GRDC Grains Research Update

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Tuesday, 23rd & Wednesday, 24th February 2016

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GRDC Grains Research Update

Day 1 – Tuesday 23rd February, 2016

Time	Topic	Speaker (s)
10:00 AM	**Welcome**	**GRDC**
10:15 AM	**Coupling pre-emergent herbicides & crop competition for big reductions in weed escapes** *(page 18)*	**Chris Preston** (University of Adelaide)
10:50 AM	**Characterising soils for plant available water capacity - methods, tools, accuracy & drivers of fallow efficiency** *(page 23)*	**Brett Cocks & Kirsten Verburg** (CSIRO)
11:25 AM	**Calculating water use efficiency in the northern region - should evaporation losses be deducted?**	**Andrew Verrell** (NSW DPI)
11:50 AM	**Driving the new soil water app** *(page 50)*	**David Freebairn**
12:10 PM	**GOA –key outcomes & engagement** *(page 60)*	**Maurie Street** (GOA)
12:20 PM	*Lunch*	
1:20 PM	**Concurrent session 1** *(See concurrent sessions for details)*	
3:05 PM	*Afternoon tea*	
3:35 PM	**Concurrent session 2** *(See concurrent sessions for details)*	
5:20 PM	**Close**	
6:40 PM	**Pre-dinner drinks** *(courtesy of Nufarm - Acacia Restaurant)*	
7:30 PM	**Dinner (*Acacia Restaurant -* *Touch of Australian Bush Cuisine*)**	

Day 2 – Wednesday 24th February, 2016

Time	Topic	Speaker (s)
8:30 AM	**Concurrent session 3** *(See concurrent sessions for details)*	
10:15 AM	*Morning tea*	
10:45 AM	**Concurrent session 4** *(See concurrent sessions for details)*	
12:30 PM	*Lunch*	
1:30 PM	**"Big data is lots of small data in a common platform"** Managing big data in grain production - new opportunities & challenges *(page 211)*	**Mark Pawsey** (SST Software Australia)
2:00 PM	**Using remote data sources to improve agronomic management** *(page 215)*	**Ben Boughton** (Nuffield Scholar & CEO Satamap)
2:25 PM	**Understanding & managing N loss pathways** *(page 222)* • Where do losses occur, how big are they & what are the drivers • The impact of N source • Urease & denitrification inhibitors	**Mike Bell** (QAAFI) & **Graeme Schwenke** (NSW DPI)
3:05 PM	**Rust - what worked, what didn't & what's new** *(page 230)* • Suntop⊕ & Gregory⊕ in 2015 • New leaf rust strain - what to look out for • Why we need minimum varietal disease standards	**Steve Simpfendorfer** (NSW DPI)
3:20 PM	**Close**	

Location of concurrent sessions

	Main auditorium	Side room	Dramatic society
Day 1			
Sessions 1 and 2	Frost & cereal agronomy *(page 66)*	Canola, pulses & insects *(page 74)*	Nematodes & soil health *(page 112)*
Day 2			
Session 3 and 4	Crown-rot & weeds *(page 135)*	P&K, day degrees & dual purpose crops *(page 166)*	Soil water *(page 202)*

Concurrent sessions – Day 1

Frost & cereal agronomy (sessions 1 & 2 on day 1)

Field ready frost research for central NSW & the Liverpool Plains Varieties, management & environment • Varietal susceptibility • Management • Predicting frost impact & mapping frost events	Richard MacCallum (NSW DPI)
Wheat, yield & quality drivers • VSAP, time of sowing, nutrition, crown-rot & seeding rate • Varieties & haying-off in 2015	Rick Graham & Greg Brooke (NSW DPI)
Durum agronomy • VSAP, time of sowing, agronomy & nutrition • Early sowing windows • Crown-rot responses	Rick Graham (NSW DPI)
Frost risk, date of flowering, yield, temperature change - matching varieties to elevation in the same paddock	Matt Gardner (AMPS)

Canola, pulses & insects (sessions 1 & 2 on day 1)

Matching canola variety to sowing date & yield expectation	Leigh Jenkins (NSW DPI)
Pushing pulse crop yield • 2015 agronomy trial update for chickpea & fababean • Chickpea podding patterns in 2015 • Frost risk in chickpeas & stubble • PBA Nasma⦶ fababeans - can we keep small seed for sowing?	Andrew Verrell & Leigh Jenkins (NSW DPI)
Aphids & new research on other insects • Aphids direct damage vs viral transmission & beneficials in spray decisions • Better thresholds for Heliothis & mirids in fababean • Rutherglen bug after canola	Melina Miles (DAF Qld)

Nematodes & soil health (sessions 1 & 2 on day 1)

Nematodes - "If you know nematode numbers at harvest, we can predict how long it takes for them to decline to less than 2K/kg" • The science behind population change • Response curves & rules of thumb for different situations	Jeremy Whish (CSIRO)
Soil health, biology, diseases & sustainable agriculture - links between soil properties & plant health.	Graham Stirling (Biological Crop Protection)
Herbicide impacts on soil biology - a multi-state & year study & review of literature	Lukas van Zwieten (NSW DPI)

Concurrent sessions – Day 2

Crown-rot & weeds (sessions 3 & 4 on day 2)

Crown-rot research • Fungicides & varieties • PredictaB® as a management tool • The impact of tillage	Steve Simpfendorfer (NSW DPI)
GOA weeds research • Resistance survey data • Pre-emergent herbicides • Windrow burning & fallow efficiency	Maurie Street (GOA)
Non herbicide tactics - row orientation & crop competition	Greg Brooke (NSW DPI)
Adviser experience managing glyphosate resistant ryegrass	Peter McKenzie (Agricultural Consulting & Extension Services)
Weeds discussion Sequencing tactics; will costs send growers broke; issues with increased use of pre-emergent herbicides; effecting change	

P&K, day degrees & dual purpose crops (sessions 3 & 4 on day 2)

P & K nutrition • Critical test values & P & K interactions • Trade-off between rate, when & how it's applied? • Seasonal responses patterns • Chickpeas as a 'canary crop' for K deficiency • On-farm trials, test strips & 'best bet' options	Mike Bell (QAAFI) & Rick Graham (NSW DPI)
Day degrees for crop management	Jeremy Whish (CSIRO)
Optimising productivity in dual-purpose crops – new tool to help manage lock-up & other decisions	John Kirkegaard (CSIRO)
Panel session - the pros & cons of dual purpose crops • Profit, risk management, cash flow, grazing & follow crop issues with weeds, water & nitrogen	Keith Harris, John Kirkegaard (CSIRO), Bob Freebairn & Andrew McFadyen (Paspaley Pearls Properties)

Soil water (sessions 3 & 4 on day 2)

<table>
<tr>
<td>Profit from better soil water decisions - closing the yield gap workshop

Soil water, yield, gross margins, pillar crops & rotations
Optimising soil moisture
Yield projections, WUE & benchmarks & harvest index impact
Fallow length & opportunity crop impact on gross margin
Planting time, WUE & moisture seeking capability impact on wheat margins
Risk management & resilient farming systems - diversification of crops, sowing times & inclusion of fallow
Monitoring moisture & analysing data on yield, WUE & profit

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<td>Simon Fritsch & Peter Wylie (AgriPath)</td>
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SOIL WATER WORKSHOP CONCURRENT SESSION (DAY 2)

GENERAL PLENARY SESSION DAY 2

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Coupling pre-emergent herbicides and crop competition for big reductions in weed escapes

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School of Agriculture, Food & Wine, University of Adelaide

Key words

Crop competition, pre-emergent herbicides, herbicide resistance, time of sowing, wheat, canola

GRDC code

UCS00020

Take home message

Extensive resistance to post-emergent herbicide in grass weeds means greater reliance on pre-emergent herbicides for weed control.

Early sowing of wheat coupled with effective pre-emergent herbicide packages can provide greater competition against grass weeds, increase wheat yields and limit grass weed seed set.

The competition provided by hybrid canola cultivars provides an opportunity to reduce annual ryegrass seed set by about 50% compared to open-pollinated cultivars.

Why crop competition again?

The increasing occurrence of herbicide resistance in grass weeds in particular is creating new challenges for weed management in crops. Over recent decades there had been the introduction of a suite of herbicides that could control grass weeds post-emergent in crops. This made grass weed management relatively simple. As resistance to these post-emergent herbicides has increased to the point where few of them are effective any more, there has been greater reliance on pre-emergent herbicides.

Pre-emergent herbicides are more difficult to use than post-emergent herbicides for effective weed control. They need to be applied before the weeds emerge, need to be close to the weed seed in the soil and need the right moisture conditions to activate. These herbicides also rely on residual activity to control weeds after the crop has emerged. This leads to situations where weed escapes occur early in the season and these escapes, if not managed, set a large amount of seed.

Crop competition has long been known to be a useful tool in weed management. Practices such as decreasing row spacing, increasing seeding rates and growing more competitive cultivars have all been demonstrated in research settings as practices that can reduce grass weed impacts. However, adoption of more competitive crops has been mixed. There are numerous reasons for this including seeder design, the need to manage stubble at sowing, other priorities in crop management, reducing costs and risk management. Where post-emergent herbicides still work the value of crop competition is less obvious and other management desires can take precedence. As a result of the escapes from pre-emergent herbicides and the lack of later management options, crop competition becomes much more important in the absence of effective post-emergent herbicides. The question is not so much: “Do I need to employ crop competition?”, but “How do I improve crop competition in a practical way?”

Over the past few years, we have been looking at how to improve weed control where pre-emergent herbicides are the only grass weed options. This work has highlighted a couple of opportunities for reducing weed seed set through improving the competitive nature of the crop in combination with pre-emergent herbicides.

The interaction of sowing date and pre-emergent herbicides for grass weed control in wheat

It has been a long held mantra that weedy paddocks should be sown last in the cropping rotation. This is so an extra knockdown application, or a double knock, can be employed to reduce the number of weeds emerging in the crop. This is a perfectly valid practice when post-emergent herbicides can be employed to clean up the remainder of the weed problem and has the added benefit of taking pressure of post-emergent herbicides.

However, one consequence of later sowing is that wheat grows more slowly as the soil temperature decreases going into winter, taking more time for canopy closure and giving weeds a greater opportunity to use resources. The question is whether in the absence of post-emergent herbicides, sowing the worst paddocks last is still the best strategy.

In collaboration with the Hart Fieldsite Group we conducted a trial in 2014 with two times of sowing. Scout wheat was sown on 4 May and 2 June 2014. There was a knockdown herbicide treatment between the two sowing times. Pre-emergent herbicide treatments used at each time of sowing were: nil, Sakura® (118 g ha^{-1}) and Sakura (118 g ha^{-1}) + Avadex® Xtra (2 L ha^{-1}) .

In this trial, the delay in sowing did not lead to a reduction in the number of ryegrass plants present in crop (Table 1). Where no pre-emergent herbicide was used, there were more head counts from the early time of sowing. In contrast, where effective pre-emergent herbicides were used there was no difference in the number of seed heads produced. Wheat yield from TOS1 was 4.15 T ha^{-1} and from TOS 2 2.93 T ha^{-1}.

Table 1. Annual ryegrass present in crop and seed heads at maturity for two times of sowing (TOS) at Hart in 2014. For each measurement, different letters indicate significant differences in means.

Pre-emergent herbicide*	Plant counts (8 Aug) (m^{-2})		Head counts (10 Oct) (m^{-2})	
	TOS1	TOS2	TOS1	TOS2
Nil	59 a	77 a	350 a	164 b
Sakura (118 g ha^{-1})	8 b	8 b	39 c	41 c
Sakura (118 g ha^{-1}) + Avadex Xtra (2 L ha^{-1})	3 b	3 b	32 c	9 c

*Rates listed in this table are for trial purposes. If using these products commercially ensure you follow the rates listed on the registered labels.

The 2014 season in SA ended with an exceptionally dry spring period, although there was enough stored early moisture to allow most crops to finish well. There had also been abundant winter rainfall that helped pre-emergent herbicides to work well.

In 2015 we conducted a trial at Roseworthy, SA where we used three times of sowing. Mace wheat was sown on 8 May, 27 May or 9 Jun 2015. There was a knockdown herbicide treatment prior to each sowing time. Pre-emergent herbicide treatments used at each time of sowing were: nil, Sakura (118 g ha^{-1}), Boxer Gold® (2.5 L ha^{-1}) and Sakura (118 g ha^{-1}) + Avadex Xtra (2 L ha^{-1}).

In this trial (Table 2), the numbers of annual ryegrass plants remaining in the crop were high for all treatments. Sakura + Avadex Xtra had the lowest numbers. Seasonal conditions during 2015 in SA were difficult. Rainfall around sowing was patchy, but there were good falls of rain through July and August before rainfall fell away again. The early patchy rainfall meant that pre-emergent herbicides struggled and the good rains in July and August germinated a late cohort of ryegrass.

Despite this, the herbicides were effective at reducing annual ryegrass seed heads. Sakura + Avadex Xtra was the most effective pre-emergent herbicide option. The early applications of Sakura and Boxer Gold struggled; Sakura as a result of the low rainfall for 2 months after sowing and Boxer Gold due to its shorter persistence. The trial was not harvested as it was destroyed by the Pinery fire.

Table 2. Annual ryegrass present in crop and seed heads at maturity for three times of sowing (TOS) at Roseworthy in 2015. For each measurement, different letters indicate significant differences in means.

Pre-emergent herbicides*	Plant counts (25 Aug) (m^{-2})			Head counts (1 Oct) (m^{-2})		
	TOS1	TOS2	TOS3	TOS1	TOS2	TOS3
Nil	441 a	239 ab	439 a	585 a	285 b	287 b
Sakura (118 g ha^{-1})	179 ab	176 ab	241 ab	140 bcd	58 cde	53 de
Sakura (118 g ha^{-1}) + Avadex Xtra (2 L ha^{-1})	112 b	109 b	139 b	47 de	28 e	19 e
Boxer Gold (2.5 L ha^{-1})	128 b	241 ab	176 ab	171 bc	66 cde	55 de

*Rates listed in this table are for trial purposes. If using these products commercially ensure you follow the rates listed on the registered labels.

These trials have demonstrated that early sowing of wheat with an effective pre-emergent herbicide package can provide at least as good control of annual ryegrass compared to later sowing with an additional knockdown herbicide. The reason is that early sown wheat is more competitive than later sown wheat and tends to reduce the number of seed heads produced per plant. The higher yields that typically occur with earlier sowing of wheat mean that more crop is produced for the same number of weed seeds.

There are risks associated with this strategy, particularly in very weedy paddocks. The most important is the increased risk of patchy moisture conditions after sowing leading to poorer performance of pre-emergent herbicides. Boxer Gold can also struggle with high moisture conditions in the middle of the season leading to additional germination events after the herbicide is dissipated. A robust pre-emergent package appears essential for early sowing of wheat.

Hybrid canola and pre-emergent herbicides for grass weed control in wheat

Clethodim resistance in annual ryegrass has become a major concern for canola production. During 2013 and 2014 we conducted trials to examine potential new herbicides for the control of clethodim-resistant annual ryegrass in TT and Clearfield® canola at Roseworthy, SA. These trials were sown on 17 May 2013 and 23 May 2014. The varieties used were ATR Stingray (TT) and Pioneer® 45Y84 hybrid (Clearfield) and were sown to achieve plant stands of 50 plants m^{-2} for the TT canola and 35 plants m^{-2} for the Clearfield canola. Several pre-emergent herbicide options used alone were compared with current usual practice of a pre-emergent herbicide followed by post-emergent herbicides. The population was tested as resistant to clethodim, but was also clearly resistant to Group B and Group D herbicides.

The results of these trials were that pre-emergent herbicides alone would be ineffective at managing annual ryegrass in canola. However, it became clear that the surviving annual ryegrass plants set a lot more seed in TT canola than it did in hybrid Clearfield canola (Table 3). Typically there was more than twice as much ryegrass seed produced in the open-pollinated TT canola than in the hybrid Clearfield canola. This was a result of the slower-growing open-pollinated TT canola achieving canopy closure much later than the hybrid Clearfield canola. The result was that each surviving ryegrass plant had more opportunity to set seed.

Table 3. Annual ryegrass plants in crop, annual ryegrass seed production and canola yield at Roseworthy in 2013 and 2014. Different letters in each column for each year indicate significant differences in means (there was no significant difference for yield of Clearfield canola in 2014).

Pre-emergent herbicide**	Ryegrass plants (m^{-2})		Ryegrass seeds (x1000 m^{-2})		Yield (T ha^{-1})	
	2013					
	ATR Stingray	45Y82 (CL)	ATR Stingray	45Y82 (CL)	ATR Stingray	45Y82 (CL)
Usual practice*	171 a	47 a	1.82 a	1.40 a	2.15 a	1.73 a
Rustler (1 L ha^{-1})	96 a	63 a	15.83 b	4.58 b	1.68 b	1.62 ab
Experimental A	269 b	186 c	21.70 b	5.80 bc	1.62 b	1.48 b
Experimental B	381 c	198 c	34.82 c	8.86 d	1.30 c	1.60 ab
Experimental C	133 a	101 b	22.31 b	7.37 c	1.65 b	1.60 ab
	2014					
Usual practice*	522 ab	632 a	6.79 a	5.40 a	1.69 a	1.71
Rustler (1 L ha^{-1})	354 a	553 a	32.78 b	17.27 ab	1.49 ab	1.65
Experimental A	864 b	1697 b	51.47 c	45.35 c	1.15 b	1.41
Experimental B	869 b	1643 b	51.19 c	27.11 b	1.26 b	1.36
Experimental C	767 b	1088 b	54.53 c	26.45 b	1.31 b	1.62

* Usual practice was Atrazine (1.5 kg ha^{-1}) pre followed by 240 gai/L Clethodim (500 mL ha^{-1}) post for TT canola (ATR Stingray) and Trifluralin (2 L ha^{-1}) + Avadex Xtra (2 L ha^{-1}) pre followed by Intervix (750 mL ha^{-1}) + 240 gai/L Clethodim (500 mL ha^{-1}) post for Clearfield canola (45Y82).
**Rates listed in this table are for trial purposes. If using these products commercially ensure you follow the rates listed on the registered labels.

In 2015 a further trial was conducted at Roseworthy, SA that included three TT canola cultivars: ATR Stingray (open-pollinated), Hyola 559TT (a hybrid) and Hyola 750TT (a high biomass hybrid). The trial was sown on 15 May 2015 with a target population of 35 plants m^{-2}. There were three herbicide management strategies employed: Herbicide Treatment 1 - no herbicides; Herbicide Treatment 2 - Atrazine (1.5 kg ha^{-1}) pre followed by Clethodim (500 mL ha^{-1}) post; and Herbicide Treatment 3 - Rustler (1 L ha^{-1}) pre followed by Clethodim (500 mL ha^{-1}) + Factor (80 g ha^{-1}) + Atrazine (1.1 kg ha^{-1}) post.

In this trial there was a significant effect of both cultivar ($p < 0.0001$) and herbicide treatment ($p < 0.0001$) on the number of annual ryegrass spikes present at maturity. The annual ryegrass population at the site was resistant to clethodim, so post-emergent treatments were not very effective. The high biomass canola (Hyola 750TT) significantly reduced the number of annual ryegrass spikes at harvest compared to the other two cultivars in the absence of herbicides (Herbicide Treatment 1), demonstrating the impact of extra competition provided by this cultivar (Figure 1). Where Herbicide Treatments 2 and 3 were employed (Figure 1), there was about twice the number of annual ryegrass spikes at maturity in the ATR Stingray plots compared with the two hybrid cultivars. Simply changing from an open-pollinated cultivar to a hybrid canola has the potential to reduce annual ryegrass seed set by half.

South Australia experienced a hot and dry spring during 2015 and so canola yields in this trial were low. The early finish to the season did not suit the longer season cultivars and in addition yield of Hyola 750TT was affected by frost. There were significant effects of cultivar ($p = 0.042$) and herbicide treatment ($p < 0.001$) on canola yield; however, the highest yield was only 1.17 T ha^{-1} for Hyola 559TT with Herbicide Treatment 3.

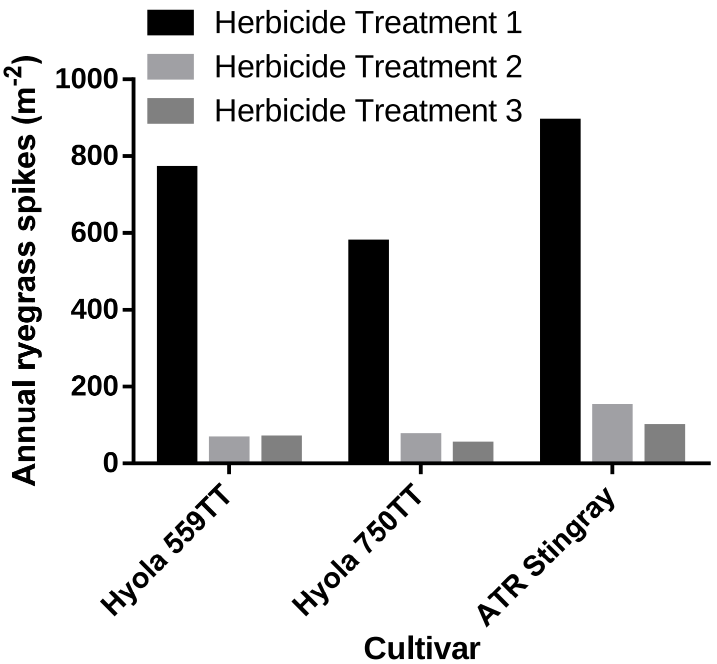

Figure 1. Effect of canola cultivar and herbicide treatment on annual ryegrass spike numbers at maturity at Roseworthy in 2015. Herbicide Treatment 1: no herbicides; Herbicide Treatment 2: Atrazine (1.5 kg ha^{-1}) pre followed by 240 gai/L Clethodim (500 mL ha^{-1}) post; and Herbicide Treatment 3: Rustler (1 L ha^{-1}) pre followed by 240 gai/L Clethodim (500 mL ha^{-1}) + Factor (80 g ha^{-1}) + Atrazine (1.1 kg ha^{-1}) post.

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The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. The authors would also like to thank collaborators at the Hart Fieldsite Group for hosting and managing a field trial and Pacific Seeds for providing canola seed and funding additional weed suppression trials.

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Drivers of fallow efficiency: Effect of soil properties and rainfall patterns on evaporation and the effectiveness of stubble cover

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Key words

Plant Available Water (PAW), Plant Available Water Capacity (PAWC), fallow management, stubble retention

GRDC code

CSP00170 and past projects CSA00013 and ERM00002.

