickpeas? How best to manage high biomass crops? Can early biomass production be reduced to conserve soil moisture for later in the season?

Trials with many plant growth regulators (PGRs) and other chemicals were conducted in 2016. While there were some products that did have a minimal effect on harvest index (HI), no products improved yields. Work with PGR's has many seasonal, rate and timing variabilities that make consistent results difficult to obtain. Due to this and that currently there are no PGR products registered for use on chickpeas, this aspect of the research was not pursued further.

In other trials, the water use of chickpeas was monitored with neutron moisture meters (NMM) to determine when and where the crop was accessing soil water and to explain why narrower row spacings were able to access more water and convert it more efficiently to grain.

Water use

To monitor soil moisture and where chickpeas are drawing moisture from using the neutron moisture meter (NMM), plots were planted at 2 different row spacings of 50 and 75 cm. Within the plot 2 access tubes were installed, one in the planted row and the other between the 2 rows. In 2016 the variety was PBA HatTrick ⃠ planted at 30 plants/m^2. Access tubes were in all 3 replicated plots and measurements averaged.

This chickpea trial at Hermitage in 2016, had an unusually wet late winter and spring with close to 500 mm of in-crop rain for the main season planting time and 350mm for the later sowing. This led to a very late January harvest and a badly lodged crop. Grain yield results from this trial had no statistical differences across variety and row spacing, with a trend for higher yields at the later sowing time.

For the earlier sowing time, flowering commenced by mid-September. The critical 15°C average temperature for pod retention was not consistent until well into October, with below 5°C minimum temperatures recorded on the 25th of October.

Due to the very wet season, NMM data shows that the crop grew from August to mid-October on rainfall, with soil moisture depletion only starting to occur after this time. This soil draw down coincided with the warmer temperatures and pod retention of the crop. The NMM data shows that even with the high rainfall, soil moisture was removed from the profile to the deepest measuring point of 125 cm (Figure 4). We can only assume the chickpea crop was the cause of this as roots were not assessed.

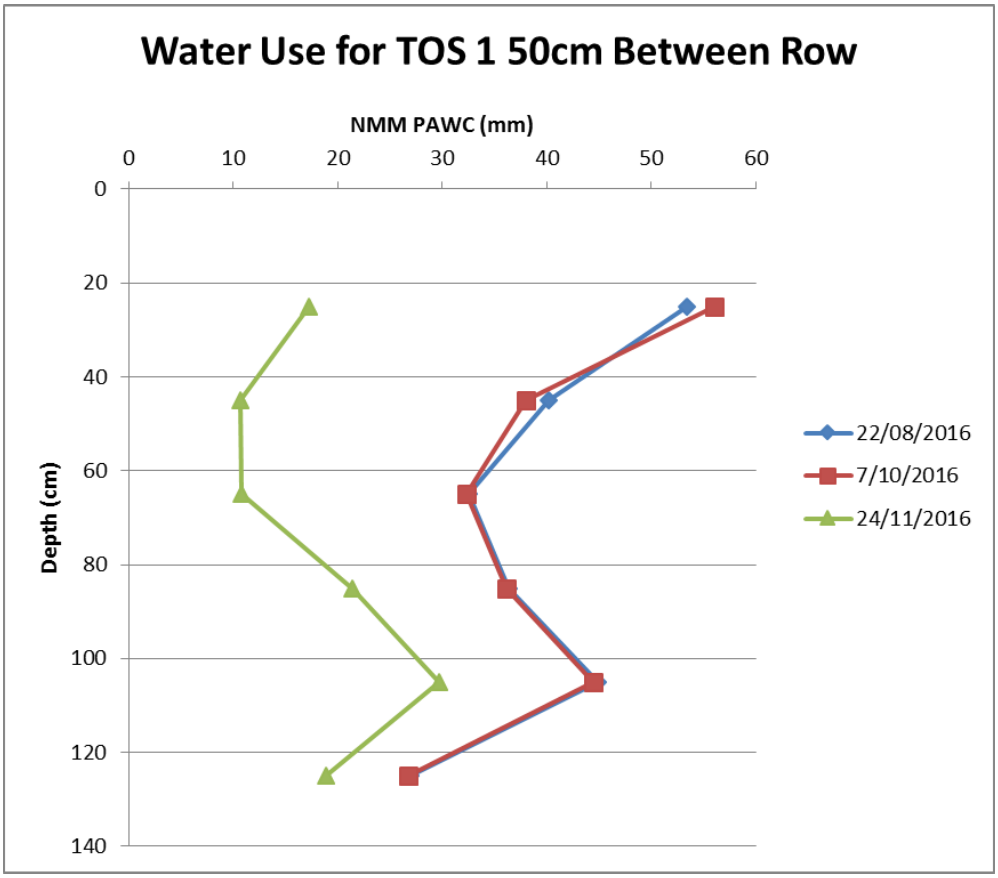

Figure 4. Soil water use as measured by neutron moisture meter at Hermitage Qld. at 3 times during the growing season. Access tube was in the middle of 2 rows planted 50 cm apart.