Take home message

- Soil properties (bulk soil and surface conditions) affect fallow efficiency through their effects on the different water balance terms.
- Rainfall patterns affect fallow efficiency as well as the effectiveness of stubble cover to reduce evaporation losses.
- The more limited effect of stubble retention on evaporation does not take away the benefits stubble cover provides in protecting the soil surface, increasing infiltration and reducing runoff and erosion.

Plant available water at sowing and fallow efficiency

Plant available water (PAW) at sowing will depend on water left behind by a previous crop, rainfall amount during the fallow and its distribution, efficiency of water infiltration (versus runoff), evaporation, water use (transpiration) by weeds, drainage beyond the root zone and in some cases subsurface lateral flow. Fallow efficiency, defined as the proportion of rain falling during the fallow period that becomes PAW, is similarly affected by these water balance terms (Figure 1).

Fallow management like stubble retention or weed control can change the magnitude of some of these water balance terms. In this paper we discuss how soil properties and rainfall patterns affect evaporation and the effectiveness of stubble cover.

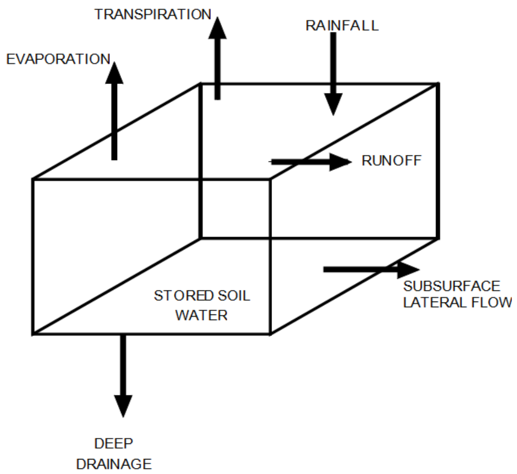

Figure 1. The relative magnitude of the different water balance terms determines the balance of inputs and losses and hence the fallow efficiency.

Impact of soil properties on evaporation

Just like soil properties affect the Plant Available Water Capacity (PAWC; see Verburg et al. paper in these proceedings), they also influence the magnitude of the different fallow water balance terms and hence PAW and fallow efficiency. The smaller particle size of clay soils allows them to hold larger quantities of water than sandy soils (i.e. lower drainage losses), but also causes the pore space (space between particles) to be finer. This reduces the water infiltration rate and can increase runoff losses, particularly in high intensity rainfall events and following prolonged rainfall. Soil surface conditions can, however, dramatically change this picture: open cracks in shrink-swell soils will aid infiltration, whereas surface sealing will increase runoff.

The higher PAWC of clay soils also means that water from small events is stored close to the soil surface where it will often be lost to evaporation if no follow up rain occurs. In sandy soils the water will infiltrate deeper into the profile.

Evaporation can dry the soil to below the crop lower limit in the surface layer. While this is a slow process in clay soils, the amount of rainfall needed to replenish this unavailable 'bucket' following a prolonged dry period will be larger in a clay soil than in a sandy soil. This is illustrated in Figure 2 where a sandy clay loam soil can hold 11.9 mm of water between the air-dry value and drained upper limit, but with only 8.7 mm available to the plant and an unavailable water capacity (UWC) of 3.2 mm. If evaporation had dried the soil to air dry and we had a 10mm rainfall event only 6.8 mm would be available for plant growth.

In contrast the heavy clay soil in Figure 2 holds 42mm between air dry and drained upper limit of which 20 mm is available for plant growth. In the same scenario as before, if the soil was dry and we had a 10 mm rainfall event there would be no water available for plant growth, unless it want down a deep crack into deeper and less dry soil. Over 22mm of rain needs to fall to fill the unavailable bucket in the surface of this soil. Fortunately, the fine structure of the heavy clay soil also means the unavailable bucket will take a long time to dry out, so that on many occasions only the upper layers of the soil will need to be refilled.

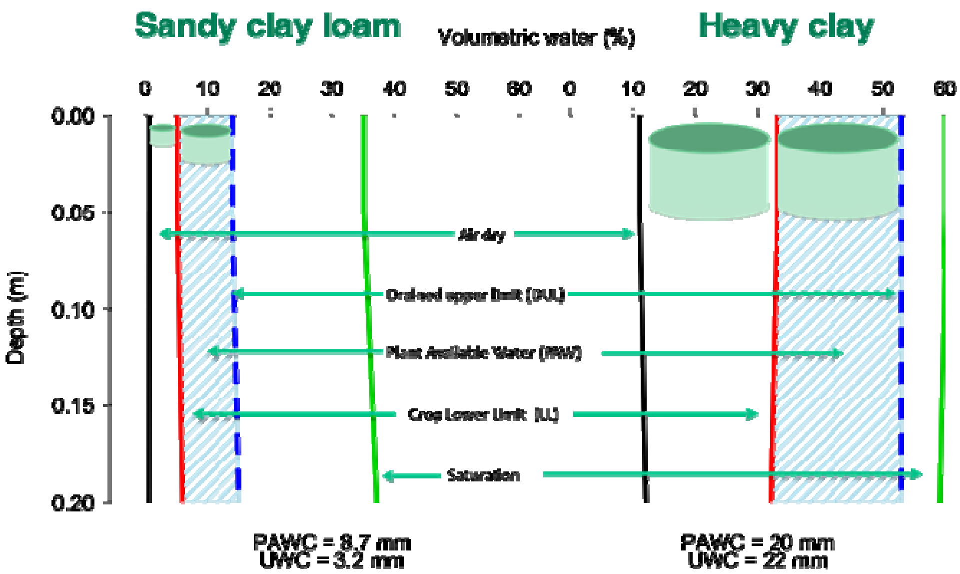

Figure 2. Conceptual diagram of the difference in unavailable water bucket size (UWC) in the surface 20 cm of a sandy clay loam and a heavy clay soil

Impact of rainfall pattern

The interaction between depth of infiltration and susceptibility to evaporation loss also plays a role in determining the effectiveness with which rainfall is turned into PAW for the subsequent crop. Unless runoff is an issue, large rainfall events will infiltrate deeper than small events, allowing some of the water to be pushed below the evaporation zone and contribute to PAW at sowing. Single, isolated rainfall events have, however, typically a lower efficiency than more frequent events. When two or more rainfall events occur closely together, the resulting soil water 'pulses' can build on each other (Figure 3). The amount of water needed to refill the unavailable bucket in the surface layer (following evaporation) is reduced, thereby allowing the water to move deeper into the profile.

The amount of overlap between soil water 'pulses' is affected by a balance between pulse frequency and pulse duration. Rainfall frequency is the driver behind pulse frequency, whereas pulse duration is affected by the amount of infiltrated rainfall, evaporative demand, stubble cover and soil type.

The above illustrates why the same amount of rainfall can result in different fallow efficiencies. Surface conditions can, however, complicate the picture. Surface sealing following multiple or prolonged rainfall events can reduce the infiltration rate and increase runoff. Conversely, a single large storm on a dry cracking clay soil can infiltrate deeper via the open cracks.

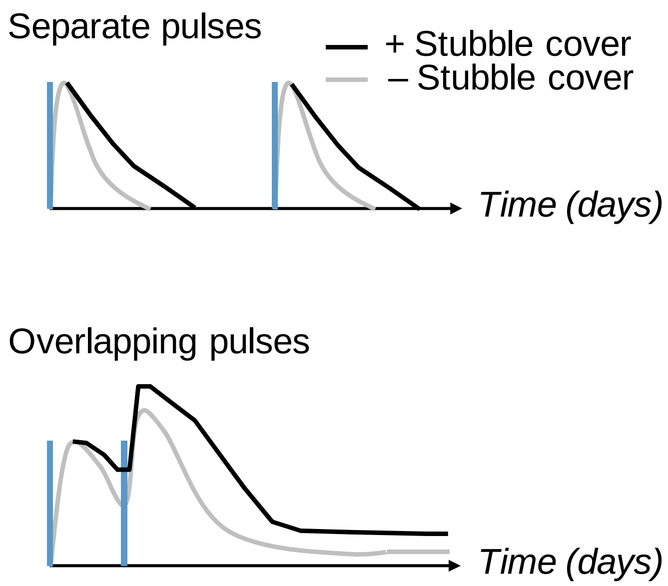

Figure 3. Rainfall events (vertical blue bars) cause pulses of soil water that last for different amounts of time in the presence (black lines) or absence (grey lines) of stubble. When pulses overlap, more water infiltrates beyond the evaporation zone in the presence of stubble cover and this will increase fallow efficiency. (Adapted from Verburg et al. 2010)

Impact of rainfall pattern on the effectiveness of stubble to reduce evaporation

While rainfall pattern effects are beyond our control, fallow efficiency can be maximised by reducing the losses. Several trials in recent years have demonstrated that weed control dramatically reduces transpiration losses (e.g. Hunt et al. 2011; Routley 2010) and that stubble retention increases infiltration and hence reduces runoff losses (Whish et al. 2009; Hunt et al. 2011). The effect of stubble and stubble management (e.g. standing vs. flattened stubble) on reducing evaporation losses has, however, often disappointed people with many trials returning no significant treatment effects (e.g. Scott et al. 2010; Hunt et al. 2011; Hunt 2013). The exception is when large amounts of stubble are concentrated on a smaller area to create high loads (Hunt et al. 2011).

The observed limited effectiveness of stubble cover to reduce evaporation losses can be explained using the same concept of soil water pulses. The high evaporative demand experienced during summer in Australia limits the duration of the soil water pulses. In the case of sparse rainfall events this allows the system with stubble cover to 'catch up', despite the initial reduction in evaporation. Freebairn et al. (1987) showed this experimentally in soil evaporation studies using shallow weighing lysimeters. Stubble cover slowed evaporation for around 3 weeks following rainfall, but there was no longer term benefit to soil moisture levels. If the next rainfall event occurs prior to the system catching up, soil water will move deeper in the system with stubble cover and may store (more) water beyond the nominal evaporation zone. A higher level of stubble cover (as in experiments by Northern Grower Alliance, 2015) will prolong the duration of the soil water pulse, increasing the chance of events overlapping and of causing a lasting increase in PAW. In the event of small, isolated rainfall events, high loads of stubble may be detrimental to overall PAW with the water captured in the stubble layer and prone to evaporation.

As shown in Figure 3, evaporative demand plays a role too. A lower evaporative demand will lengthen the duration of soil water pulses and hence increase the chance of pulses to overlap. Indeed simulations as well as data from lysimeter experiments near Wagga Wagga by Verburg et al. (2012) showed that stubble cover later in autumn and early winter (when evaporative demand was lower and rainfall frequency higher) did cause a significant reduction in evaporation (10-15 mm over an 8-week period following sowing into a stubble load of 4 t/ha while differences over the preceding 4 months during summer were only 3-4 mm).

Final remarks

Understanding the drivers of fallow efficiency and awareness of the particular conditions experienced during the fallow will assist in explaining observed PAWs and predict which fallow seasons may have higher or lower fallow efficiency. When using PAW to inform management decisions, it is, however, recommended to confirm actual PAW levels through measurement (soil core, push probe).

While this paper specifically discussed the evaporation loss term of the water balance, it should be noted that the more limited effect of stubble retention on evaporation does not take away the benefits stubble cover provides in protecting the soil surface, increasing infiltration and reducing runoff and erosion.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. The concepts and findings presented in this paper were developed as part of GRDC projects CSP00170, CSP00111, CSA00013 and ERM00002.

References

Freebairn, D.M., Hancock, N.H. and Lott, S.C. (1987), Soil evaporation studies using shallow weighing lysimeters: Techniques and preliminary results, Trans. Mech. Engn., Inst. Engn. Australia, Vol. ME12. pp 67-72.

Hunt J et al. (2011) Summer fallow management. GRDC Update paper. https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/02/Summer-fallow-management

Hunt J (2013) Control summer weeds to reap yield benefits. Ground Cover Supplement-Water Use Efficiency, edited by J Paterson. Grains Research and Development Corporation, Canberra. March-April 2013. ISBN 1039-6217.

Northern Grower Alliance (2015) Stubble impact on fallow water efficiency in western zones 2014/15. Project report – Results in a nutshell. http://www.nga.org.au/results-and-publications/download/356/project-reports-general/results-in-a-nutshell/stubble-impact-on-fallow-water-efficiency-2014-15.pdf

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

Scott BJ, Eberbach PL, Evans J and Wade LJ (2010) Stubble Retention in Cropping Systems in Southern Australia: Benefits and Challenges. EH Graham Centre Monograph Series Monograph No. 1 (http://www.csu.edu.au/research/grahamcentre/research/publications/stubble-retention-SA.htm)

Verburg K, Bond WJ, Hunt JR (2010) Variable soil water accumulation under fallow management: Explanation using a pulse paradigm. In "Food Security from Sustainable Agriculture" Edited by H. Dove and R. A. Culvenor Proceedings of 15th Agronomy Conference 2010, 15-18 November 2010, Lincoln, New Zealand.

Verburg K, Bond WJ, Hunt JR (2012). Fallow management in dryland agriculture: Explaining soil water accumulation using a pulse paradigm. Field Crops Research 130, 68-79.

Whish, J.P.M., Price, L., Castor, P.A., 2009. Do spring cover crops rob water and so reduce wheat yields in the northern grain zone of eastern Australia? Crop Pasture Science 60, 517–525.

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Methods and tools to characterise soils for plant available water capacity

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Key words

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GRDC code

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Take home message

- Information regarding the plant available water (PAW) at a point in time, particularly at planting, can be useful in a range of crop management decisions. Estimating PAW, whether through use of a soil water monitoring device or a push probe, requires knowledge of the plant available water capacity (PAWC) and/or the Crop Lower Limit (CLL).
- A wide variety of soils in the northern region have been characterised for PAWC and the characterisations are publicly available in the APSoil database, which can be viewed in Google Earth and in the 'SoilMapp' application for iPad.
- The field-based method for characterising PAWC has been tried and tested across Australia, but users need to be mindful of common pitfalls that can cause characterisation errors.
- Knowledge of physical and chemical soil properties like texture or particle size distribution and (sub) soil constraints helps interpret the size and shape of the PAWC profiles of different soils. It can also assist in choosing a similar soil from the APSoil database.
- Extrapolating from the point-based dataset to predict PAWC at other locations of interest is a challenge that needs further research. Preliminary analyses drawing on soil landscape mapping (NSW) and land resource area (LRA) mapping (Queensland) suggest that an understanding of position in the landscape and the story of its development may assist with extrapolation. This is because in many landscapes the soil properties determining PAWC are tightly linked to a soil's development and position in the landscape and these same aspects underpin soil and land resource surveys.
- While the concept of using soil-landscape information to inform land management is not new (e.g. Queensland land management manuals draw on the same concept), the availability of these maps on-line makes them more accessible and assists with visualising a location's position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors.
- Uncertainty of PAWC estimates translates into uncertainty in PAW. The extent to which this affects potential decision making depends on the question asked, but also needs to be viewed in terms of the spatial variability in PAW and the accuracy of the method to convert this water into a yield forecast.

Plant available water and crop management decisions

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

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

Over the past 20 years, CSIRO in collaboration with state agencies, catchment management organisations, consultants and farmers has characterised more than 1000 sites around Australia for PAWC. The data are publicly available in the APSoil database, including via a Google Earth file and in the 'SoilMapp' application for iPad (see Resources section).

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

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

The APSoil database provides geo-referenced data (i.e. located on a map), but the PAWC characterisations are for points in the landscape. To use this information one needs to find a similar soil. This is not a straight forward process and subject of ongoing research, but a number of data and information sources are available that can assist. If suitable PAWC data are not found, local measurement of PAWC is required. This will often also provide a more accurate estimate although spatial variability may still be an issue.

This paper describes the measurement of PAWC, including practical tips and pitfalls, and outlines where to find existing information on PAWC. It discusses the principles behind extrapolation from known soil profiles and illustrates this with examples of PAWC data for local soils.

Plant Available Water Capacity (PAWC)

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

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

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

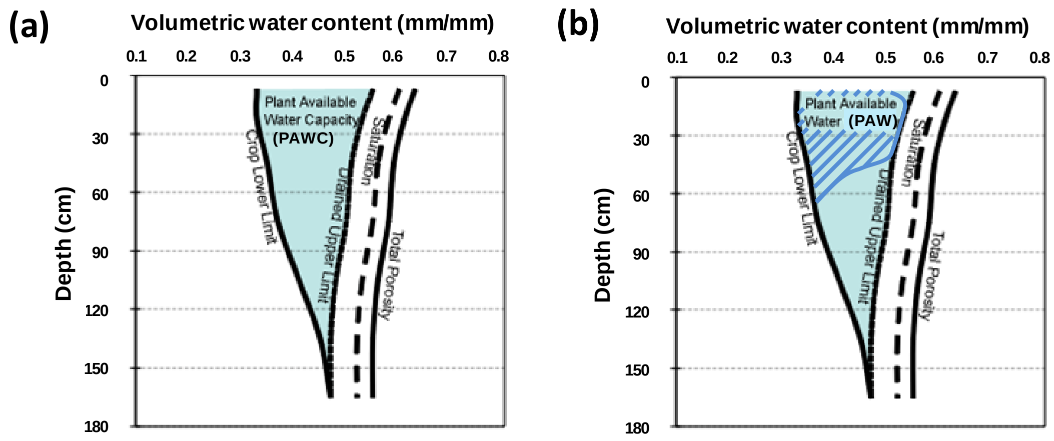


Figure 1. (a) The Plant Available Water Capacity (PAWC) is the total amount of water that each soil type can store and release to different crops and is defined by its Drained Upper Limit (DUL) and its crop specific crop lower limit (CLL); (b) Plant Available Water (PAW) represents the volume of water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

Plant Available Water (PAW)

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

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

Knowledge of PAW can inform management decisions and many in the northern region have, formally or informally, adopted this. Several papers at recent GRDC Updates have illustrated the impact of PAW at sowing on crop yield in the context of management decisions (see e.g. Routley 2010, Whish 2014, Dalgliesh 2014 and Fritsch and Wylie 2015).

Field Measurement of PAWC

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

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

Figure 2. Wetting up for DUL determination and rainout shelter used for CLL determination

Pitfalls and common mischaracterization issues

While the concept of PAWC is simple and the measurement methods for DUL and CLL were developed to be straightforward and not require any sophisticated equipment, it is important to keep an eye out for possible sampling errors. The list below summarises some of the key pitfalls and common mischaracterization issues that we have come across in our collective experience of PAWC characterisations across Australia.

To allow interpretation and use of the data by others, PAWC characterisations should be accompanied by as much extra information as possible, including descriptions of the landscape position, surface condition (e.g. cracking, waterlogging), colour, texture (ideally with a full particle size analysis), Australian soil classification and any local classification soil name.

DUL

- Weeds are often seen growing on the side of the plastic cover. It is important that these are strictly controlled throughout the wetting up process until sampling.
- In sandy-textured soils the concentric rings of dripper line must be laid sufficiently close to each other to ensure consistent wetting across the whole area.
- Allowing insufficient time for drainage may lead to overestimation of DUL, especially at depth. Heavier soils can take 1-2 months to drain.
- Insufficient water application or application at too high a rate leads to underestimation of DUL at depth. This is particularly an issue with heavy clay soils, dispersive sodic soils and strong duplex (texture contrast) soils where water may move sideways. Both the GRDC *PAWC booklet* and the *Soil Matters* book provide indicative rates and amounts for different soils. The wetting and drainage processes may be monitored (e.g. using NMM or a moisture probe), but this is not often done due to cost constraints (time, money).
- Bulk density sampling, which is often done in conjunction with DUL sampling, requires a relatively high level of precision as any error in bulk density values will propagate when used to convert gravimetric water contents (including DUL, CLL and PAW) into mm of water. The procedure is described and illustrated in detail in the GRDC *PAWC booklet*.
- Snakes like to hide under the plastic, so take care when wetting and sampling the plot.

CLL

- The CLL method as described above relies on crop roots exploring the soil to the fullest extent. If the crop had insufficient moisture to establish its root system prior to anthesis, the CLL may not reflect maximum soil water extraction. Roots will not grow through a dry layer even if there is moisture underneath. It is, therefore, important to perform CLL measurement in paddocks with a well established and healthy crop. Wetting up of the CLL site prior to the growing season may help, but requires close attention to weeds and to supplying the right amount of nitrogen fertiliser.

- In wetter climates and years with rainfall in the weeks just prior to the erection of rainout shelters at anthesis may refill the PAWC 'bucket'. If the PAWC is large, this may prevent the crop from using all soil water and result in an overestimate of CLL (too wet). Ideally CLL is measured over multiple seasons, but this is rarely done in practice. Calibrated moisture probes can be an effective tool to assess a crop's ability to extract moisture over a range of different seasons.
- The CLL measured for one crop type may not apply to a different crop type, especially where growing season length or susceptibility to subsoil constraints differs. It is possible that long-season varieties may extract water from a greater depth than short season varieties because of more extensive root development, and hence result in different CLL.
- If sampling is not deep enough to capture the full root zone, PAWC will be underestimated. In this case the CLL and DUL do not reach the same value at the bottom of the profile.
- If there is insufficient wetting of the profile prior or during the growing season, the measured CLL may reflect the CLL of a previous crop. If the current crop has a shallower root system this could cause the PAWC to be overestimated. Wetting up of the CLL site prior to the season may help. Taking a soil core when the rainout shelter is installed and comparing values against those determined at the time of final sampling can assist with interpretation of the data.
- Rainout shelters have blown loose or away on occasions, so it is important to secure the sides firmly into the soil.
- For duplex soils located on hills slopes > 3-5% or soils at the break of slope, subsurface lateral flow can cause soil wetting despite the presence of a well constructed rain-out shelter. Keep an eye on late season rainfall and note any unusual wetness in samples collected.
- Sampling after harvest when the soils are dry and hard, or have hard layers can be tricky. Digging a soil pit can be a better alternative than soil coring from the surface in these situations.

General

- Soil variability may mean there is more than one PAWC profile within the paddock. Variability in depth of layers, e.g. texture contrast in duplex soils, can occur over small distances. This makes mixing replicates and selecting a "representative soil" difficult.
- High soil variability can cause the DUL and CLL measurements to effectively be on different soils (even though they are usually only 2-3 m apart). It is essential to measure DUL and CLL on the same soil type. Yield or soil maps may assist in deciding where to sample.