A further point of interest was from where water was extracted in the different row spacings of 50 cm and 75 cm. In the 50 cm, plots water extraction patterns were virtually the same where measured in the planted row or between the row. In the wider spaced rows at 75 cm, as the season progressed, more water was extracted in the between row space and this occurred in the top 65 cm of the profile. The difference over the season was 30 mm of additional PAWC removed in the inter row space as compared to the on row readings. If you averaged the 2 tubes it would mean an additional 15mm of water extracted in 75cm plot for no additional yield benefit.

In previous trials within the Pulse Agronomy project where starting and ending gravimetric assessments of soil water were taken, the results show that crops planted on narrow row spacing access up to 20mm more of the stored soil water, and due to higher yields convert this moisture more efficiently to grain.

The trial data for chickpeas grown in 2017 which will provide additional NMM data were unavailable at the time of publishing.

Discussion

Chickpeas have the potential for yields approaching 5 t/ha given the right environment/season (this project's best small plot yield 4.7 t/ha dryland). Dry matter production of above 10t/ha and up to 13 t/ha have been produced, and results have seen harvest index of 0.45, however the crop seems unable to maintain a constant harvest index above 8 t/ha dry matter and it is difficult to get the combination of high dry matter and HI.

The results suggest several management options to give the crop the greatest potential; starting with narrow rows. The farming system also needs to be considered, as well as any associated risk with disease for the coming season. Improved yields from narrow rows are evidenced in high and low yield scenarios, with disease pressure high 1 in 7 – 10 years.

Planting early produces large biomass that has a higher disease risk potential. The bigger risk however, is using up stored soil moisture and adding to the possibility of terminal drought and being unable to maintain this yield potential through pod fill.

Chickpeas should be sown into paddocks with good soil depth and minimal soil constraints. It has long been known that chickpeas are very adept at chasing deep moisture and NMM suggests extraction to 125 cm in a soft year. Choosing paddocks with the biggest bucket is highly adventitious for high yields.

Continue with best management crop scouting for pests and diseases and utilise preventative fungicide applications as appropriate.

Management options once the crop is growing, apart from the usual crop protection/good agronomy, have been elusive and work will continue to manipulate the crop to improve harvest index particularly for high biomass crops but also for lower biomass situations.

Current farming systems aim to store rainfall and fill the soil profile between crops. Good management enable the crop to withdraw more from this bank of stored soil water.

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Contact details

Kerry McKenzie
Queensland Department of Agriculture and Fisheries
204 Tor St Toowoomba QLD 4350
Mb: 0477 723 713
Email: kerry.mckenzie@daf.qld.gov.au
Twitter: @onthepulseAUS

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Connecting to our farming future

David Lamb, Precision Agriculture Research Group, University of New England

Key words

SMART farm, sensors, telecommunications, technology, future

Call to action/take home messages

The progression of telecommunications and technology must be accompanied by education and extension. A recent survey identified that more that 60% of Australian farmers did not know of on-farm connectivity options or who to talk to about getting connected. And 'connectivity is king'. Lack of connectivity is identified as one of THE constraints to adopting tools that improve productivity, safety and workflow. There are many challenges and opportunities of getting connected into a SMART farming future that, in 5-10 years, will just be farming. Farmers need to understand the basics of how connectivity works to be able to make informed decisions when getting connected. Government, policy makers and telco providers need to understand what farmers need and why.

Introduction

The role of the internet in agriculture is fast approaching a 'third wave.' The first wave was connecting people to data via the World Wide Web (1990s); the second wave was about connecting people to people e.g. through Facebook and Twitter (2000s). The third wave will connect people to 'things' (2010 onwards). These waves are not specific to agriculture. Developments in the agricultural field are contained within and mirror wider technological progressions that have led us to a place where every part of our lives relies on an internet connection.

In terms of on-farm developments, advances in wireless sensor networks coupled with in-situ, low-cost machine, crop, animal and asset sensors; the so-called 'internet of things' means our farms and fields will become sources of high-quality, real-time management data. Big data is really made up of lots of small data, and will become increasingly useful in day-to-day and long-term management decisions. Some of this data will be utilised alongside intelligent and autonomous systems operating both on ground and in the air.

The SMART Farm

I lead the University of New England's SMART Farm project (Sustainable Manageable Accessible Rural Technologies Farm). UNE has transformed a 2,900 ha, predominantly sheep farm into a SMART Farm which showcases the latest technologies aimed at improving productivity, environmental sustainability, safety, workflow and social/business support networks on Australian farms (www.une.edu.au/smartfarm, 2018). Buts is a CONNECTED farm; linked via AARNet and the national broadband network (fibre, terrestrial wireless AND satellite) because the predominantly grazing SMART Farm is a national demonstrator site.

Examples of the types of sensors we use include 100 soil moisture probes, which create a living map of soil moisture. The farm also has another telemetry network that allows devices to be 'plug-and-played' ranging from monitoring water use in trees, pasture growth through to honey accumulation in beehives.