Where to find existing information on PAWC

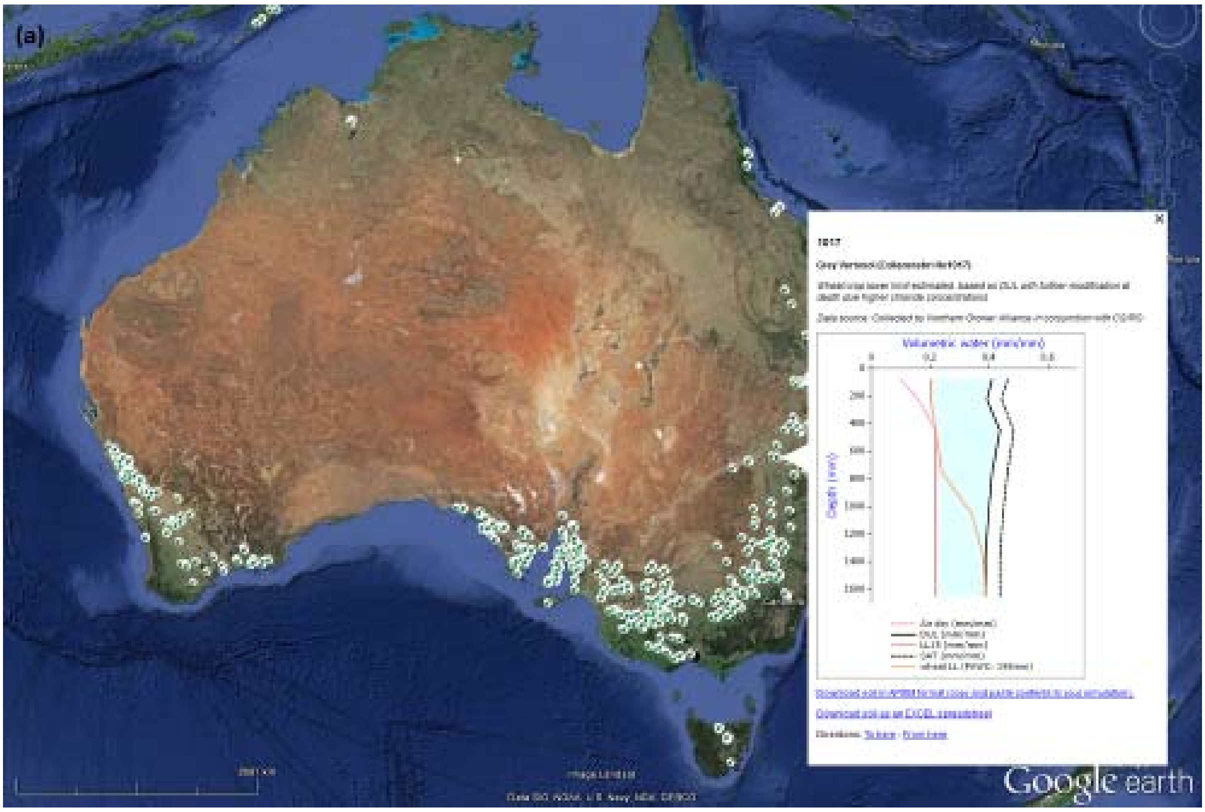
Characterisations of PAWC for more than 1000 soils across Australia have been collated in the APSoil database and are freely available to farmers, advisors and researchers. The database software and data can be downloaded from https://www.apsim.info/Products/APSoil.aspx. The characterisations can also be accessed via Google Earth (KML file from APSoil website) and in SoilMapp, an application for the iPad available from the App store. The yield forecasting tool Yield Prophet® also draws on this database.

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

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

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

The report *PROFILE descriptions – District guidelines for managing soils in north-west NSW* by Daniells et al. (2002) provides PAWC characterisations for 17 soils in the region drawing on the same methodology. In addition this report provides valuable soil descriptions for areas around Coonabarabran, Coonamble, Moree, Pilliga, and Walgett.



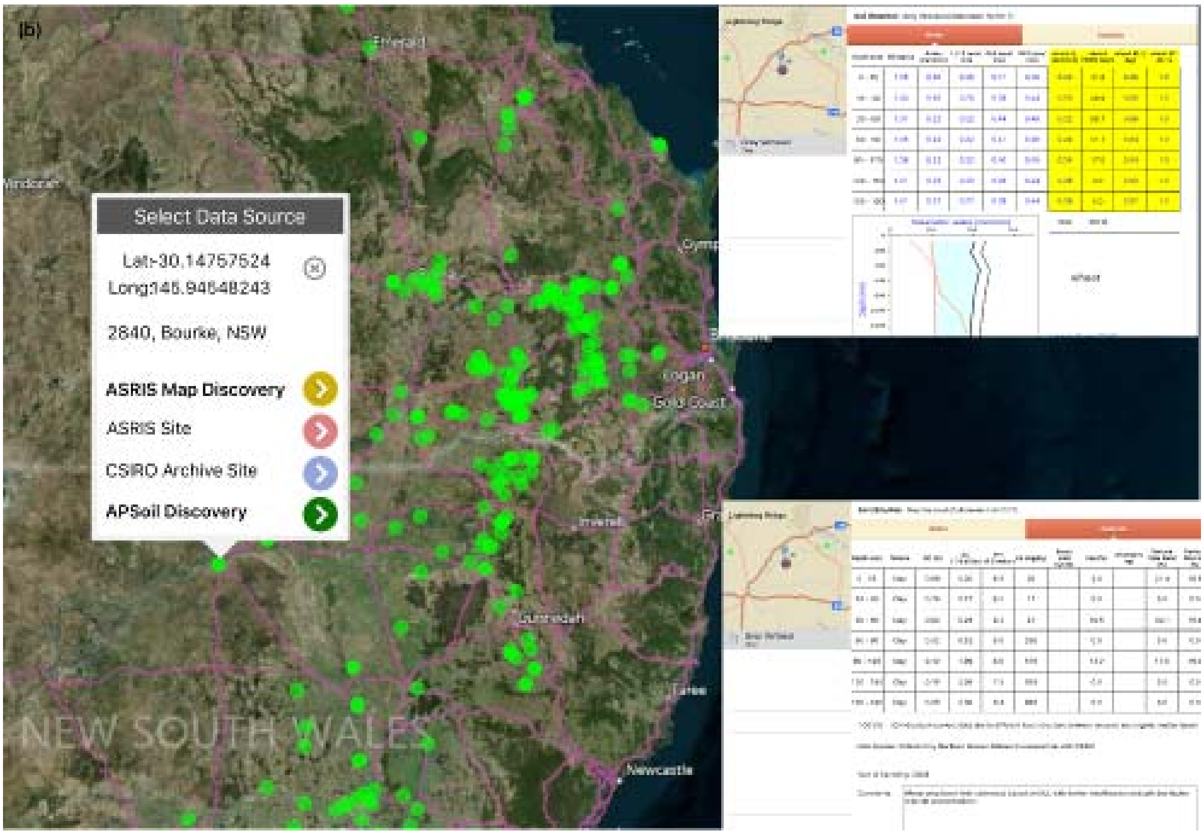


Figure 3. Access to geo-referenced soil PAWC characterisations of the APSoil database via (top) Google Earth and (bottom) SoilMapp (APSoil discovery screens as inserts).

Factors that influence PAWC

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

The effect of texture on PAWC can be seen by comparing some of the APSoil characterisations from the northern region, as illustrated below (Figures 4-11). The soil's structure and its chemistry and mineralogy affect PAWC as well. For example, subsoil sodicity may impede internal drainage and subsoil constraints such as salinity, sodicity, toxicity from aluminium or boron and extremely high density subsoil may limit root exploration, sometimes reducing the PAWC bucket significantly.

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth. Some APSoil characterisations only determined the CLL for a single crop. The CLL for wheat, barley and oats are often considered the same and that of canola can be found to be similar as well, but care needs to be taken with such extrapolations as different tolerances for subsoil constraints can cause variation between crops.

A detailed explanation of the factors influencing PAWC is included in the *Soil Matters – Monitoring soil water and nutrients in dryland farming* book, a pdf of which is available for free online (see Resources section).

__Nyngan-Trangie-Coonamble__

The APSoil database contained relatively few PAWC characterisations in the wider Nyngan-Trangie-Coonamble area, despite the high variability in soils. The complex set of soils is dominated by alluvial soils laid down by the Macquarie, Bogan and Castlereagh Rivers between 5,000 and 1.5 Million years ago. There are also soils formed on bedrock to the west of Nyngan and south east of Collie. The *Glovebox guide to Soil of the Macquarie-Bogan Flood Plain* (Hulme 2003) provides a description soils and their features. It does this through a mapping based on the underlying 1:250,000 Nyngan geology map, which distinguishes different formations and position in the flood plain (meander plain vs. back plain). The guide does not provide information on PAWC, but the current project is characterising further soils in this area, targeting different soil-landscape units. Examples below illustrate that texture as affected by parent material is an important factor affecting the PAWC (Figure 4), that soils can vary significantly over a short distance (Figure 5; distance between the sites is < 3 km), but can also have a similar sized PAWC, despite being in different parent materials (Figure 6).

(Figure captions refer to soil-landscape units from a draft Nyngan soil-landscape map and accompanying report – see subsequent section on using soil-landscape information.)

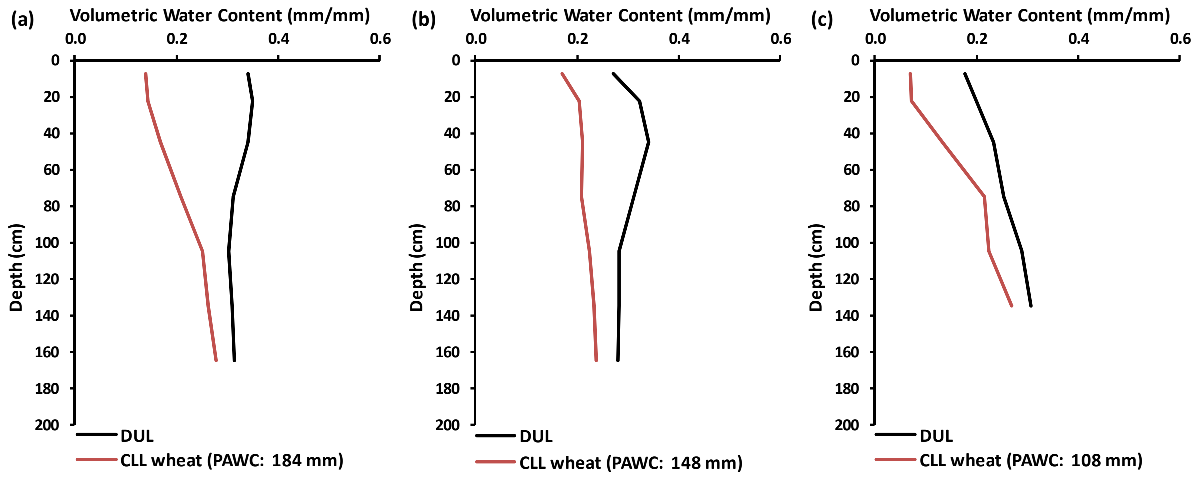


Figure 4. Select soils near Warren NSW and Nyngan NSW (see (a), (b) and (c) below):

(a) Medium clay (APSoil 705) near Warren. Exact location unknown, but likely from back plain position in alluvial sediments of the Macquarie River.

(b) Sandy clay loam over light clay changing to clay loam at depth (APSoil 248) near Warren. Exact location unknown, but likely from meander plain position in alluvial sediments of the Macquarie River.

(c) Sandy clay loam over sandy clay (APSoil No246) near Nyngan on. On an older, higher alluvial plain of Pangee Creek. The different parent material results in a much lighter texture (e.g. 70 % sand in top 30 cm compared with 50% for APSoil 248).

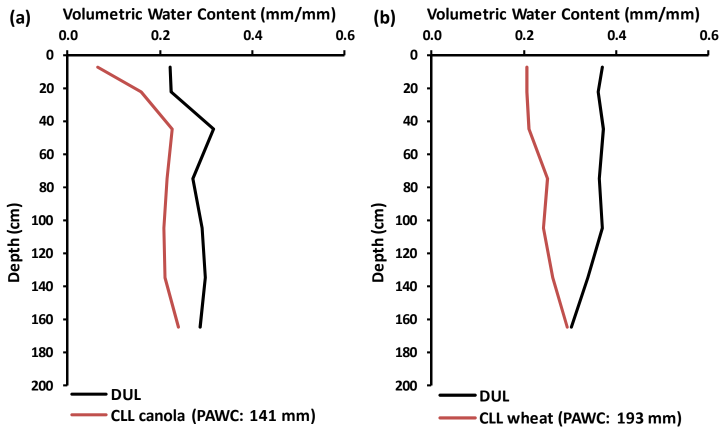


Figure 5. Select soils near Trangie NSW (see (a) and (b) below):

(a) Sandy clay loam (APSoil 683) near Trangie. Alluvial sediment formed on a meander plain of the Macquarie River more than 150,000 years ago. There is a higher proportion of sand, particularly in the surface of this soil reflected in a lower PAWC.

(b) Light over medium clay reverting to a sandy clay at depth (APSoil 684) near Trangie. Alluvial sediment formed on a back plain of the Macquarie River more than 150,000 years ago. The back plains are characterised by large flat areas where finer sediments were deposited from the lower energy flows. These finer sediments produce soils with higher PAWC.

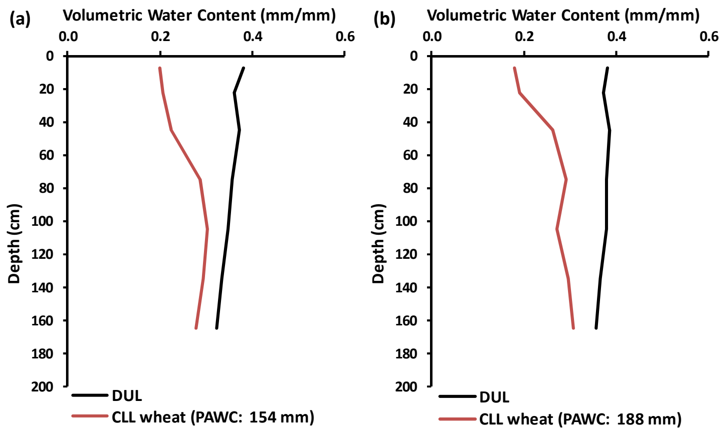


Figure 6. Select soils near Collie NSW(see (a) and (b) below):

(a) Vertosol formed on alluvial back plains of the Castlereagh River between 15,000 and 150,000 years ago. Alluvial material originated from Jurassic and Cretaceous sandstone to the east and deposited in low energy flows forming large, flat, treeless areas dominated by cracking clays. Chemistry data pending, but soils in this soil-landscape unit commonly have sodic subsoils which may explain the narrowing PAWC. Draft characterisation.

(b) Vertosol formed primarily from basaltic tertiary volcanic material. This landscape was the lower colluvial slopes and depressions associated with finer sediments. The PAWC of this basaltic origin soil is similar to the nearby vertosols formed on the back plains of the Macquarie River. Draft characterisation. (Part of a new set of characterisations with support from Neroli Brennan and Graeme Callaghan.)

Walgett – Collarenebri - Pilliga

The *Profile Descriptions - District guidelines for managing soils in north-west NSW* report (Daniells et al. 2002) provides descriptions of the soils in the Walgett, Pilliga, Moree, Coonamble and Coonabarabran areas, including PAWC data for select soils. This is a valuable resource that complements the existing APSoil characterisations and used the same methodology for the PAWC characterisations.

The report describes characterised soils in the Walgett area as being dominated by Grey and Brown Vertosols, which are all strongly sodic (and dispersive) below 15 or 60 cm and alkaline. Most are also saline in the deeper subsoil. PAWC for wheat is usually high and frequently in the 200-220 mm range, but some of the APSoil characterisations confirm that smaller and bigger buckets do occur depending on texture and subsoil constraints in particular (see e.g. Figure 7).

Soils included in the Profile Descriptions report for the area between Collarenebri, Mungindi and and Moree are described as black and grey vertosols which have lower PAWC than the 'true black earths' east of Moree (PAWC 160-205 mm). The soils are strongly sodic (and dispersive) below 30 or 45 cm, which explains their reduced PAWC. Crops respond differently to subsoil constraints, resulting in different PAWC (Figure 8). Where the differences are small, they could also be due to measurement error (including due to seasonal variation).

We have included two lighter textured soils from the Profile Descriptions report from the Pilliga area to illustrate the effect that their lighter texture has on PAWC (Figure 9b,c).

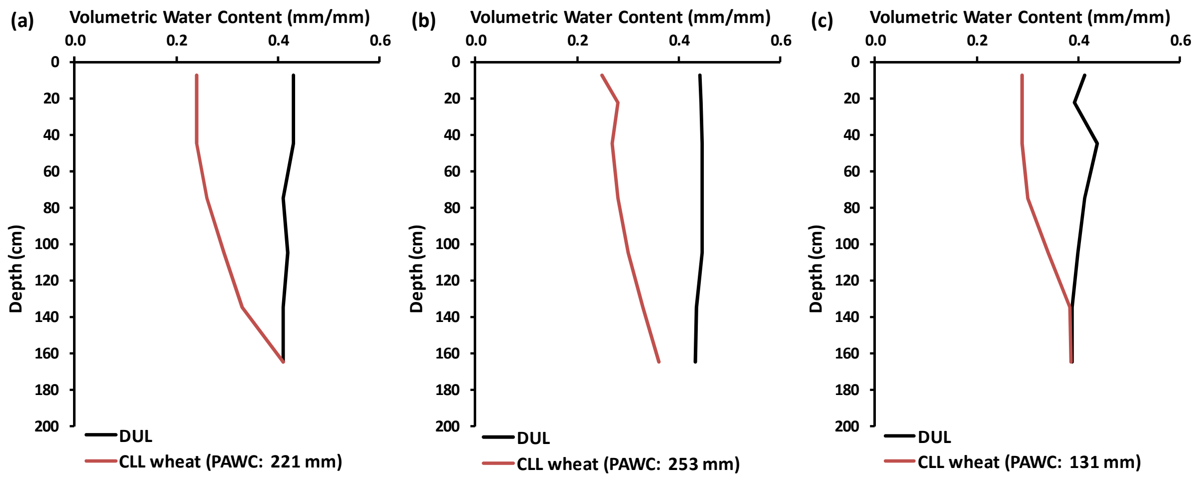


Figure 7. Select soils west of Walgett(see (a), (b) and (c) below):

(a) Grey Vertosol (APSoil 1013) (also W79 in Profile Descriptions report). Strongly sodic subsoil below 90 cm. Rotten Plain land system unit (low-lying back plains of Quaternary alluvium, periodically partially inundated by local run-off or floodwaters; depressed to 4m; land systems unit report via ESpade).

(b) Grey Vertosol (APSoil 1015) near Angledool Lake with a deeper and hence larger PAWC profile not limited by subsoil constraints.

(c) Grey Vertosol (APSoil 1016) between Walgett and Cumborah in alluvial deposits. Particle size and chemistry data not available, but shape suggests subsoil constraints limit the PAWC.

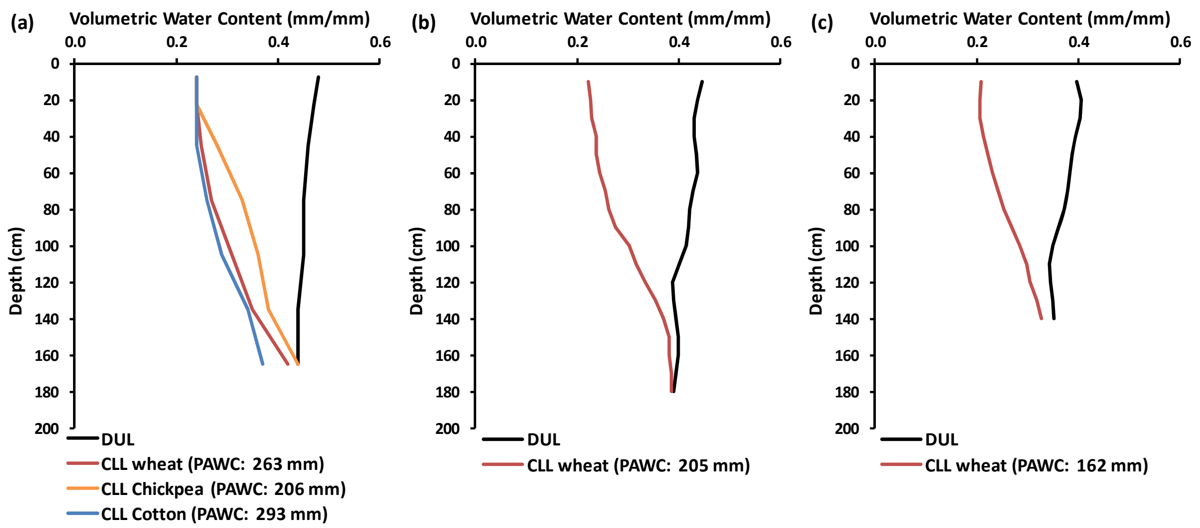


Figure 8: Select soils near Collarenbri (see (a), (b) and (c) below):

(a) Grey Vertosol (APSoil 126) near Merrywinebone in alluvial deposits. The high clay content (~60%) contributes to the high PAWC although the subsoil below 90 cm is affected by chloride and sodicity.

(b) Grey Vertosol MW51 near Collarenbri from the Profile Descriptions report. It has a strongly sodic subsoil although the report notes rooting to 175 cm.

(c) Grey Vertosol MW52 near Bullarah from the Profile Descriptions report. The report notes that dispersive subsoil may limit the penetration of water and reduce the effective rooting depth, but the PAWC of 162 mm may be an underestimate as characterisation was only down to 140 cm.

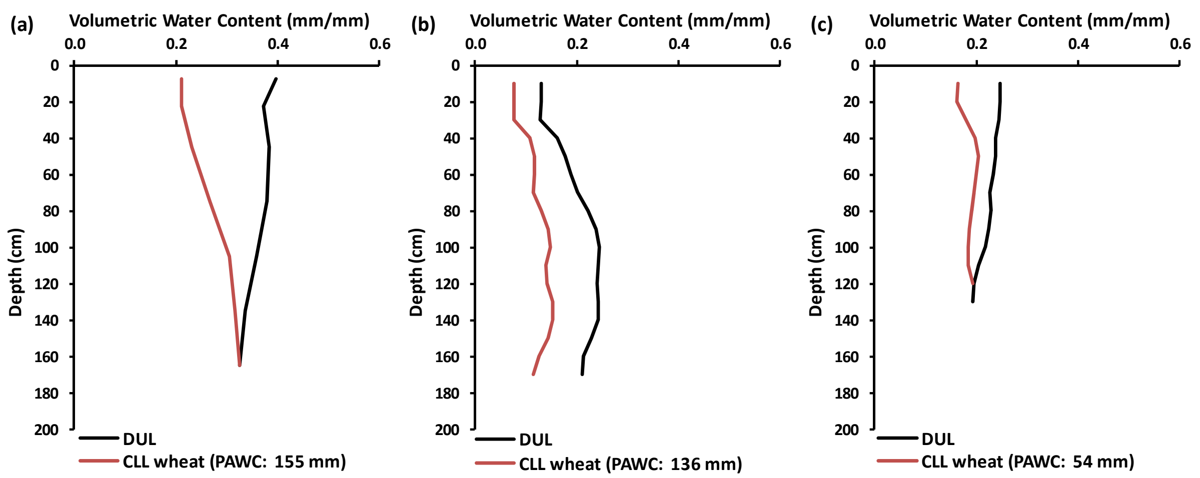


Figure 9. Select soils near Pilliga (see (a), (b) and (c) below):

(a) Grey Vertosol (APSoil 1014) just north of Pilliga and (judged by location in Google Earth) on alluvial deposits. The high clay content (58%) results in the higher PAWC compared with (b,c), but subsoil constraints (chloride and sodicity) reduce the PAWC from what it may have been based on texture alone.

(b) Red Chromosol (texture change (duplex) soil) North of Gwabegar (P56 from the Profile Descriptions report). The abrupt increase in clay % causes the shift and widening of the PAWC profile between 20 and 40 cm depth.

(c) Brown kandosol (structure less soil) north-east of Gwabegar (P57 from the Profile Descriptions report). Described in the report as being dispersive and poorly structured below 15 cm, the soil has a very low PAWC despite having a clay texture throughout.

Liverpool Plains

Cropping within the Liverpool Plains is primarily on the vertosols. The various APSoil characterisations in the area show, however, that within the vertosols there is still variation in PAWC in response to texture, parent material and subsoil constraints (Figure 10). Current new characterisations in the area are underway with local coordination of William Manning. The new characterisations are attempting to characterise the vertosols of different soil-landscape units. This followed the observation of an informal, qualitative analysis of the limited existing APSoil profiles that it seemed that the PAWC of vertosols in different areas of the Liverpool Plains could be characterised within 30-50 mm ranges. There are similarities with the soil characterisations in the Central Darling Downs Management manual (see below) where the indicative PAWC ranges for soils are provided in 50 mm intervals (e.g. 150-200, 200-250, > 250). Whether and how well this works for the Liverpool Plains still needs to be tested. One complication is that PAWC for different crops can be quite different (Figure 10), although seasonal differences could affect that if measurements were not made in the same year.

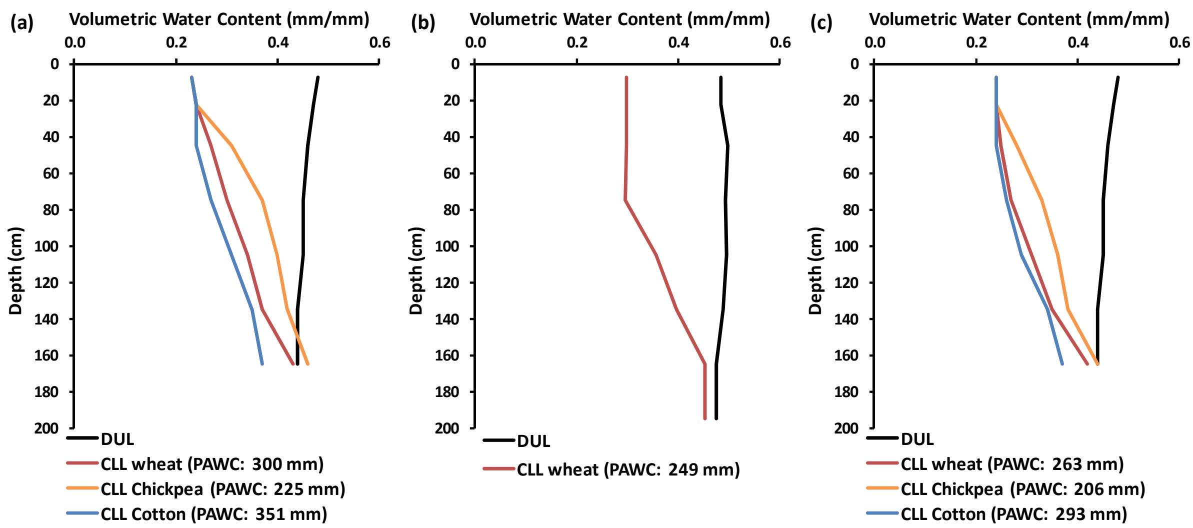


Figure 10. Select soil PAWC characterisations from the Liverpool Plains (see (a), (b) and (c) below):

(a) Vertosol on footslopes in Jurassic basalts and associated alluvium south of Goran Lake (APSoil site 128) has a large PAWC bucket, although PAWC for chickpea was smaller than for wheat and cotton was larger. Other characterisations in the same soil-landscape unit had very similar PAWC.

(b) Vertosol on flood plain in tertiary and quaternary alluvium near Quirindi (APSoil 866) has a slightly smaller, but still sizable PAWC bucket. A nearby characterisation (APsoil 869) in the same soil landscape unit had a similar PAWC (245 mm wheat).

(c) Black Vertosol (APSoil 119) near Breeza is located on the broad, level floodplains of the Mooki River on Quaternary alluvium derived from the Tertiary basalts, which contributes to the large PAWC bucket. Other characterisations in this soil-landscape unit had similar PAWC buckets.

Central Darling Downs

While outside of the area of interest for most people attending the Coonabarabran Updates, we include a few examples from the Central Darling Downs (Figure 11) as it is another example (like Figures 4-6) where soil-landscape information has helped us interpret and explain the observed PAWC profiles.

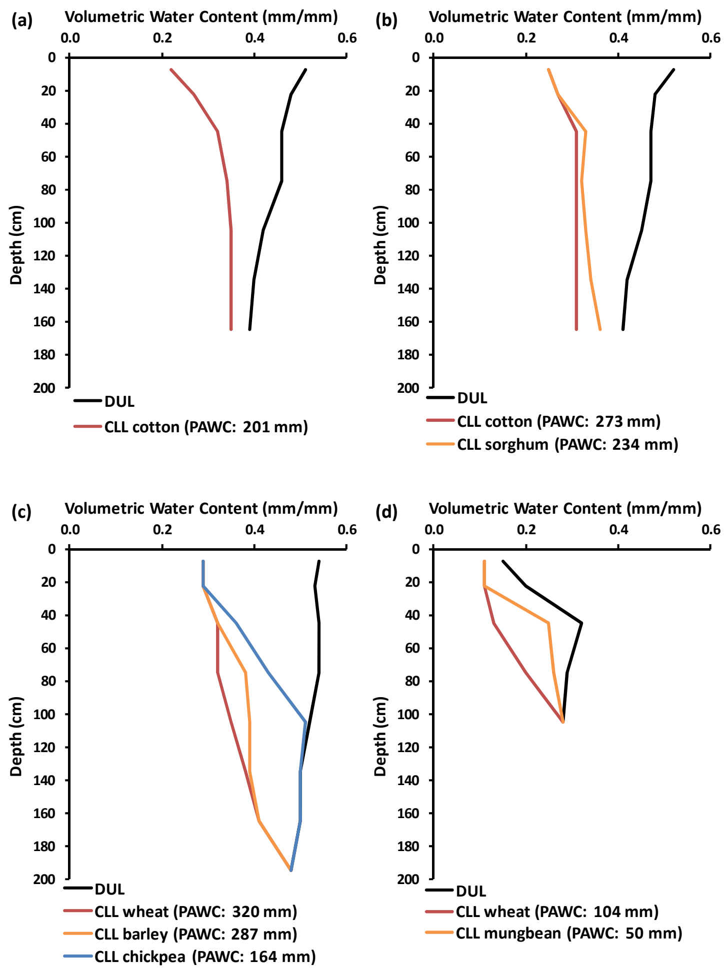


Figure 11. Select soil PAWC characterisations from the Central Darling Downs (see (a), (b), (c) and (d) below):

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

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

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

Choosing an APSoil characterisation

As shown above, the soil PAWC can vary significantly. How do we choose the most appropriate APSoil characterisation, if we are not in the position to do a local field PAWC characterisation? This is still research in progress, but some guidance can already be provided.

- The nearest APSoil may not be the most appropriate as its soil, parent material and landscape position could be quite different (cf. Figure 5)
- Compare soil with descriptions of the APSoil sites (texture, colour, soil classification, chemical analysis). More recently collected APSoil characterisations include chemical analysis and particle size. As illustrated in Figures 4-11 both particle size and subsoil constraints strongly affect the PAWC.
- Dig a hole (soil auger, soil core, backhoe trench, roadside bank or cutting); note surface features (cracking, hard setting), subsoil issues (salinity, sodicity, etc), rooting depth. This can assist with APSoil selection as well as adapting an APSoil profile to local conditions (e.g. if depth of texture change or rooting depth is different).
- A measured sowing soil water profile (convert to volumetric) needs to 'fit' between CLL and DUL and can assist with APSoil selection (Figure 1b). If the measured (volumetric) water content profile is below CLL or above DUL then the texture of the soil does not match that of the chosen APSoil.
- Opportunistic CLL (e.g. soil core following a dry finish; convert to volumetric) can be compared with CLL of APSoil characterisations.
- Check for nearby soil survey characterisations (SoilMapp, Espade, Queensland Globe (see Resources section) and local soil reports) to help describe soils.
- Draw on soil-landscape mapping (where available) to find APSoil sites in similar landscape positions (see below).
- Native vegetation is often a useful indicator of soil type too and is indeed often included in information about soil-landscape, land resource area and land systems units.

Using soil –landscape information

In many landscapes the soil properties are tightly linked to a soil's development and position in the landscape and these same aspects underpin the many soil and land resource surveys that have been carried out over the years and that are increasingly becoming available on-line. Many of these present a mapping of so-called soil-landscape units that are based on a combination of geology, landscape features like slope and relief, vegetation and groups of soils. Effectively the distribution of soil types described by these maps and their mapping units descriptions are based on a landscape model or story. These descriptions, where available, can be used to interpret and potentially extrapolate APSoil characterisations.

In parts of NSW these soil-landscape units can be accessed through the ESpade tool (see Resources section), which delineates the units and provides a description and typical soil profiles for each unit (see Figure 12). In parts of Queensland, similar land resource area (LRA) mappings are used as part of land management manuals (see Figure 13). Where this information is available, it may be possible to use it to find an APSoil site in a similar landscape position as a first approximation of PAWC.

The concept of using soil-landscape information to classify and inform soil properties is not new. The Queensland land management manuals accompanying the LRA maps draw on the same concept as do the *Glovebox Guide to Soil of the Macquarie-Bogan Flood Plain* by Hulme (2003) and several *Soil Specific Management Guidelines for Sugarcane Production* in different sugarcane growing areas from northern NSW to northern Queensland (e.g. Wood et al 2003). The availability of these maps on-line makes them more accessible and assists with visualising a location's position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors.

Using these resources to inform or even predict PAWC profiles is, however, still research in progress. In particular its predictive power and spatial accuracy still needs to be assessed as well as the required level of soil and landscape information. Not all areas within the northern region are covered by these soil-landscape maps and knowledge of (hydraulic properties of) soils within these areas varies too. Another resource that may proof useful in the future but requires further testing for its use in predicting PAWC profiles, is the new Soil and Landscape Grid of Australia (see Resources section) which provides digital soil and landscape attribute predictions at a spatial resolution of 90 m x 90 m).

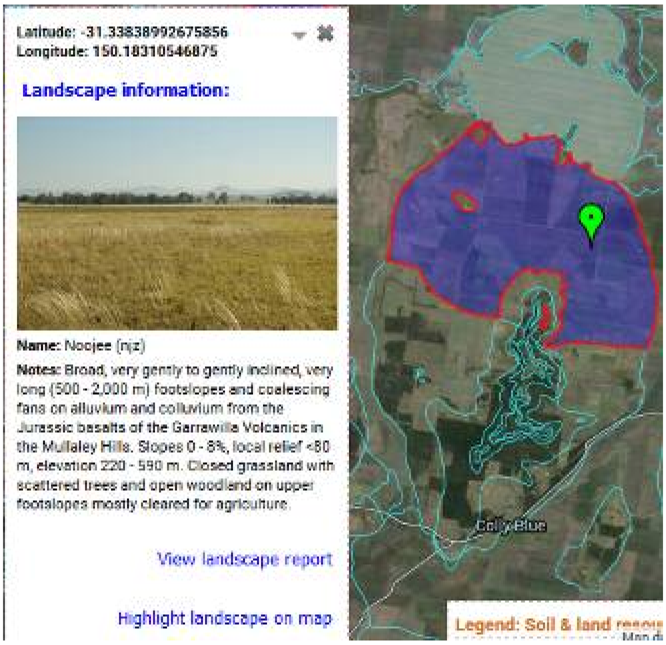


Figure 12. Example of soil-landscape mapping available for parts of NSW through ESpade showing the location of the characterisation of Figure 10a. Mapping unit description is available through a pdf report.

Figure 13. Section of Central Darling Downs with Land Resource Areas (LRA) delineated on Google Earth map with APSoil sites indicated. The accompanying description assisted in describing the differentiation between APSoil 6 and 8 of Figure 11a,b.

Local soil and landscape mapping information

Nyngan-Trangie-Coonamble

ESpade does not provide on-line access to soil-landscape mapping in this area, but a draft map based on the 1:250,000 Nyngan geology map exists and a pdf copy of this draft can be found on http://archive.lls.nsw.gov.au/__data/assets/pdf_file/0007/495979/archive-nyngan-soil-landscape-phase2.pdf

Walgett – Collarenbri – Pilliga

ESpade does not provide on-line access to soil-landscape mapping in this area and a draft map based on the 1:250,000 Walgett geology map only covers the south-western part of this region (south of Walgett and west of Come By Chance). A pdf copy of this draft can be found on http://archive.lls.nsw.gov.au/__data/assets/pdf_file/0004/495886/archive-walgett_map.pdf

ESpade does provide higher-level land systems mapping for the western part of this region (north of Kamilaroi Highway and west of the Gwydir Highway). The pdf descriptions of the different land systems can provide some insights in typical floodplain components and their soil types.

Useful information about soils in the region is contained in the Profile Descriptions report by Daniells et al. (2002).

North Star

ESpade does not provide on-line access to soil-landscape mapping in this area and neither is land systems mapping available online. Soilmapp provides a broad distinction of where the heavier vertosols and lighter texture change soils may be, but within these there will be local exceptions and variations.

The Profile Descriptions report provides descriptions and PAWC information for soils a bit further south in a region labelled in the report as 'Moree East'.

Liverpool Plains

ESPade provides access to soil-landscape maps and reports on each soil-landscape unit covering the Liverpool Plains (soil & land resources mapping). Within each of the mapping units there are still different soil types. The typical position of these soil types is described.

Central Darling Downs

The Central Darling Downs is covered by a LRA map, of which Google Earth files can be obtained (see Resources section). This allows simultaneous viewing of the LRA units and APSoil characterisations. Descriptions of the LRA units as well as the various soils identified in a local classification and their typical positions within the various LRA units are provided in the accompanying Land Management Manual (see Resources section). Estimated PAWC ranges (in 50 mm intervals) are provided for each local soil type.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. We also gratefully acknowledge the contributions of CSIRO colleagues and many collaborators and farmers to the field PAWC characterisations. Their feedback also helped prepare the list of 'tips and tricks'. The information on PAWC presented in this paper heavily draws on the work over many years by Neal Dalgliesh. Discussions with him and others, including with those involved with soil-landscape mapping in NSW (Neil McKenzie, Rob Banks, Brian Murphy and Neroli Brennan) were invaluable for the development of concepts and ideas presented in this paper. New characterisations in the Nyngan-Trangie-Coonamble area were supported by Neroli Brennan and Graeme Callaghan. New characterisations in the Liverpool plains were supported by a group of consultants led by William Manning. We thank Sean Murphy for access to the Profile Descriptions report for north-west NSW and its authors for the work involved with the PAWC characterisations and soil descriptions. Claire Yung provided assistance with the preparation of graphs.

Resources

APSoil, PAWC methodology and national information

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

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

GRDC PAWC booklet: http://www.grdc.com.au/GRDC-Booklet-PlantAvailableWater

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

Soil and Landscape Grid of Australia: http://www.csiro.au/soil-and-landscape-grid

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

NSW

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

Unpublished soil-landscape maps exist for: Nyngan, Walgett, Narromine, Narrabri, Gilgandra

Soil Profile Descriptions - District guidelines for managing soils in north-west NSW (Daniells et al. 2002)

Queensland

Land Management Manuals: https://publications.qld.gov.au/dataset?q=land+managament+manual

Land Resource Area (LRA) maps: Google Earth files: https://data.qld.gov.au/dataset/land-resource-areas-series or via the Queensland Globe https://www.business.qld.gov.au/business/support-tools-grants/services/mapping-data-imagery/queensland-globe

References

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

Daniels I, Manning B, Pearce L (2002) Profile descriptions. District guidelines for managing soils in north-west NSW. NSW Agriculture.

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

Hulme P (2003) Glove-box guide to the soils of the Macquarie – Bogan floodplain, Sustainable Soils Management, Warren.

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

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

Wood A, Schroeder B, Stewart B (2003) Soil Specific Management Guidelines for Sugarcane Production. CRC for Sustainable Sugar Production, Townsville.

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A review of water use efficiency in the northern grains region - why it makes sense to not deduct for evaporation losses in the north

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SoilWaterApp – a new tool to measure and monitor soil water

David Freebairn, University of Southern Queensland

Key words

Soil water, PAWC, soil type, decision making

GRDC code

USQ00014

Take home message

SoilWaterApp (SWApp) provides farmers and advisers with a ready estimate of plant available water in the soil (PAW) during fallows and early crop growth.

SWApp uses weather data from the Bureau of Meteorology that can be localised with manual entry of rainfall or a newly-developed "wireless" rain gauge. Soil types and crops are selected for each paddock.

SWApp is for iPhone and iPad (iOS) devices. Visit www.soilwaterapp.net.au for details.

Background

Grain production in Australia is limited in most seasons by water supply. Soil water stored during the fallow and early season maintains crop water supply leading up to the critical time around anthesis. SWApp has been designed to give grain growers and advisers a simple tool to efficiently and reliably estimate soil water content during a fallow and early crop phases.

The App

The first thing SWApp asks the new user for is a property and paddock name, then by selecting a relevant climate station. Since you are using smart device, it will present you with the 5 nearest available climate stations but you have a choice of 4,500 stations across Australia! SWApp uses long-term records for your site to estimate upcoming rainfall.

A soil type that best represents your soil is then selected from a comprehensive list covering the major soil types in your state. If you want to use more locally relevant rainfall data than the BoM, you have an option to replace the BOM data with records from your rain gauge.

When you "update the site" with the selections listed above, the next screen (below) allows you to: (1) set a start date and soil water distribution; (2) select the soil cover conditions for fallow or crop, and set crop plant and maturity dates; and (3) make additions to a local rain gauge if previously added.

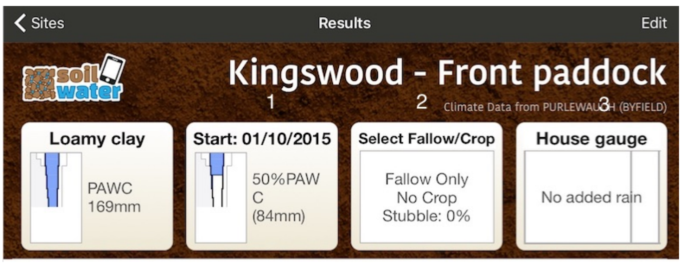

Figure 1. Screen allowing user to (1) set a start date and soil water distribution; (2) select the soil cover conditions for fallow or crop, and set crop plant and maturity dates; and (3) make additions to a local rain gauge if previously added.

Results are shown as text and graphics. Percentage of PAWC and mm water available take centre stage with the water balance and where the water is in the soil profile on either side. The graphic at the bottom of the screen shows the pattern of water accumulation, soil and crop cover. Accumulated rain can be compared with historical patterns as an option.

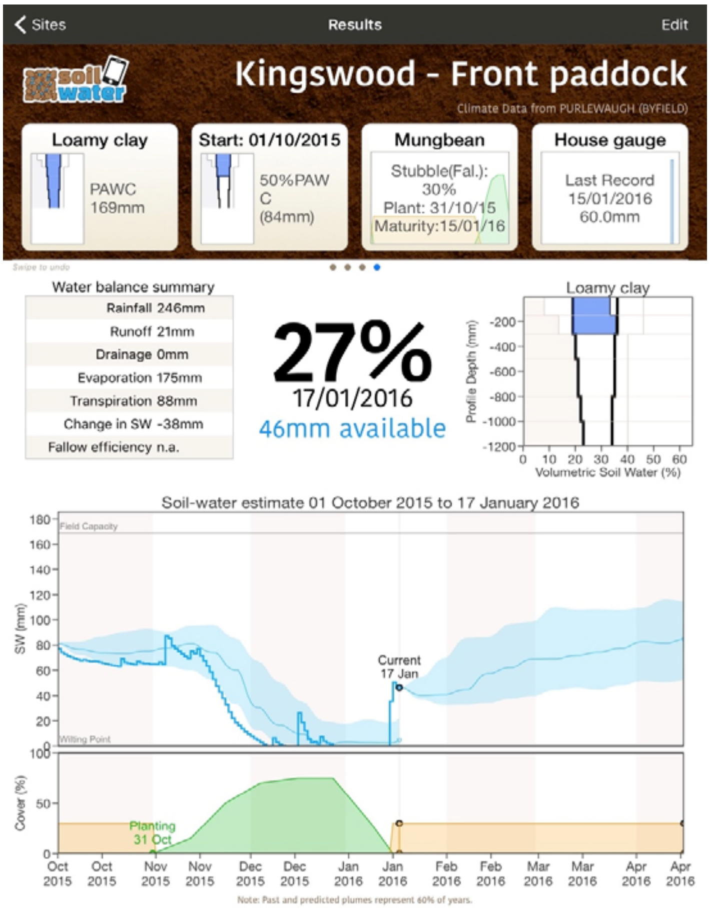

Figure 2. Results screen showing both text and graphics. Percentage of PAWC and mm water available take centre stage with the water balance and where the water is in the soil profile on either side. The graphic at the bottom of the screen shows the pattern of water accumulation, soil and crop cover.

The blue line looking forward from todays date (17 Jan in this example) is based on previous years weather for the specified conditions while the shaded “plume” envelops 60% of likely outcomes.

Data is securely stored and available to multiple devices (other iPhones and iPads). We are currently testing a wireless Bluetooth rain gauge and soil water sensors that SWApp detects and collects data from when your device is nearby (10 metres). Additional facilities such as report generation, a Push Probe data entry and an irrigation module are to be added during 2016.