We are also working with livestock tracking and are investigating opportunities around developing fingerprints of animal behaviour ranging from when they're attacked, if they're calving, whether they have internal parasites and also how much pasture is left behind from grazing.

Live satellite derived pasture data is available through the Pastures from Space™ program. This provides estimates of pasture production during the growing season by means of remote sensing.

Satellite data is used to accurately and quantitatively estimate pasture biomass or feed on offer, or combined with climate and soil data is used to produce estimates of pasture growth rate (https://pfs.landgate.wa.gov.au/).

The SMART Farm is just an example of what the future of farming will look like- buts it's connected to the hilt. In order for that future to be realised across 137,000 Australian farms, action is required in the telecommunications sector.

Telecommunications

As well as sensor technology and big data, telecommunications is a key enabling part of the SMART Farming future. In 2016, the Commonwealth Department on Agriculture and Water Resources initiated a Rural R&D for Profit Research Project entitled 'Accelerating Precision Agriculture to Decision Agriculture' or 'P2D'. One of the aims the project was to deliver 'recommendations for data communications to improve decision making - or decision agriculture'; effectively to undertake a 'telecommunications review' for agriculture. During the period of August 2016 – June 2017, a series of eight workshops, numerous phone interviews and site visitations around Australia sought to understand the current status of on-farm telecommunications at the farm level in support of a big data future for agriculture. This review sought a 'producer-eye' view, seeking to understand the dimensions of key enabling telecommunications utilised by producers, factors constraining the uptake or adoption of available enabling technologies, as well as investigating the future telecommunications needs and opportunities. Information was solicited from not only producers, but also developers and providers of technologies and data services, as well as looking at the developments 'top-down' such as the ACCC Inquiry into Domestic Mobile Roaming and the Productivity Commission Review of the Universal Services Obligation (USO).

In the last couple of years the notion of telecommunications as a 'critical infrastructure' for rural and regional Australia, and in particular in agriculture, has at last well and truly taken root. Over this period there has also been a significant increase in the development of end-to-end telecommunications technologies and services offered to producers. These so-called 'second-tier' telecommunications providers (as distinct from the 'big telcos'), also offer their own transmission backhaul capability and in some cases associated cloud based services. Moreover they seek to 'guarantee' speeds. Second tier providers will help extend the value and potential of existing NBN and mobile telecommunication networks. The role of telecommunications in supporting a big data future in agriculture is not necessarily technology constrained; if a farm has access to the mobile network somewhere on the farm, or NBN into the farm house then there is invariably technology available to beam it to where it is needed. But the external connectivity MUST be stable 24/7. There is little value having high speed internet for only short periods of the day. If this is the case, as it often is, then at least we should be able to know IN ADVANCE when that will be so we can work to get the best out of it. Reliability is as important as absolute speed, and speed is different from signal 'strength' or 'reception'. The other real constraint is around service and price. Entirely new innovative methods of extending connectivity over remote regions are in the R&D pipeline; some are even surfacing now. Others have been around for some time and overlooked. It is time to visit or revisit them. Business models are evolving, and need to evolve further to support the types of connectivity functionality that farmers need.

The on-farm telecommunications market is rapidly evolving but like with all things in precision agriculture, education is one of the biggest challenges faced by both those looking for solutions and those offering solutions. Industry needs well-curated case studies and education/educators must target not only consumers of telecommunications services but also technology developers and service providers seeking to put something in the market place.

Conclusion

The progression of telecommunications and technology must be accompanied by education and extension. A recent survey identified that more that 60% of Australian farmers did not know of on-farm connectivity options or who to talk to about getting connected. There are many challenges and opportunities of getting connected into the SMART farming future that, in 5-10 years, will just be farming.

Acknowledgements

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Contact details

David Lamb
Precision Agriculture Research Group, University of New England
Armidale, NSW, 2351
Email: dlamb@une.edu.au

Setting the farm up for broadband connectivity

Nick Gillingham, Keytah

Contact details

Nick Gillingham
Mb: 0427 253 581
Email: nick.gillingham@bigpond.com

Notes

KEY CONTACTS

NORTHERN REGION

TOOWOOMBA
Unit 4, 4 Tourist Road,
Toowoomba QLD 4350
P: +61 7 4571 4800

PO Box 4697
East Toowoomba,
QLD 4350 Australia
northern@grdc.com.au

APPLIED R&D GROUP

SENIOR REGIONAL MANAGER NORTH
Jan Edwards
Jan.Edwards@grdc.com.au
M: +61 4 2960 7357

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

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

CONTRACT AND TEAM ADMINISTRATOR
Linda McDougall
Linda.McDougall@grdc.com.au
P: +61 7 4571 4801

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

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

GROWER COMMUNICATION AND EXTENSION GROUP

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

BUSINESS AND COMMERCIAL GROUP

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

APPLIED R&D GROUP (DUBBO OFFICE)

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

DUBBO OFFICE
2/2 Blueridge Drive,
Dubbo NSW 2830
P: +61 4 2728 9783

PO BOX 4262
Dubbo East LPO,
NSW 2830
Australia