Acknowledgements

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The App’s development has benefited from the significant contributions of grain growers and research scientists across Australia who contributed data for model testing. Valuable feedback from

“beta testers” over the last 12 months has improved the App. We look forward to further constructive comments from users.

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Improving fallow efficiency

David Freebairn, University of Southern Queensland

Key words

Soil water, fallow efficiency, conservation tillage, soil monitoring, Australian CliMate, Soil water App

GRDC code

USQ00014

Take home message

- While ~20% of rain is stored during fallows, small changes in soil management can improve this apparent low efficiency and have large impacts on profit.
- Water stored can be improved through longer fallow, weed control, soil cover and reduced compaction. This can be achieved through reduced tillage, controlled traffic and planting crops before the soil fills.
- Stubble retention combined with reduced or zero tillage almost universally results in better water storage.
- Better water storage results in better yields, especially in dry years.
- Soil water and N mineralisation can be tracked using a number of decision support tools (e.g. Australian CliMate, Soil Water App, Yield Prophet).

Getting water into the soil

Storing soil water is a challenge in our environment where evaporation potential is higher than rainfall in all months. Typically, we have 2-3 times the evaporation potential compared to rainfall. High clay content soils, which hold so much water in the surface, make the value of small falls of rain less useful than we might hope for. High intensity rainfall, a feature of summer rainfall in the northern grain region, can result in valuable water being lost as runoff and resultant erosion.

The starting point for improving rainfall capture is to minimise runoff. Soil cover is a crucial factor determining infiltration (*Table 1*). Cover, either as crop residue or a crop canopy, reduces surface sealing. A puddled crust of 1-2 mm thickness is enough to slow infiltration. On average, a soil cover greater than 40 per cent over the summer can reduce annual runoff by 15-30mm compared to bare fallows.

Table 1. Influence of tillage and soil cover on runoff and water storage on a grey brigalow clay (Greenwood 1978-83).

Tillage management (fallow cover)	**Bare fallow** (<5%)	**Disc tillage** (25%)	**Blade tillage** (45%)	**Min/no till** (>65%)
Fallow efficiency (%)	21	25	26	32
Range of FE	9-29	8-38	17-36	12-32
Reduced runoff (mm)	-	24	32	15
Extra soil water (mm)	-	13	16	36

Soil cracks also offer a pathway for rapid uptake of rainfall, with intense storms putting some water at depth through cracks, out of evaporations harm's way. Avoid cultivation if soil cover is low and soil is cracked (*Figure 1*).

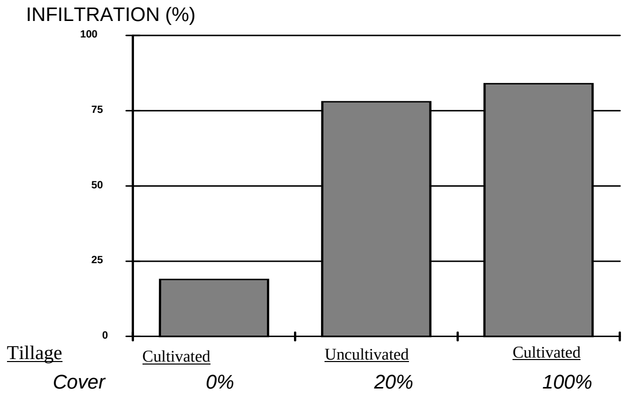

Figure 1. Infiltration of simulated rainfall (40 mm at 100 mm h-1) on a brown clay near Wallumbilla where the soil was cultivated with no soil cover after cultivation, left uncultivated with low cover and cracks, or cultivated with good cover.

Soil water content (How wet?) is important in determining the rate of infiltration. When a soil is full, further rain will either runoff or evaporate. Crop sequences need to be flexible to capitalise on wetter than average conditions and likewise be prudent when soil water is low. As a general rule, fallows longer than one summer are wasteful in terms of storing water. If the soil profile is greater than 50-75 per cent full, planting another crop should be considered.

Keeping it in?

Once rainfall is captured in the soil, the next major challenge is to keep it there for crop use. This is not as easy as it might first seem. During fallows, an average of 65 per cent of rainfall is lost as evaporation - this high loss is largely a result of the high water holding capacity of our clay soils, infrequent rainfall and high evaporation conditions. Many small falls of rain are 'captured' in the top 10 cm, only to be lost to evaporation before the next rainfall.

Stubble can reduce evaporation by increasing the reflectance of the soil surface and reducing the velocity of air movement at the soil surface, but these differences are not long lived. If it stays dry for a few weeks, any gains associated with stubble can be lost. Surface cover and good soil structure allow water to move below the "hot" zone where it will be relatively safe from evaporation "pull". Improvements in water storage have mostly been explained by reductions in runoff losses although evaporation reduction can be important in extending planting dates.

Weeds can be a serious cause of water loss within a crop and fallow - up to 5 mm/day. It is essential that weeds be controlled while they are small to avoid use of soil water and seed setting.

Money in the bank?

Extra water safely stored in the soil through best management can be worth up to 500 kg/ha, especially in dry years. *Figure 2* shows a comparison of grain yields from all tillage trails in southern and central Queensland over a 30-year period. Minimum/no-tillage results in superior yields except in wetter years. In order to make use of available water, nutrition and disease management are equally important, with good rotations a key part of the better water management game. It would be fair to say that farmers have got better at agronomy (compared to researchers) with time than the results in *Figure 2* suggest.

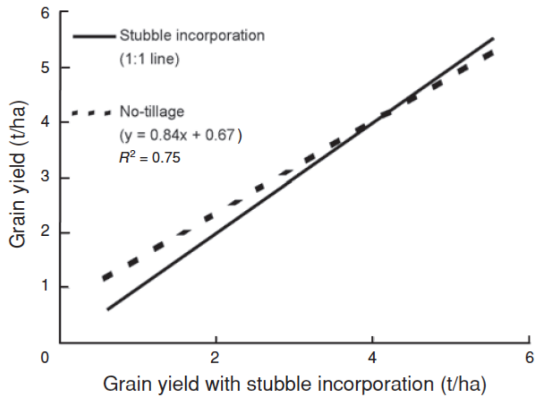

Figure 2. Comparison of grain yields from 120 experiment years from tillage trails in southern and central Queensland in the 1970's to 2007 (Thomas et. al 2007).

Soils are different

While it seems obvious, soils vary greatly, even in the one paddock, so are there any general rules? Much is talked about regarding tillage or no-tillage. Recent research by Dang et al (2014) has shown that an occasional tillage does not appear to undo hard-won gains in soil structure. Some common principles can be summarised as:

- soil cover from stubble or crops is good, and generally the more the better;
- when no soil cover occurs, tillage may be the best option;
- water storage and use is best when crops are growing – provide cover and keep soil drier;
- compaction can only be a bad thing for roots and infiltration; and
- weeds will always be robbers of moisture and nutrients, but may be tolerated at times if small and don't seed.

But each soil needs to be managed differently, and good observation with contrasting management is the best way to learn about your soil. For example, the following observations from a simple rainfall simulation demonstration raised many questions and much discussion (*Figure 3*).

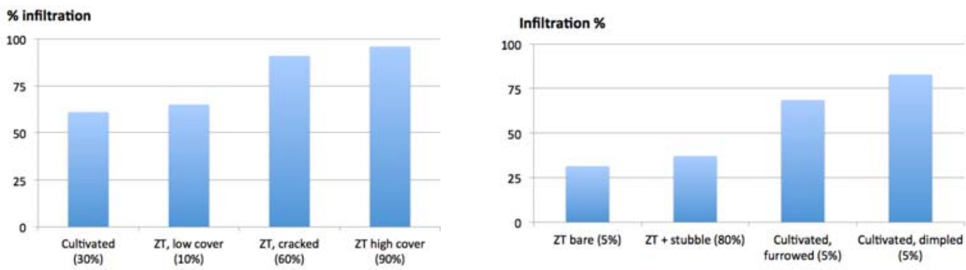

Figure 3. Infiltration of simulated rain on two soil types: a Brigalow-belah clay near Wallumbilla (left) and a red brown earth near Goondiwindi (right) (Cawley et. al 1992).

An example fallow decision pathway

A possible decision pathway for deciding what tillage strategy to follow after harvest.

How long to fallow?

If good rain occurred before harvest, and the soil profile is greater than 3/4 full, extending a fallow is a waste of time, water and money. Remember that on average, only one mm in every 4-5 mm of rain (20-25 per cent) is stored in the soil. Push probes, soil cores and SoilWaterApp should be sueful here.

Are weeds a problem?

If no, best option is to do nothing. If weed control is necessary, either spray, or cultivate to maximise stubble cover.

Is soil cracked?

- If yes, cracks indicate moisture is gone. Do not cultivate until cracks close.
- Once cracks are closed, either a) maintain stubble cover or b) if little cover, create a rough surface
- Roughness can be created with tillage, but don't use harrows. Extra cover (stubble) cannot be created after harvest so look after it.

What happens if no stubble is available?

Once cracks are closed, tillage is needed to maintained roughness and break crusts. Hard setting soils especially need tillage and roughness (some of these soils may need a pasture phase to improve soil structure).

What happens if the soil is fine and no stubble is available?

An unenviable position - hope for gentle rain and plant a crop as soon as possible.

References

Cawley ST, Hamilton NA, Freebairn DM, Markey LJ, Wockner GH. 1992. Evaluating fallow management options by using rainfall simulation - action learning approach with farmers. QDPI Proj. Rept. SQA 91012. 27 pp.

Dang YP, Seymour NP, Walker SR, Bell MJ, Freebairn DM. 2015. Strategic tillage in no-till farming systems in Australia's northern grains-growing regions: I. Drivers and implementation, Soil Tillage Res.

Thomas GA, Titmarsh GW, Freebairn DM, Radford BJ. 2007. No-tillage and conservation farming practices in grain growing areas of Queensland –a review of 40 years of development. Aust. J. Experimental Agric. 47:887-898.

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Commonly asked questions about soil water and soil management

Graeme Wockner and David Freebairn

Key words

Soil water, soil management, stubble, evaporation, organic matter, infiltration, burning, no till

Stubble factors

Does stubble reduce evaporation?

Yes, in the short term because of reduced soil temperatures but any long-term benefits are negated if we have any hot dry weather after rain. Evaporation is the great equaliser (e.g. 8-12mm free water evaporation a day in summer) which can quickly vaporise any moisture in the surface 0-10cm layer. Stubble is still necessary however, to maintain an open surface structure that reduces the formation of a surface seal and promotes the infiltration of rain.

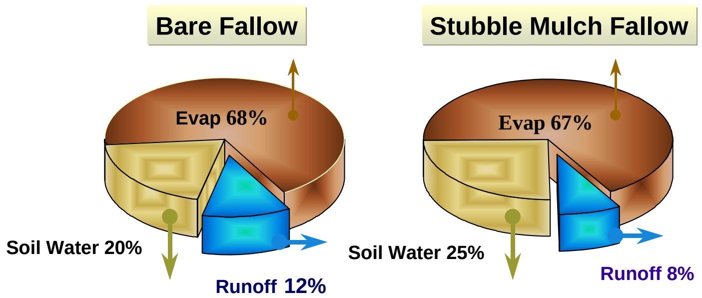

Figure 1. Comparison of two surface management treatments that show only small differences in evaporation but significant differences in soil water infiltration between a bare and a stubble mulch fallow.

Does burying stubble get organic matter into the soil?

Not anymore than leaving it standing. Buried stubble ties up nitrogen in the short term as soil microbes use nitrate for energy to break down the stubble. Above ground, stubble is broken down more slowly by fungi because it is dryer. Eventually the organic matter returns to the ground but in the breakdown process 70% is converted to carbon dioxide.

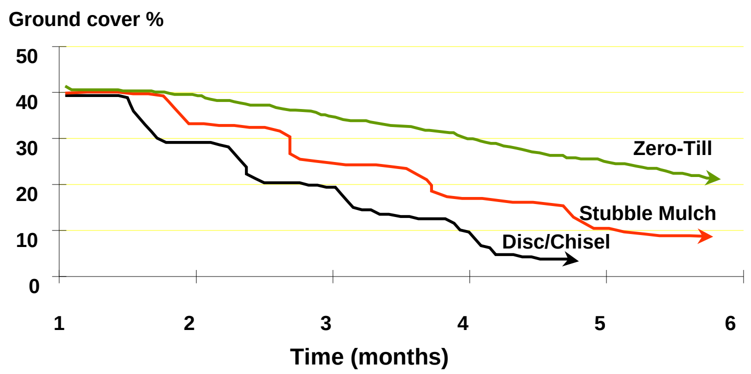

Figure 2. Relationship between time and surface cover breakdown using different tillage instruments

Does burying stubble get more water into the soil than leaving it on the surface?

No, because unless the straw protrudes through the surface infiltration will actually be inhibited. Soil absorbs water like a sponge. You won't improve a sponge by pushing pieces of straw in it! Straw works best by absorbing the energy of raindrops and preventing the surface of the soil from sealing.

Is it better to leave stubble standing or slash it or knock it over?

A catch 22 question because they both have advantages and disadvantages but it is generally accepted that standing stubble is more effective in erosion control. Stubble laying flat increases the overall cover percentage but most high intensity summer storm rainfall falls at an acute angle so standing stubble absorbs a lot of the rainfall energy. Standing stubble is also rooted in the soil and less likely to be washed downhill. Standing stubble is less likely to clog planters in a no-till farming system than slashed or flattened stubble.

Does organic matter improve soil structure and infiltration?

Yes, but we need a lot of organic matter to make a difference. All soils benefit from increased organic matter but unfortunately this is a slow process. It can take less than 20 years to run soils down but much longer to rebuild good soil structure. Organic matter encourages soil fauna; eg: beetles, ants and worms which effectively improve infiltration.

What is the best way to improve organic matter?

Maintaining or improving soil organic fertility through management practices is an important basis for sustainable farming. A decline in organic carbon is accompanied by degradation of a range of properties important for soil fertility. A pasture phase incorporated into your rotation is probably the best way to build organic matter. No-till farming is also beneficial but takes time to substantially raise levels.

Is a late stubble burn OK with regards to soil erosion?

Yes; with the proviso that we delay it as long as possible (e.g. late April). March traditionally has the highest runoff but not the highest rain. This is because the soil moisture profile at this time is nearly filled to capacity and "when a bucket is full", water can only run off. If the rain is intense it will take soil with it. The downside of this is that burning is often a more difficult procedure later in the season. If a clean burn is not possible then the use of fire harrows to substantially reduce stubble levels is recommended. Modern no-till machinery is capable of handling large amounts of stubble that don't require burning.

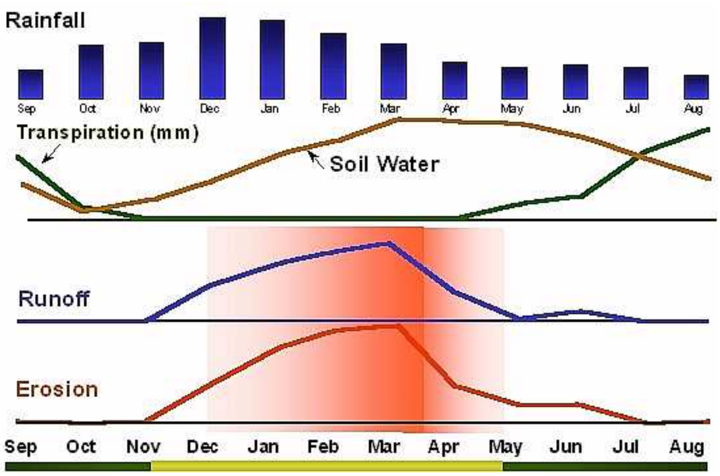

Figure 3. Water dynamics of a summer fallow

Stubble burning is an option available for farmers to control diseases such as yellow spot, minimise nitrogen tie-up in crop residues, and make planting easier with conventional equipment after heavy crops. The 1998 winter wheat crop was severely affected by leaf diseases, and burning was an option for reducing potential carry over of disease. However, in many cases, there is sufficient disease inoculum in the environment to reinfect crops if weather conditions are favourable. Burning a paddock will not remove spores that are present in adjacent grassland for instance.

Bare ground left after burning greatly increases the chance of erosion while reducing the efficiency of water storage during the fallow. If stubble must be burnt, the risk of extreme erosion can be reduced if burning is carried out at an appropriate time. While it is not a prescribed management practice, burning may be practiced from time to time. The key is to understand the risks of runoff and consequent soil erosion.

Other considerations

Will a delay in burning mean it gets too wet to burn!

The risk that a season will turn wet, thus losing an opportunity for a clean burn, needs to be weighed against improved water storage and erosion control. Typically there are many opportunities for a burn through March - April. As a compromise, it may be worth considering burning fewer acres initially.

What if a crop is planted soon after a burn?

If another crop is established quickly, it will provide soil cover, and use soil water (water deficit is the best guarantee for minimising runoff and erosion) thereby minimising the risk of soil erosion.

Will a stubble burn result in less nitrogen tie up?

Generally there is initial less plant available nitrogen when stubble is retained. Over the longer term, losses of organic carbon and nitrogen associated with burning, increased erosion and faster declines in total nitrogen and organic matter in soil eliminate the difference between the two practices.

Will stubble burning reduce disease in other crops?

The main reason to burn is to reduce carry over of yellow spot. Yellow spot mainly affects wheat, so the best strategy to avoid yellow spot is to plant an alternative winter or summer crop in rotation.

Does No-Till promote diseases and pests?

Although some disease organisms grow or survive on stubble, there are strategies to overcome most problems. Rotation of crops is the key. Mice thrive on grain, not stubble - it has too low a feed value, just as it is not preferred by stock. Stubble does provide some protection for mice, but avoiding spilt grain and good farm hygiene are major preventative measures. Complete removal of winter grains can be a challenge in seasons where cereal grains are small or crops lodge.

What can we do when there is no stubble?

Roughness is an option as the increased micro-relief acts as a physical barrier to water movement and increases the entry points for water because of the larger surface area. Results from research work at Wallumbilla show that rough tillage with a chisel plough decreased runoff by 10mm over a summer fallow when compared with smooth scarified tillage.

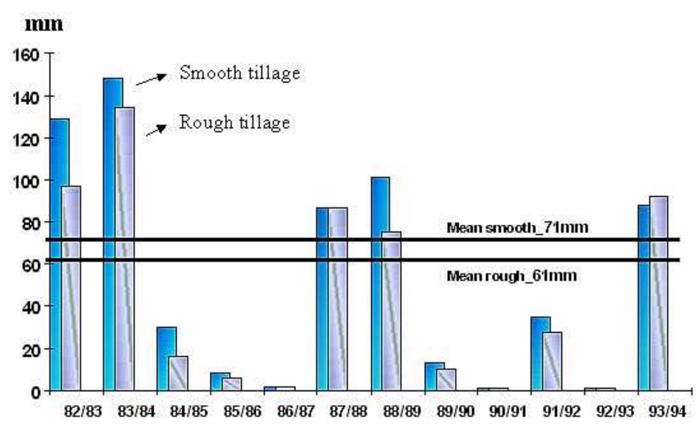

Figure 4. Runoff from smooth and rough tillage treatments at Wallumbilla; Queensland showing the mean 10mm increase in runoff between smooth and rough tillage.

Tillage factors

In controlled traffic can I plough up and down the slope?

Most work in Controlled traffic, which has shown a benefit of up and down working, has been done on fairly low slopes. More work is needed to show the effects on steeper slopes. However, controlled traffic is only successful in reducing erosion in no-till farming systems. In the end, cover is the key to reducing runoff and erosion.

No-till promotes waterlogging and runoff in wet years. Is that so?

Yes and No. Untilled soil with good soil cover increases infiltration and therefore the "bucket" (soil profile) fills sooner. In a wet year because our bucket fills quicker any further rain can only run off or remain on the surface if there is insufficient drainage. Trial work at Greenmount in south-east Queensland has recorded relatively high runoff from no-till treatments sooner in the season than other treatments because the no-till profile filled the quickest. Conversely, in dry years this rapid filling of the bucket gives no-till its big yield advantage.

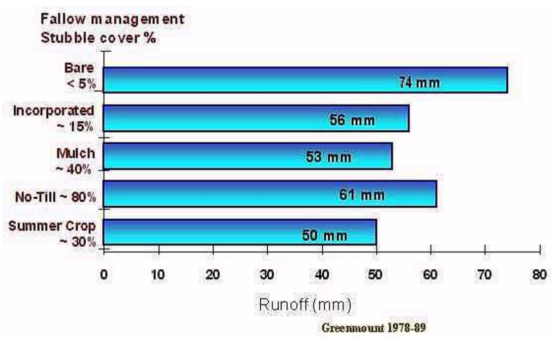

Figure 5. Mean runoff data from Greenmount showing the relatively high runoff from no-till when compared to other treatments.

What effect does herbicide have on worms?

Herbicides (plant killers) should not be confused with insecticides which are sometimes deadly for non-targeted species. The most common herbicides used in no-till systems have no effect on worm populations. Populations of worms in tilled paddocks are usually quite small. Worms and steel ploughs don't mix.

Is opportunity cropping worth it?

Generally, Yes, in Queensland's variable climate. Since the 1970's the best farmers have been saying "Use it or lose it" when talking about soil water. However, opportunity cropping means your farming system must be very flexible. E.g. machinery, seed and long or short crop varieties must be available.

How soon do weeds start having a negative effect on stored moisture?

As a rule of thumb if weeds (e.g. summer grasses)have 8 days to establish, they can then grow at 2-3 centimetres a day. Therefore they are depleting our stored reserves (below 10cm) after 12 days.

Rainfall factors

Are weather forecasts based on the SOI too late to make winter cropping decisions?

The SOI forecast for winter is most accurate after late May. Weather experts have to be conservative in their predictions until they know for sure that the pattern has stabilised. If you keep your own records you can observe weather trends, which allow individuals to make earlier decisions. Weather forecast systems are constantly improving and researchers are confident that earlier, more accurate long-term predictions will eventually be possible.

Is rainfall amount a useful measure of how much soil moisture is stored in the fallow?

Not necessarily, it depends on how much rain fell. Steady rain over several days fills the soil bucket. Sporadic light rain (<15mm in a day) will mostly evaporate if dry days follow. Heavy rain (>50mm in a single storm) will produce runoff. Flood rains may only wet a hard setting soil to a few centimetres.

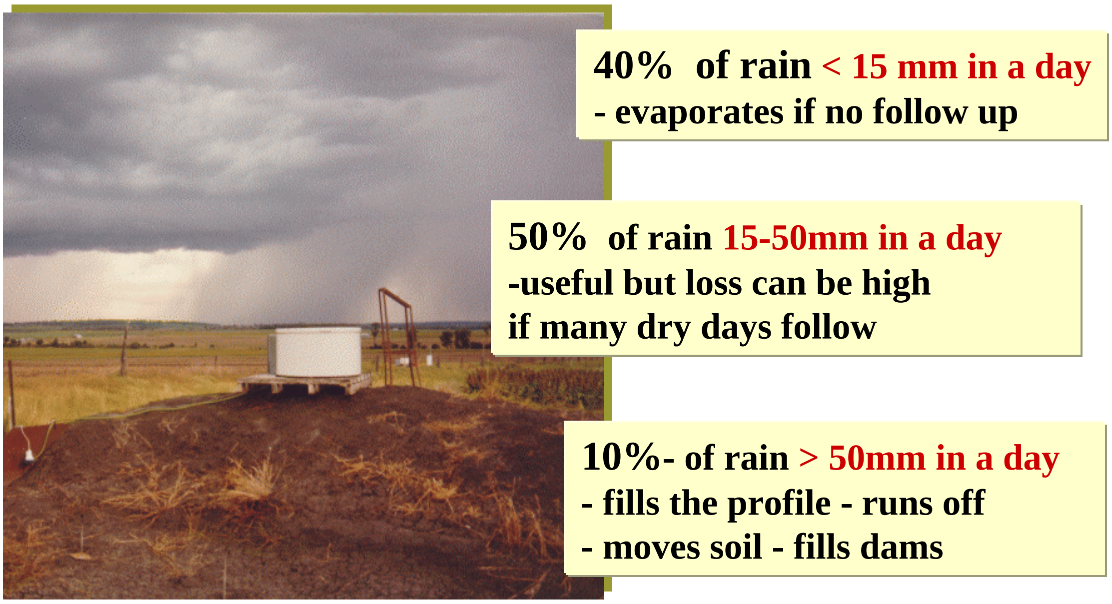

Figure 6. Rainfall fits into different categories

Soil factors

Should nitrogen be applied early or late?

No firm answers because it depends on the season. If we don't have any rain after we apply early we can have losses. (This may be compensated if nitrogen is cheaper earlier in the season.) Early application means one less job at planting but we might just end up fertilising the early weeds! Nitrogen is extremely mobile and a wet fallow can move it deeper into the profile so a small starter application at planting may be necessary. Some experts feel that banding is best as the growing crop has a better chance of competing for the available N. Top dressing before the flag stage is important because the efficiency of N use drops off dramatically.

Do cracks promote evaporation from the sub soil?

Only in negligible amounts. A soil cracks when it is dry so if a soil is cracked the water has already gone. The crack is more likely to be a net receptor of any storm runoff that a net loser through evaporation. There is little sunlight or air movement in a crack and these are the main causes of evaporation.

Why does my lighter country do better than my heavy country sometimes?

Rainfall on lighter soils infiltrates deeper and more evenly than into a heavy clay but a clay soil holds a lot of water in a small volume of soil. A black earth may hold 18mm of rain per 100mm depth of soil. By contrast, a red earth may only hold 10mm per 100mm or 80% less. Therefore a light fall of rain will only wet a shallow depth of a clay soil but will soak down to a greater depth in a lighter textured soil. This means that light falls of rain on clay soils may evaporate more easily because the water is held close to the surface.

Lighter soils hold water less tightly than a clay soil. Plants can more easily soak up water in a light soil whereas some water in clay soils is not available to plants. Clay soils, then, require more rainfall before plants can extract water from them. This means that plants will respond to light falls of rain better in a light soil. Because clay soils store a greater amount of water, they can supply plants with water longer than light soils when droughty conditions follow good soaking rains.

Can cultivation seal in the moisture?

No. Cultivation turns soil over and exposes moist soil underneath to evaporation. Sometimes a cultivated layer “dust mulch” feels dry while the subsoil feels damp. The surface soil is not sealing in the moisture; it is just evaporating to dryness faster than the sub-soil. At night, when evaporation is less, the dust mulch, too will feel moist as water diffuses from the wetter subsurface to the dry surface.

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"What's been GOAing on?"
A review of Grain Orana Alliances' achievements of the last five year project

Maurie Street, Grain Orana Alliance

Key words

Grain Orana Alliance, GOA, Grower solutions project, research, on farm trials

GRDC code

GOA00001

Take home message

- GOA has brought to growers in the central west of NSW a terrific return on their levies invested in the project over the past 5 years
- GOA regularly engages with the local industry to identify research priorities to ensure the highest priority issues are being addressed
- GOA has proven its ability to tackle a wide range of research topics relevant to the local region in a timely and effective manner
- GOA has comfortably integrated itself in to the current research community and cemented its place in the region as a key research body and information provider
- GOA will continue to build on its success's with the signing of a new 5 year agreement with the GRDC taking the project through to 2020

Introduction

June 2015 saw the completion of GOA's sixth year of effective operation. In that time GOA has grown from an organisation with just one employee, armed with a mobile phone, laptop and a ute, to a fully functioning research organisation with three full time permanent employees. In that time GOA has successfully run an ever expanding research program specifically tailored to the growers of the central west region of NSW and beyond, tackling many of the key production constraints that they face every day.

This report presents a brief snapshot of many of the key projects GOA has undertaken and some of the key findings developed from GOA's activities.

What is GOA?

Grain Orana Alliance or GOA for short, is a purpose built, not for profit incorporated association that was formed in 2009, specifically to undertake the then newly tendered GRDC project "GRDC- Grower Solutions for Central West NSW".

The GRDC Grower Solutions Project was developed specifically to provide a framework to-

- Regularly engage the local industry to understand and document research priorities or knowledge gaps in the grain production industry
- Design and implement a research program to address key issues identified, but with an emphasis in addressing issues with a shorter research term (1-3 years) or those issues requiring a rapid response

- Communicate all the issues raised in the consultation process to help guide the GRDC's investment strategies, particularly in the mid to longer research terms (3-8 years, 8 years +)

Over the past 5 years, GOA has had over 500 growers and advisers attend their regular meetings ensuring a good cross section of the industry is consulted to help GOA and the GRDC understand the major issues. In turn, research findings are extended directly and indirectly (via agronomists) back to the region's growers.

These meetings also ensure GOA's trial program is concentrating on the key issues facing growers. GOA's trial program has grown steadily since 2009 to 2015. The 2015 season consisted of over 2000 trial plots, over 35 separate trials, in more than 15 different locations across the GOA region.

Detailed below is a brief summary of some of the key achievements, findings and outcomes from GOA's activities over the past 5 years. There are a number of key research topics that have been undertaken by GOA leading to changes in industry practice which has then flowed through to our farming system, resulting in increased profitability, reliability or sustainability.

Weed management

Windmill grass control

Since 2010 GOA has run over 30 trials investigating herbicide control options for windmill grass (WG). From this trial work it was shown that the use of a group A herbicide, in this case 'Targa®', followed by a double knock of paraquat was effective in controlling this problem weed. Other trials investigated the effects of delayed application, optimising the timing of the double knock and the potential fit of residual herbicides.

GOA's trial work on WG possibly remains as the largest and most comprehensive body of work for herbicide control of WG to this date. Data generated from GOA's trials was central in the granting by the APVMA, of a minor use permit (permit number PER13460) for the use of Targa/ double knock strategy in summer fallow that represents the only really effective herbicide control option for growers. Prior to this, many growers had been forced to return to cultivation as the only effective control option for WG.

Fleabane

Since GOA's inception, GOA has run over 25 trials investigating herbicide control options for Fleabane (FB). This work helped show the need for a double knock of paraquat to control medium to large fleabane, as single pass strategies were often completely ineffective. A wide range of herbicide spikes to control FB were investigated with 2,4-D spikes being the most consistent and reliable. GOA's trial work was some of the only work to investigate the relative effectiveness of the various 2,4-D formulations as tank mix partners.

GOA also demonstrated the potential for paraquat mixed with various tank mix partners for single pass FB control. Results showed those mixes often rivalled or even surpassed what was achieved by the best double knock strategies, giving growers a useful alternative to glyphosate based knockdown strategies. This is particularly useful in light of confirmation of resistance of FB to glyphosate in that same period.

GOA also undertook trials investigating a number of pre- sowing herbicide spikes for seedling FB control; a situation that was often overlooked by many other research bodies.

GOA in collaboration with NSW DPI was also the first to demonstrate the value that Lontrel® (clopyralid) had as an in crop residual to prevent establishment of FB in crop, eventually leading to the registration of Lontrel Advanced with that very claim.

Herbicide resistance surveys

Whilst GOA has addressed some of the more acute weed issues, the organisation has also been conscious of the development of herbicide resistance particularly in our key winter weeds.

Leading growers and advisers across the region continually highlighted the lack of strong empirical evidence of resistance in the local region and the tendency of many growers to dismiss its existence or true severity.

Ahead of the harvest of 2013, GOA initiated a program where growers or advisers could submit weeds samples of annual ryegrass (ARG) or wild oats (WO) for testing to a wide range of herbicide options. The response was immense. Within a day, our projected intake of samples had been surpassed by nearly 4 times and submission of samples had to be shut down. Over 120 weed seed samples were submitted to the survey and the results were alarming. Of the ARG samples submitted, none were completely susceptible to the herbicide tested, 100% were resistant. The level of cross resistance was also alarming with 54% of samples showing resistance to four or more herbicide groups or herbicide subgroups tested. The WO samples also showed alarming results.

This survey undeniably showed that resistance was present in the GOA region and in many cases it was severe. Following on from the results of the 2013 survey a second survey was initiated ahead of the 2014 harvest. The response to this survey (94 weed samples) was numerically lower than the 2013 survey, but the results were arguably much worse.

Samples submitted in 2014 showed high levels of resistance and cross resistance. Resistance to clethodim was present in 61% of populations and 57%of populations showed glyphosate resistance.

These surveys have undeniably shown resistance to be present in the region and provide some insight into its severity. The evidence from these surveys serves as an immensely strong weapon to promote acknowledgement of the issue by growers and advisers in the region as the first step to addressing it. The level of cross resistance revealed puts serious challenges to the belief by many that there are other herbicides out there to use and that simple herbicide rotation is enough.

This data gives industry leaders and advisers a launch pad to talk about other options for weed management such as harvest weed seed management and alternate agronomic tools.

Annual ryegrass management

Driven by concerns raised by growers and advisers regarding increasing resistance in ARG to many of our post emergent herbicides and the increasing reliance on pre-emergent chemistries, GOA initiated a series of trials aimed to improve pre-emergent performance and grower confidence in their use. The need for this work was only enhanced by the results emerging from the herbicide resistance surveys, particularly with resistance to clethodim.

The trials aimed to offer independent data on the performance of a range of chemistries available to growers over a range of crop types and locations. The trial looked at the standard "off the shelf" pre-emergent herbicides including older ones such as trifluralin or atrazine but also newer options like Sakura®, Boxer Gold® or Rustler® (propyzamide). It also trialled a number of tank mix combinations and the results of some of these mixes was nothing short of impressive.

The stand-alone chemistries, even the newer generation products, in the high weed populations in which they were trialled achieved only around 80% control at best, with some "district practice" options achieving little more control than applying nothing at all. Across three seasons and more than 12 trials, the tank mix options generally performed better than the individual components resulting of up to 99% control in exceptional cases. The other finding was that in many cases growers could easily add extra products into their current or common district practice pre-emergent strategies and see substantial improvements in their efficacy against ARG.

In some of these trials, ARG populations of over 300 plants/m^2 in the UTC control was reduced to less than 1 plant/m^2 but only when multiple modes of action were applied. No single pass treatment achieved such levels of efficacy.

If growers were to implement some of these findings into their systems, significant reductions in ARG should result in less crop competition and improved yields. By applying follow up treatment with in-crop herbicides and weed seed capture and destruction on these reduced weed populations it should in turn lower the chances for resistance selection potentially prolonging the useful life of these chemistries.

Harvest management of canola

Windrow timing in canola

GOA initially investigated windrow timing in canola for its potential to influence of canola oil %. What was found over numerous trials, was that windrow timing had more influence over crop yield than on oil %.

It was found that windrowing canola earlier than the current recommendations of 40-60% seed colour change, could negatively impact on yields by up to 30%. These impacts were shown to be the case even when timings were only a number of days too early, as was often the district practice.

It was seen that district practice had drifted earlier than recommended timings most likely due to concerns over potential yield loss through pod shattering with delaying windrowing. GOA's research showed that even with delays well past the recommended timings, yield was not usually compromised and in a number of trials, further yield gains were achieved where seasonal conditions were favourable.

Direct heading of canola

GOA has investigated the potential fit and performance of direct heading of canola. Trial work showed that direct heading compared to a well-timed windrowing had comparable yield, but with cost savings up to $40/ha added to growers' bottom line.

Further work investigating the benefits of desiccants, pod sealants and yield impacts by delayed direct heading, have all combined to increase grower confidence and understanding of when to use direct heading and windrowing techniques.

GOA advocates direct heading as an option for growers particularly in lower yielding environments and this has driven strong adoption by many growers as their preferred harvesting option. It is estimated that less than 5% of the region's crop was previously direct headed prior to this research. By 2015 it is estimated that possibly more than 30% of the crop is now direct headed. Comments from a number of experienced growers sums up the situation well- "I have direct headed crops from 1 t/ha up to 3 t/ha now and I don't think I will windrow again- it's just not needed."

GOA's research has shown to have universal appeal and application across many growing environments. This is demonstrated by the requests for GOA to present on the topic on more than 30 occasions including numerous GRDC Updates at locations as diverse as Adelaide, Eyre Peninsula, Victoria and all areas of NSW.

Canola nutritional management

Sulfur

GOA has been investigating canola nutrition in the central west since 2010, although the focus has changed over time. This work was originally initiated with the aim to investigate if sulfur nutrition was influencing the low oil% achieved in the regions canola crops.

However, after nearly 30 trials across the GOA region over the past six years, with all but a couple of sites predicted to be responsive to the addition of S, no positive response in yield or oil % has been measured to applied S.

These findings have challenged long accepted recommendations that applying sulfur to each and every crop was essential to optimise production. This body of work also highlighted that S removal rates in canola grain are all too commonly exaggerated and that there is very limited data used to calibrated soil test critical values. Which in both cases has contributed to a perpetuation of such high and unnecessary fertiliser recommendations.

Nitrogen

What was revealed was the responsiveness of canola to added N. In almost all of the 30 canola nutrition trials, canola has shown a strong positive response to added N.

Trials in 2014 near Dubbo demonstrated an economic response to the addition of 200 units of applied N to canola achieving a yield increase of over 1 t/ha. This trial work also demonstrated the potentially negative effect such high rates of N may have on oil %, but also the positive attribute of canola to resist “haying off” in response to high N applications, even in moisture limited environments.

Previous narrative for canola nutritional strategy was that S was non-negotiable in its requirement and that N could be more prescriptive. Our work suggests that N should be more heavily focussed on and that the fertilising of canola with S should be based on confirmed symptoms or other evidence rather than standard practice. That is, if growers shifted their fertiliser expenditure on N instead of S, they would almost universally increase their bottom line with return on investments as high as 3:1.

Disease management

Yellow leaf spot (YLS)

During the yellow leaf spot epidemics of 2010 and 2011 GOA undertook over 10 trials aimed at fine tuning fungicide strategies for the control of this disease. What these trials revealed was that although fungicides have the ability to supress the YLS infection, suppression was short lived and there was very limited yield benefit. Trials showed that only where five fungicide applications were made to YLS infected crops was there a positive yield benefit, although it was barely enough to cover the fungicide costs.

Common application strategies of Z32 and Z39 timings were not effective in reducing the impact of the disease. These trials also demonstrated that the concern with seedling infection and the need to apply fungicides at an early stage were not justified with no yield advantage gained.

The trials demonstrated the source of the YLS infection is from the underlying infected stubbles which fungicides did not address, and any protective or prophylactic effect of fungicides was very short term. This allowed for re infection potentially at each rainfall event.

Trials run at the same time investigating pre-sowing / stubble management and the potential to impact YLS helped reinforce this view. In these trials, burning or removal of infected stubble ahead of sowing resulted in significant reductions in the level of infection and improved yield performance. The burning treatments in these trials out yielded treatments in the adjacent trials even where they had received 5 fungicide applications.

This work suggests that expenditure on fungicide application for YLS is generally not cost effective and better strategies that address the source of the infection are often more effective.

Stripe rust

Trials investigating the management of stripe rust in the central west provided local field validation of core recommendations developed in research conducted outside the GOA region. This gave growers and advisers confidence that outcomes from trials that were at that time conducted in different climatic regions would still be effective.

GOA also investigated the management of stripe rust in dual purpose wheat, as this crop was seen as a major source of inoculum in the region. Previous recommendations supported the use of Jockey® fungicide on the seed and grazing to reduce disease incidence. GOA's work showed however that Jockey or grazing of the crop did not delay or reduce the infection or associated yield penalty.

Besides trial work

GOA value has been shown to extend beyond just undertaking trial and research work. GOA has been a strong advocate for a number of key issues and principles as well as acting as voice for the central west of NSW.

For example, GOA is well known for its advocacy for herbicide resistance management, particularly with techniques such as narrow windrow burning. As little as 4 years ago, only one or two growers in the region practiced the technique. Since then, the number of growers adopting the technique has increased steadily in a large part through GOA promotion. GOA's Chief Executive Officer is well known publicly promoting the topic with numerous Podcast interviews, YouTube videos and via presentations at GRDC Updates and other industry forums.

The list above is not an exhaustive list of GOA trials conducted over the past 5 years, but summarises several of the key projects with the largest potential to increase growers' profitability or sustainability.

GOA undertook quite a number of other trials investigating regional or season specific issues. Some of these found answers and outcomes adopted quickly. Some did not reveal any change or development in our current understanding - which may not have alleviated the problem, but may have helped avoid unnecessary or ineffective attempts to manage them.

In either case, these sorts of investigations or trials are examples of what GOA and other grower solutions groups have been designed to address - local issues raised that need a quick response. Issues that may not otherwise not be worthy of larger investment or capture the attention of existing research bodies.

Central to process of identifying such problems is the Local Research Updates (LRU) that GOA runs twice a year. The LRU's are an opportunity for growers and advisers to raise issues that are challenging their production systems. These meeting are open to anybody to attend. Details of when and where these meetings will be held are available on the GOA website at www.grainorana.com.au

Our website is where you can also subscribe to our mail list to ensure you will be kept informed via email.

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Ranking cereal varieties for frost susceptibility using frost values

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Keywords

Frost, wheat, barley, grain sterility, frost induced sterility, flowering

GRDC project code

UA00136, DAW00234, UW00005

Take home message

- Wheat and barley varieties differ in susceptibility to reproductive frost damage during booting and flowering.
- Barley is less susceptible to reproductive frost damage than wheat. No varieties are frost tolerant. Under severe frost (for example -8°C) or multiple minor frosts (several nights of -2° to -4°C) all varieties tested to date are equally susceptible, resulting in up to 100 percent sterility in flowering heads.
- Variation in reproductive frost susceptibility has not been linked to variation in susceptibility to stem frosts experienced in 2014 across Southern Australia or to later frosts during grain filling.
- Frost Values have been developed for cereal varieties to rank their relative susceptibility to reproductive frost. This information will be available through the use of an interactive tool on the National Variety Trial website and can be used to manage frost risk and fine tune variety selection after first selecting for local adaptation, yield, flowering time, and other key target traits.

Background

Frost has been estimated to cost Australian growers around $360 million in direct and indirect yield losses every year.

Breeding new cereal varieties with improved frost tolerance is one solution to minimise financial losses due to frost. Historically little has been known about variation for frost tolerance in Australian varieties, leading to the assumption that little variation exists. The limited knowledge about frost tolerance is also due to the practical difficulties in measuring frost damage under field conditions due to the sporadic and dynamic nature of frost events. However, successive GRDC funded projects have enabled dedicated frost screening nurseries to be developed in SA, WA and NSW. These nurseries have enabled the measurement of susceptibility to reproductive frost under minor frosts with greater accuracy and repeatability than previously. This research is part of the GRDC's multidisciplinary National Frost Initiative.

Methodology

The frost susceptibility data is generated from research trials grown in frost prone parts of the commercial production environment near Loxton SA, Merredin and Wickepin WA and Narrabri NSW in 2012, 2013 and 2014. To improve the predictions for these environments, similar trials grown in Loxton SA in 2010 and 2011 were also included in the analysis.

At each site, between 6 and 11 times of sowing (TOS) are planted as separate blocks at approximate equidistant thermal time from around April 15 to June 15 at each site to increase the probability that the test lines are at the flowering stage when a natural frost event occurs. On site weather stations monitor the temperature at the crop canopy. Following a frost event, 30 flowering heads are tagged and then assessed for frost induced sterility (FIS) during grain fill 4-6 weeks later. FIS is assessed on the outside grains of every spikelet excluding the terminal and basal spikelets. This approach minimises confounding effects due to maturity and enables repeatable results over successive seasons and sites. Different research agencies conducted the trials in each state, although the same protocols were used. Table 1 gives a summary of the trials.

The genotypes that were grown included a selection of the most commonly grown wheat and barley varieties in the three states, genotypes which had been well characterised previously for frost tolerance and other genotypes of particular interest to breeding companies.

Table 1. Summary of wheat experiments used in analysis, replications =2.

State	**Location**	**Year**	**Number of Sowing dates**	**Number of Varieties**
SA	Loxton	2010	6	35
		2011	6	36
		2012	11	65
		2013	10	65
		2014	10	72
WA	Merredin	2012	7	48
	Wickepin	2013	6	54
	Wickepin	2014	8	72
NSW	Narrabri	2012	7	30
		2013	7	32
		2014	7	32

Results and discussion

When cereal varieties are flowering on the same day and a frost occurs, there is a wide range in frost susceptibility within commercial varieties under mild reproductive frost conditions (minimum temperature -1° to -3°C) (Figure 1). Under very severe frost (for example -8°C) or multiple minor frosts (several nights of -2° to -4°C) all varieties are equally susceptible, resulting in up to 100 per cent sterility. It should be noted that the relationship between canopy temperature and FIS is complex and can be confounded by TOS, variety and environmental factors. Understanding this relationship will be the focus of ongoing research.

Frost values

The relative ranking of the frost susceptibility has been expressed as a frost value (FV) for each variety in each environment. FVs are presented as positive or negative differences relative to the average frost induced sterility (FIS) of all varieties in the current data-set for a given year and site. Low FVs are more desirable than high FVs. The units of measurement for FVs relate to the transformed FIS data and therefore do not directly correspond to a particular level of frost damage. Therefore the comparative ranking between a subset of varieties of interested should be considered when making variety decisions as it is the difference between FVs that is critical.

When using FVs for selection decisions, it is recommended that growers and advisors consider not just a single environment/year, but a number of relevant environments. This allows examination of stability of variety performance over a range of environments which are prone to frosts.

FVs can be displayed graphically for a set of either wheat or barley varieties of interest using the interactive tool that is available from NVT Online (http://www.nvtonline.com.au/) an example of this is shown in Figure 2.

The rankings are currently based on the variation in wheat and barley variety's ability to maintain grain number under minor reproductive frosts. Under reproductive/floret or head frosts, grain number is the main yield component affected. Yield is a function of grain size multiplied by grain number and hence grain number normally corresponds to yield. However, this may not be the case if there is variation in the length of season and the ability of varieties to compensate with late tillers, synchronisation of flowering time or plasticity of grain number. Therefore, it is critical that varieties are selected on local adaptation and yield first and FVs are only used to identify and manage frost risk.

Further research is ongoing to validate the yield relationship with FIS (DAW00234) and also compensation ability (CSP00180) as part of the GRDC's multidisciplinary National Frost Initiative.

In addition it is important to note that research to date has not conclusively assessed if the variation in reproductive frost susceptibility is related to susceptibility to frost during stem elongation and grain filling.

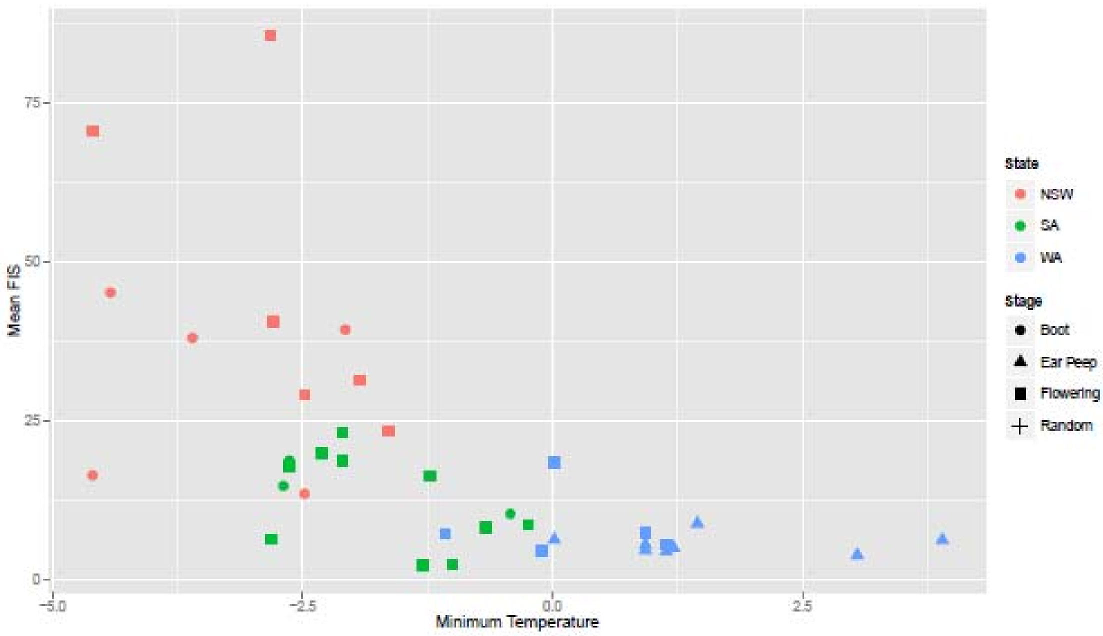

Figure 1. Relationship between minimum temperature in 3 environments and raw FIS data for each wheat tagging event, at different development stages in 2012-2013.

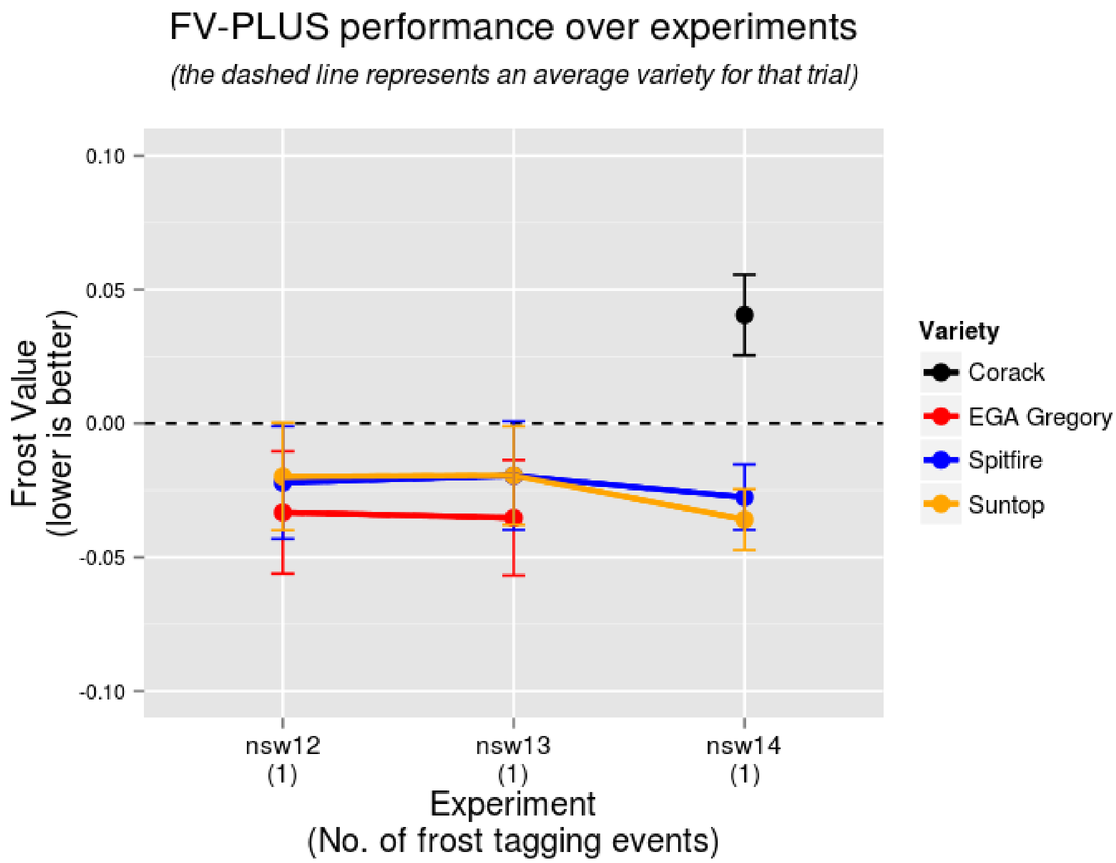

Figure 2. Frost Value graph for five wheat varieties tested at Narrabri NSW. Each FV for each variety is presented along with prediction standard error bars. The number of tagging events is indicated in brackets for each site/year. Lower FVs are better.
(ⓓ EGA Gregory, Spitfire, Suntop & Corack are all varieties protected under the Plant Breeders Rights Act 1994)

Conclusion

As frost exerts a complex production constraint in cropping systems, it requires a package of risk management strategies. These strategies should include pre-season, in-crop and post frost management tactics. These tactics should be regularly reviewed and updated as part of annual farm management planning and as new ideas and research findings are uncovered.

Variation in cereal varieties for reproductive frost susceptibility is just one component of a management strategy and may be used to fine-tune variety selection to manage the risk of frost damage.

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Yield and quality drivers in cereals

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Frost risk, date of flowering, yield, temperature change - matching varieties to elevation in the same paddock

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Getting the right sowing window in canola - matching varieties to sowing date and yield expectation

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Northern NSW pulse agronomy project –nutrition in chickpea 2015 research report

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Key words

chickpea, nutrients, grain yield,

GRDC code

DAN00171 - Northern Pulse Agronomy Initiative project (winter pulses)

Take home messages

- Phosphorus was a limiting factor to grain yield in 2015
- Zinc was limiting yield at three locations
- Iron was a limiting factor on a grey-brown vertosol with a 50 year cropping history

Introduction

The 2015 season was characterised by episodic cold weather events during flowering and terminal drought during grain fill. These seasonal conditions impacted heavily, reducing the potential yield of chickpeas across most areas of the northern NSW cropping zone.

The Northern Pulse Agronomy Initiative project had a range of experiments covering a number of agronomic themes in 2014. This paper will report on the outcomes of the nutrition experiments across northern NSW.

What we did?

Nutrients were applied in a nutrient omission format at seven locations across central and northern NSW. In nutrient omission trials, one nutrient is deliberately omitted in each treatment, while all other nutrients are applied at rates considered as non-limiting. It is therefore not possible to determine optimum nutrient application rates directly from the results of these experiments.

The 12 treatments were; Zero nutrients, All nutrients, - N, - P, - K, - Ca, - B, - Cu, - Zn, - Mn, - Mg, - Fe.

Application method varied between nutrients. Both P and N were applied at sowing, at 10 kg P/ha as Trifos and 10 kg N/ha as urea, respectively. Ca, Mg, Zn, Mn, Cu and Fe were applied as chelates in a foliar spray. K was applied as Potassium citrate and B as Boron ethanolamine as foliar sprays. Besides N and P (applied at sowing), all other nutrients were sprayed on the crop at mid vegetative period. PBA HatTrick⚘ was sown at all sites at 30 plants/m^2.

What we found?

Grain yield data for the seven experimental locations is contained in Table 1. Rowena showed no significant responses to applied nutrients. The Trangie, Edgeroi and Coonamble sites showed yield responses to applied Zn of, 28%, 18% and 7%, respectively. Coonamble, Nowley, Moree and North Star had responses to applied P of, 4%, 15%, 15% and 11%, respectively.

The Coonamble site, a grey-brown vertosol which has been cropped since the early 1960’s, also showed an 8% yield response to applied Fe.

Table 1. Effect of selected nutrient omission treatments on grain yield (kg/ha) in chickpea at northern NSW sites in 2015

Treatment	Trangie (kg/ha)	Rowena (kg/ha)	Edgeroi (kg/ha)	Coonamble (kg/ha)	Nowley (kg/ha)	Moree (kg/ha)	North Star (kg/ha)
Minus-Zn	559b	788a	1498b	1816b	1619a	1928a	2129a
Minus-P	626ab	986a	1613ab	1864b	1425b	1697b	2005b
Minus-Fe				1804b			
All	714a	1019a	1772a	1947a	1643a	1956a	2226a

Values with the same letter are not significantly different at P>0.05

Conclusions

- Frosts and cold periods during flowering at sites led to floral abortion and a reduction in yield;
- Extended dry periods at sites during September and October led to pod and seed abortion ;
- Older cropping country is showing responses to applied P as well as Zn and in one instance Fe

Acknowledgements

The research undertaken as part of project DAN00171 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The authors would like to thank them for their continued support. Thanks to Mat Grinter, Michael Nowland and Jayne Jenkins and Scott Richards (all NSW DPI) for their technical assistance in the trial program.

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Northern winter pulse agronomy - Faba bean density experiments - 2015

Andrew Verrell[a] *and Leigh Jenkins*[b]

NSW Department of Primary Industries, Tamworth[a] and Trangie[b]

Key words

faba bean, plant density, frost

GRDC code

DAN00171 - Northern Pulse Agronomy Initiative project (Winter pulses)

Take home message

- Sow faba beans at 20 plants/m^2 in northern regions
- Sow faba beans at 30 plants/m^2 in central regions
- Doza⦶ appears more prone to frost damage than either PBA Warda⦶ or PBA Nasma⦶

Introduction

The 2015 season was characterised by severe frost events, episodic cold weather during flowering and terminal drought during grain fill. These seasonal conditions impacted heavily on crop performance, reducing the potential yield of faba beans across most areas of the northern NSW cropping zone.

The NPAI (Winter Pulse) project conducted a range of experiments covering a number of different agronomic themes in 2015. This paper reports on the outcomes of a series of faba bean variety x density experiments across northern NSW.

What did we do?

Faba bean, variety x density, experiments were conducted at five locations across northern NSW in 2015. Three varieties were sown; Doza⦶, PBA Warda⦶ and the new line PBA Nasma⦶. Four target plant densities were examined; 10, 20, 30 and 40 plants/m^2. All five trials were grown under dryland cropping conditions (i.e. not irrigated).

The three lines selected represent the two preferred commercial lines (Doza⦶ and PBA Warda⦶) and the new large seeded line PBA Nasma⦶. The difference in seed size for these commercial lines is shown in Figure 1 where PBA Nasma⦶, on average, has seed that is 40% larger than Doza⦶.

What did we find?

For grain yield, there were no significant interactions between variety and plant density; only main effects (see Table 1). PBA Warda⦶ and PBA Nasma⦶ out yielded Doza⦶ at two of the five sites (Coonamble and Tamworth); while at Trangie, PBA Nasma⦶ out yielded both Doza⦶ and PBA Warda⦶ (Table 1). Plant density showed significant responses at two sites; Cryon plateaued at 20 plants/m^2, while at Trangie peak yield was obtained at 30 plants/m^2 (Table 1). The remaining sites showed no yield response to plant density.

Frosts were prevalent across the northern region in 2015 and the Tamworth site suffered a number of severe frosts. From the 28th July to the 8th of August, 6 frosts were recorded ranging from -1.3 to -3.5^{0}C. This resulted in frost damage, causing elongating stems to develop a bent stick (hockey stick) appearance and blackening of leaf margins. Treatments were scored for frost damage on a 1-9 scale on the 7th August, with 1 representing no frost damage and 9 equal to plant death. Variety ratings are shown in Figure 2 with DozaⓅ significantly worse than both PBA WardaⓅ and PBA NasmaⓅ for symptoms of frost damage.

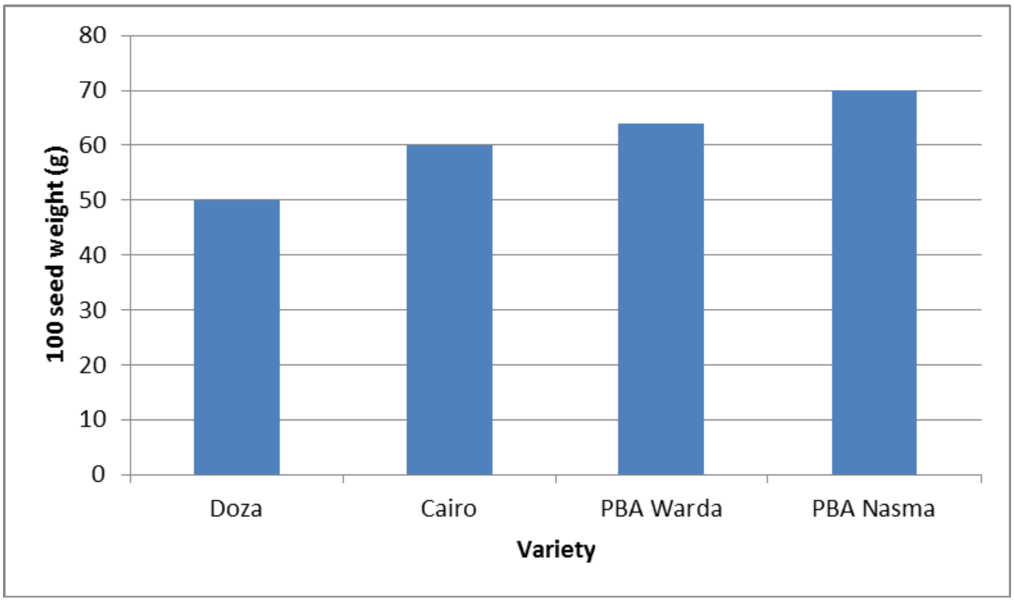

Figure 1. Average 100 seed weight (g) for selected faba bean varieties

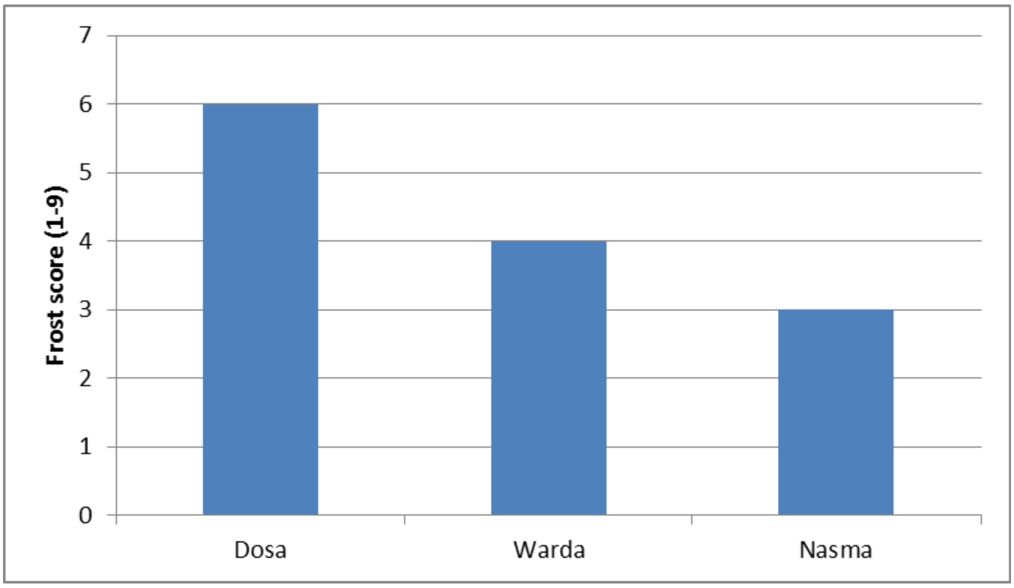

Figure 2. Frost scores for faba bean varieties (1 = no symptoms, 9 = plant death)

Table 1. Grain yield (kg/ha) for the main effects of variety and plant density at five locations in 2015

Treatment	Bullarah	Coonamble	Cryon	Trangie	Tamworth
Variety	*Grain yield (kg/ha)*				
Dozaⓓ	1602a	2900b	1547a	2036b	2954b
PBA Wardaⓓ	1687a	3280a	1700a	2246b	3296a
PBA Nasmaⓓ	1685a	3452a	1686a	2658a	3359a
Density	*Grain yield (kg/ha)*				
10	1498a	3376a	1373b	1975c	3177a
20	1670a	3411a	1772a	2275b	3329a
30	1768a	3246a	1673a	2515a	3210a
40	1666a	3270a	1745a	2489a	3096a

Values with the same letter are not significantly different

Conclusion

Limited data from the first year of trial results in 2015 suggests that for northern and western sites 20 plants/m^2 is a preferred target plant density, while in southern areas 30 plants/m^2 is a better option to achieve optimum yield of faba beans grown under dryland cropping conditions.

Large seed does not necessarily confer higher yield; with PBA Nasmaⓓ out yielding PBA Wardaⓓ at only one location, Trangie.

Dozaⓓ appears more prone to frost damage than either PBA Wardaⓓ or PBA Nasmaⓓ. Frost tolerance is a key attribute for the faba bean breeding program in northern NSW, with new releases (particularly PBA Nasmaⓓ) targeted at having better tolerance than Dozaⓓ.

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The research undertaken as part of project DAN00171 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The authors would like to thank them for their continued support. Thanks to Michael Nowland, Matt Grinter, Jayne Jenkins, Scott Richards and Gerard Lonegran (all NSW DPI) for their assistance in the trial program.

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PBA Nasma⏀ faba bean – effect of seed size at sowing on grain yield

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NSW Department of Primary Industries, Tamworth[a] and Trangie[b]

Key words

faba bean, seed size, frost, grain yield

GRDC code

DAN00171 - Northern Pulse Agronomy Initiative project (Winter pulses)

Take home messages

- At present, there is no evidence to suggest that seed size at sowing has an impact on grain yield in cultivar PBA Nasma⏀
- Seed size at sowing is positively related to seed size at harvest
- Further experimentation is needed

Introduction

In cereals, large initial seed size frequently confers distinct advantages in terms of seedling vigour, hardiness, improved stand establishment, and higher productivity (Grieve and Francois, 1992). Spilde (1988) found, for barley and wheat that grain produced from small-sized seed averaged 4 and 5% less yield than that from medium sized seed and 6 and 8% less yield than that from large-sized seed, respectively.

However, studies comparing faba bean genotypes of different seed sizes indicated a negative relationship between seed mass and grain yield (Laing *et al*., 1984; White and González, 1990; White *et al*., 1992; Sexton *et al*., 1994). Lima *et al* (2005) found faba bean plants originating from small seed presented a higher relative growth rate and net assimilation rate than plants from large seed. Large seed did not affect grain yield, but reduced the number of seeds per pod, increased the 100-seed mass, and reduced the harvest index.

The new faba bean cultivar, PBA Nasma⏀, produces very large seed averaging 70g/100 seeds compared to cultivar Doza⏀, at 50g/100 seeds . An experiment was conducted to examine the effect of seed size at sowing, at a fixed population, on grain yield and seed size distribution at harvest.

What did we do?

Seed supply for this newly released cultivar was in limited supply which restricted experimentation to two sites (TAI and TARC) in 2015.

The seed was passed thru a set of nested circular mesh sieves and partitioned into four seed size categories; < 7mm, 7-8mm, 8-9mm, >9mm. The corresponding 100 seed weights for the seed size categories, < 7mm, 7-8mm, 8-9mm, >9mm; were 34.6, 48.1, 69.5 and 90.0g, respectively.

Randomised complete block experiments consisting of the four seed size treatments and four replicates were sown at target plant densities of 20 and 10 plants/m^2 at TAI and TARC, respectively.

What did we find?

The seed size distribution of the 25kg seed lot used to obtain the seed categories for sowing these experiments is contained in Figure 1. The predominant seed size was the 8-9mm category which accounted for 72% of the total seed supply.

All plots attained their target plant densities (data not shown). At TAI, plants grown from the largest size seed produced 19% and 8% more biomass than the small seed size category at 25th June and 3rd August, respectively. Seed size categories were scored for frost damage on the 7th of August but there was no significant difference.

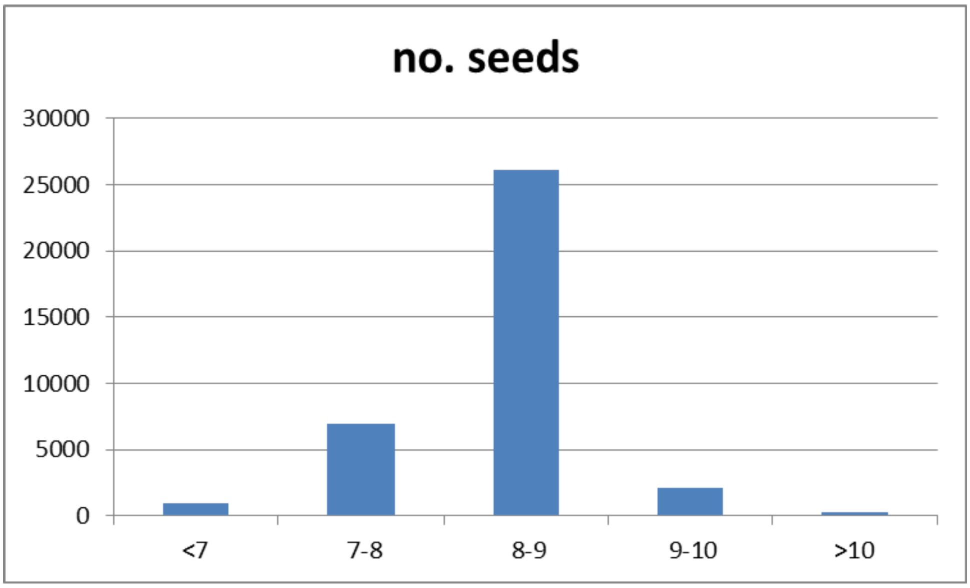

Figure 1. Seed size distribution and number of seeds per category for the seed lot used for sowing experiments.

Table 1 contains data on the effect of seed size category at sowing on plant height, height to top pod, grain yield and hundred seed weight for the TAI experiment and grain yield and 100 seed weight for the TARC experiment.

At TAI, the plants grown from seed smaller than 7mm in size were significantly shorter than all other seed categories while there was no difference in height to top pod across the seed categories (see Table 1). There was also no significant difference in grain yield between any of the seed size categories. Hundred seed weight did vary significantly and the large seed category, on average, produced heavier grain than the small seed category.

At TARC, grain yield was significantly higher for the two large seed size categories compared to the very small seed category (by 13%). Hundred seed weight had a similar response to seed size category as found at TAI, 100 seed weight increasing with seed size at sowing (see Table 1).

Table 1. Effect of seed size category at sowing on plant height, height to top pod, grain yield and hundred seed weight for TAI and grain yield and hundred seed weight for TARC

	TAI				TARC	
Seed size category	**Plant height (mm)**	**Height to top pod (mm)**	**Yield (kg/ha)**	**100 seed weight (g)**	**Yield (kg/ha)**	**100 seed weight (g)**
<7mm	1240b	1000a	3287a	55.80c	1696 c	48.1d
7-8mm	1358a	1124a	3144a	65.0ab	1726bc	50.9c
8-9mm	1329a	1030a	3267a	59.4bc	1921ab	55.2b
>9mm	1376a	1078a	3557a	68.80a	2013 a	60.0a

Values with the same letter are not significantly different at P>0.05

Conclusion

Plants grown from large seeds were taller and had significantly more biomass than the plants grown from small seed. However this did not translate into a significant difference in grain yield at TAI but did in the TARC experiment. There may be an interaction with plant density and seed size given these different results (TAI 20 and TARC 10 plants/m^2). These results are similar to that of Agung and McDonald (1998) in South Australia where yields for cultivar Fiord averaged about 400 g/m 2 but were not consistently related to seed size, although the highest yielding accession at their sites were large-seeded.

The size of seed produced at harvest was positively related to seed size with the largest seed category producing the biggest size seed compared to the small seed category (see Table 1) at both experimental sites.

Acknowledgements

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References

S. Agung and G. K. McDonald (1998). Effects of seed size and maturity on the growth and yield of faba bean (Vicia faba L.). Australian Journal of Agricultural Research 49(1) 79 - 88

C. M. Grieve, L. E. Francois (1992). The importance of initial seed size in wheat plant response to salinity. Plant and Soil, Vol 147, Issue 2, pp 197-205

Laing DR, Jones PG, Davis JHC (1984) Common bean (Phaseolus vulgaris L.). In: Goldsworthy PR, Fisher NM (eds), The Physiology of Tropical Field Crops, pp.305-351. John Wiley, New York, USA.

Elvis Rodrigues Lima; Aline Silva Santiago; Adelson Paulo AraújoII, Marcelo Grandi Teixeira (2005). Effects of the size of sown seed on growth and yield of common bean cultivars of different seed sizes, Braz. J. Plant Physiol. vol.17 no.3

Sexton PJ, White JW, Boote KJ (1994) Yield-determining processes in relation to cultivar seed size of common bean. Crop Sci. 34:84-91.

L. A. Spilde (1988). Influence of Seed Size and Test Weight on Several Agronomic Traits of Barley and Hard Red Spring Wheat. Journal of Production Agriculture, Vol. 2, No. 2, p. 169-172

White JW, González A (1990) Characterization of the negative association between seed yield and seed size among genotypes of common bean. Field Crops Res. 23:159-175

White JW, Singh SP, Pino C, Rios BMJ, Buddenhagen I (1992) Effects of seed size and photoperiod response on crop growth and yield of common bean. Field Crops Res. 28:295-307.

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Chickpea on chickpea – is it worth it?

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Key words

chickpea, Ascochyta, Phytophthora, Sclerotinia, management

GRDC codes

DAN00176, DAN00151

Take home message

Planting your 2016 chickpea crop into paddocks that had chickpeas in 2015, or earlier, is risky and you could lose money.

Further, it puts current disease management practices under pressure and could lead to reduced life of chickpea varieties, development of fungicide resistance and problems with weeds and insects.

Growers are urged to follow recommendations for current best practice especially with regard to crop rotation.

Background

Tempting as they are, current chickpea prices should not lure growers into thinking back to back chickpea is a viable option. Why not? For growers, the biggest risk is you stand to lose money – a lot of money. For the chickpea industry, the concern is that current best practices will become redundant prematurely or will fail completely.

What are the risks of back to back chickpea?

The main risks are seed borne, stubble borne and soil borne diseases. Successful disease management in chickpeas relies heavily on an integrated management package involving paddock selection (crop sequencing), variety choice, seed treatment, strategic fungicide use and hygiene.

Back to back chickpea - which diseases are of concern? There are four major chickpea diseases that will be favoured by planting chickpea on chickpea, ie:

- Ascochyta blight (AB, *Phoma rabiei* – previously called *Ascochyta rabiei*)
- Phytophthora root rot (PRR; *Phytophthora medicaginis*)
- Sclerotinia rot ("Sclero" *Sclerotinia sclerotiorum* and *S. minor*)
- Root lesion nematode (RLN, *Pratylenchus* spp)

Of these, Ascochyta, Phytophthora and Sclerotinia have the potential to cause 100% loss if conditions are conducive.

The risks of Botrytis grey mould (BGM, *Botrytis cinerea*), Botrytis seedling disease (BSD, *B. cinerea*) and viruses (several species) are unlikely to increase with chickpea on chickpea UNLESS some consequence of back to back chickpea favours these diseases eg patchy, uneven stands caused by Ascochyta, Sclerotinia or Phytophthora will increase the risk of virus.

If I did not find any disease in my 2015 crop, is it safe to plant chickpea on chickpea in 2016?

The short answer is NO. Severe disease can occur even if disease was not detected in the 2015 crop or even in earlier chickpea crops. This was demonstrated clearly in 2015 in north western NSW/southern QLD.

Case 1: The bulk of one paddock had been planted in 2013 to PBA HatTrick⦶ but a narrow strip was sown with the new variety PBA Boundary⦶. The soil was a clay grey vertosol conducive to Phytophthora root rot when wet. PBA HatTrick⦶ has some resistance to Phytophthora (rated MR) but PBA Boundary⦶ is susceptible. In 2013, no Phytophthora was observed in either variety. The entire paddock grew wheat in 2014 and in 2015 was sown to PBA HatTrick⦶. On 2 September 2015, Phytophthora (confirmed by lab test) was obvious in the area sown to PBA Boundary⦶ in 2013 but was not detected in the bulk of the paddock sown to PBA HatTrick⦶ in 2013. The 2015 Phytophthora was so severe in the 2013 PBA Boundary⦶ strip that it was not harvested whereas the 2013 PBA HatTrick⦶ area went over 2t/ha.

Case 2: In 2014 several paddocks on one farm were planted to Kyabra⦶ (susceptible to Ascochyta blight). Ascochyta was not detected in 2014 either on the farm or in the district. This, together with the prediction of an El Nino kicking in towards the end of July 2015, led to a decision to plant Kyabra⦶ in the paddocks that had Kyabra⦶ in 2014. It was reasoned that if Ascochyta did occur in 2015, it could be controlled with fungicides. What was not considered would be how to manage Ascochyta if it was too wet to spray – which unfortunately is what happened in early winter. Even though no Ascochyta was detected in 2014, the pathogen was clearly on farm and infected plants in late autumn/early winter. The first fungicide was not applied until 14 July by which time the disease was well established. When inspected on 29 July 2015, Ascochyta was rampant in all paddocks and was especially severe in those that had chickpeas in 2014, with many areas of dead and stunted plants. Although no rain fell after end July, these "bad" areas only went 0.6 – 0.8 t/ha compared with Kyabra⦶ planted into wheat stubble that went 1.0 – 1.5 t/ha.

What are the impacts of back to back chickpea on a grower?

The main short term one is losing money both from lost yield and quality and, for those diseases that can be controlled in-crop eg Ascochyta, increased production costs. Longer term consequences include increasing inoculum loads in paddocks, rendering them less productive and less flexible. For example with *Sclerotinia* spp, which have wide host ranges (including cotton), the survival structures (sclerotia) remain viable in soil for many years. Thus any practice that increases the sclerotial load reduces the potential of the paddock for host crops such as faba bean, canola, lupin, field pea, cotton (and future chickpea crops).

What are the impacts of back to back chickpea on the industry?

There are three:

1. Increased risk of changes in the pathogen ie it becomes more virulent and aggressive
2. Reduced commercial life of varieties ie back to back chickpea increases the risk of the pathogen establishing in the crop early which increases the potential for more disease cycles throughout the growing season which means resistance genes are subjected to more challenges by the pathogen. Resistance genes are limited; the loss of any gene will severely hinder the development of new chickpea varieties.
3. Increased risk of pathogens developing resistance to fungicides ie reduced life of fungicide. For diseases that can be managed with in-crop fungicides eg Ascochyta, the earlier the disease establishes, the more likely is the need for repeated applications of fungicides. If you wanted to find resistance to chlorothalonil in the Ascochyta pathogen, a good place to look would be in early sown back to back Kyabra⦶. The problem here is that any isolate that is resistant to

chlorothalonil is unlikely to be confined to the paddock (or farm) in which that resistance developed. Thus an Ascochyta isolate with resistance to chlorothalonil on a single farm in say Moree could become established in the Darling Downs and elsewhere in northern and north central NSW within a few seasons. This would be the end of chlorothalonil as a disease management tool for chickpeas.

Planting 2016 chickpeas into 2015 chickpea paddocks – is it worth it?

Definitely NOT. Besides it is doesn't make sense. As well as increased risk of disease, weed and insect management will also be more challenging. At $800/t, surely growers should be doing everything to reduce risk and maximise yield and quality.

Further information on chickpea disease management can be found at the following:

http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management

www.pulseaus.com.au

- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide#Diseasemanagement
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/sclerotinia
- http://www.pulseaus.com.au/growing-pulses/publications/manage-viruses

and in the NSW DPI 2016 Winter Crop Variety Sowing Guide

Acknowledgements

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Chickpeas – what we learnt in 2015 and recommendations for 2016

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Key words

chickpea, Ascochyta, Phytophthora, management

GRDC code

DAN00176 Northern NSW Integrated Disease Management

Take home message

- Plant seed of known identity and purity and of high quality that has been properly treated with a registered seed dressing.
- Localities where Ascochyta was found on any variety in 2015 are considered high risk for 2016 crops and growers are advised to apply a preventative fungicide before the first post-emergent rain event to PBA HatTrick(D).
- Mild temperatures, long cloudy periods and frequent rainfall events during Jun/Jul across the Northern region as occurred in 2015, are ideal for early season outbreaks of Ascochyta blight in chickpea crops.
- In wet seasons the management of Ascochyta can be hindered by getting ground rigs into wet paddocks and shortage of fungicides.
- Follow the disease management recommendations in this article and associated links – they will maximise your chance of a profitable chickpea crop in 2016.

The 2015 northern NSW/southern QLD chickpea season

Unprecedented high prices (peaking at $900 in Jun) led to a record planting of chickpeas in the region. The 2015 winter crop season in northern NSW/southern QLD followed a wet Jan, dry Feb/Mar, wet Apr (except Dalby) and wet May (except Roma, Table 1).

In most centres in northern NSW, mild, wet to very wet conditions in Jun/Jul were followed by average or below average Aug, a very dry Sep, below average Oct rain and a wet Nov harvest. On the Downs conditions were much drier. Rainfall totals and long term averages for the Jun-Nov period were: Dubbo 292mm (LTA 279mm), Gilgandra 301mm (LTA 261mm), Trangie 251mm (LTA 225mm), Nyngan 204mm (LTA 190mm), Coonamble 158mm (LTA 231mm), Walgett 236mm (LTA 201mm), Moree 204mm (LTA 258mm), Tamworth 341mm (LTA 315mm), Roma 173 (LTA 226mm), Dalby 124mm (LTA 261mm) with monthly figures in Table 2.

With the exception of the Downs and western areas, these conditions, together with early sowing resulted in high biomass crops which used a lot of water. Cold, dry weather from late August to late September led to flower and pod abortion. This was not helped by considerable temperature fluctuations in the last 10-14 days of September (up to 20°C in a 24hr period). Hot, dry conditions in early October put crops under further stress (as most had run out of water). Thus, in many parts of northern NSW, seasonal conditions conspired to produce big canopies that ran out of water during the major pod filling period. Coupled with frosts, low and fluctuating temperatures, this resulted in missing pods, ghost pods or single-seed pods.

Table 1. Jan – May 2015 rain (mm) at selected locations in NSW/QLD

Location	Jan	Feb	Mar	Apr	May
Roma	86	31	33	46	12
Dalby	107	49	13	11	86
Dubbo	131	32	8	82	48
Gilgandra	103	21	3	99	73
Trangie	59	1	11	114	48
Nyngan	91	5	13	44	44
Coonamble	74	11	6	76	51
Walgett	34	0	6	24	30
Moree	105	4	60	63	33
Tamworth	90	23	52	86	38

Table 2. Jun – Nov 2015 rain (mm) at selected locations in NSW/QLD

Location	Jun	Jul	Aug	Sep	Oct	Nov
Roma	64	12	24	16	16	41
Dalby	10	18	24	15	47	9
Dubbo	72	60	39	8	46	67
Gilgandra	87	59	31	1	32	92
Trangie	44	44	33	3	28	99
Nyngan	51	35	29	7	13	70
Coonamble	39	27	13	4	29	35
Walgett	58	44	27	1	34	72
Moree	62	36	11	4	10	83
Tamworth	109	34	54	24	50	71

Nevertheless, in NSW yields east of the Castlereagh and Newell highways were generally good with the better crops going 2.5 – 3.0t/ha. However, farmers west of these highways were disappointed with some crops yielding less than 0.2t/ha.

In QLD, some crops on the Downs planted on wide rows went >3.0 t/ha with at least one Kyabra⟅ crop going 3.6 t/ha. The Downs crops were sown on a full profile but with in-crop rainfall well below average, they did not have a lot of biomass. This, coupled with wide rows which allowed the soil to warm up, is believed to account for the large yield differences between crops at say Dalby and those at Moree.

Chickpea diseases in 2015

In 2015, 243 crop inspections were conducted as part of DAN00176. Ascochyta blight, AB (*Phoma rabiei* formerly called *Ascochyta rabiei*) was detected in 60 crops. High chickpea prices tempted some growers to break rules, eg plant back to back chickpeas and they paid the price, in terms of AB infection and AB management costs in 2015 chickpea crops that followed 2014 chickpeas. Some growers reported more AB in PBA HatTrick⟅ than they ever saw in Jimbour, but many of these crops had been inundated in Jun/Jul and we know that AB resistance of waterlogged chickpeas is compromised. Further the genetic purity of the variety could not be determined. Generally, however, good management and dry conditions through Aug – Oct kept AB under control and no major yield losses were reported.

Phytophthora root rot, PRR (*Phytophthora medicaginis,* 23 cases) caused light to moderate losses but only in paddocks with a history of medics or where the susceptible variety PBA Boundary⟅ was planted.

The mild wet winter also favoured Sclerotinia (24 cases) especially in paddocks with a canola history, with both basal and aerial infections detected. Where canola was involved, the species was always

S. sclerotiorum. One crop in the wetter areas east of Narrabri had aerial infection from ascospores of *S. minor* instead of the typical infection of roots and stem base by mycelia from sclerotia. This was the first record in this region for infection from windborne ascospores from sclerotia (due to carpogenic germination of sclerotia) leading to infection of chickpea by of *S. minor*. If such windborne infection is common, greater *S. minor* infection may result.

Botrytis Grey Mould, BGM (*Botrytis cinerea*) threatened to be a problem in high biomass crops and some of these were sprayed with carbendazim in early spring. This together with the hot dry finish, diminished the risk of BGM and no damage was reported.

Across the region, viruses were uncommon only reaching damaging levels in crops with poor, patchy stands (often the result of early season waterlogging) or where weeds had not been controlled.

Herbicide injury (Groups B, C, & I) was detected in most crops during Jun/Jul inspections including one striking example of damage predisposing a crop of PBA HatTrick⁽ᴰ at Billa Billa to PRR. Overall, herbicides caused no serious yield loss.

Disease management recommendations for 2016

Seed treatment and seed purity: Seed borne Botrytis, seed borne Ascochyta and several soil borne fungi can cause pre- and post-emergence seedling death. Irrespective of source of seed and year of production all chickpea planting seed should be treated with a registered seed dressing (Table 3). Proper coverage of the seed with an adequate rate of product is essential. Be confident of the identity and purity of your planting seed. If unsure acquire certified seed from a reputable seed merchant.

Table 3. Chickpea seed treatments

Active ingredient	Example Product	Rate	Target disease
thiabendazole 200 g/L+ thiram 360 g/L	P-Pickel T®	200 mL/100 kg seed	Seed-borne Ascochyta, Botrytis, Damping off, Fusarium
thiram 600 g/L	Thiram 600	200 mL/100 kg seed	Seed-borne Botrytis and Ascochyta, Damping off
thiram 800 g/kg	Thiragranz®	150 g/100 kg seed	Seed-borne Botrytis and Ascochyta, Damping off
metalaxyl 350 g/L	Apron® XL 350 ES	75 mL/100 kg seed	Phytophthora root rot

Ascochyta Blight

The following strategy should reduce losses from Ascochyta in 2016:

- In areas where AB was detected in 2015, spray all varieties, including PBA HatTrick⁽ᴰ and PBA Boundary⁽ᴰ with a registered Ascochyta fungicide prior to the first rain event after crop emergence, three weeks after emergence, or at the 3 branch stage of crop development, whichever occurs first.
- In areas where AB was NOT detected in 2015, spray all varieties with AB resistance lower than PBA HatTrick⁽ᴰ with a registered Ascochyta fungicide prior to the first rain event after crop emergence, three weeks after emergence, or at the 3 branch stage of crop development, whichever occurs first.
- 2-3 weeks after each rain event, monitor all crops irrespective of variety and spray if Ascochyta is detected in the crop or is found in the district on any variety.

- Ground application of fungicides is preferred. Select a nozzle such as a DG TwinJet or Turbo TwinJet that will produce no smaller than medium droplets (ASAE) and deliver the equivalent of 80–100 litres water/hectare at the desired speed.
- Where aerial application is the only option (e.g. wet weather delays) ensure the aircraft is set up properly and that contractors have had their spray patterns tested.

Botrytis grey mould, BGM

In areas outside Central Queensland, spraying for BGM is not needed in most years. However, if conditions favour the disease it will develop even though BGM was not a problem in 2015. Thus, in situations favourable to the disease (high biomass, average daily temperature 15C or higher, overhead irrigation in spring), a preventative spray of a registered fungicide before canopy closure, followed by another application 2 weeks later will assist in minimising BGM development in most years. If BGM is detected in a district or in an individual crop particularly during flowering or pod fill, a fungicide spray should be applied before the next rain event. None of the fungicides currently registered or under permit for the management of BGM on chickpea have eradicant activity, so their application will not eradicate established infections. Consequently, timely and thorough applications are critical.

Phytophthora root rot

Phytophthora root rot is a soil and water-borne disease, the inoculum can become established in some paddocks. Alternative Phytophthora hosts such as pasture legumes, particularly medics and lucerne must be managed to provide a clean break between chickpea crops. Damage is greatest in seasons with above average rainfall but only a single saturating rain event is needed for infection. Avoid high-risk paddocks such as those with a history of Phytophthora in chickpea, water logging or pasture legumes, particularly medics and lucerne. If considerations other than Phytophthora warrant sowing in a high-risk paddock, choose PBA HatTrick⦶ or Yorker⦶ and treat seed with metalaxyl. Metalaxyl can be applied in the same operation as other seed dressings providing all conditions of permits and labels are met. Metalaxyl only provides protection for about 8 weeks; crops can still become infected and die later in the season.

Further information on chickpea disease management can be found at the following

http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management

www.pulseaus.com.au

- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/ascochyta-blight
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide#Diseasemanagement
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/sclerotinia
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and in the NSW DPI 2016 Winter Crop Variety Sowing Guide

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Chickpea Ascochyta – latest research on variability and implications for management

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Key words

chickpea, Ascochyta, pathogenicity, latent period

GRDC code

DAN00176, UM00052, DAN00151, DAV00126, DAN00151, DAV00098

Take home message

- In 2015, Ascochyta blight occurred in a higher proportion of chickpea crops (60 of 243 crop inspections) than in 2014 (62 of 332 crop inspections). Most infected crops were PBA HatTrick which was also the most commonly grown variety.
- Work to determine if the Ascochyta pathogen is changing started in 2013, where a number of projects are working together to provide an integrated approach to chickpea Ascochyta blight to improve variety resistance and best management practices.
- Initial results show that the population varies in time for spore germination, germ tube length, ability to cause disease (pathogenicity), and time to develop fruiting bodies (latent period).
- Significant differences in the reaction of some varieties and advanced breeding lines to two aggressive isolates of the AB pathogen have been found
- It is essential that growers adhere to best management practices, such as sustainable rotations, to minimise selection pressure on the pathogen and maximise the longevity of variety resistance.
- While research into variability of the AB pathogen continues, it seems prudent to adopt a conservative approach to AB management

Ascochyta blight in 2015 chickpea crops

In 2015, 243 chickpea crop inspections were conducted as part of DAN00176. Ascochyta blight (AB) (*Phoma rabiei* formerly called *Ascochyta rabiei*) was detected in 60 crops. Inoculum had carried over from the 2014 season and wet conditions during Jun/Jul favoured infection and disease development. High chickpea prices tempted some growers to break best practice eg plant back to back chickpeas resulting in severe disease. Some growers reported more AB in PBA HatTrick than they ever saw in Jimbour but many of these crops had been inundated in Jun/Jul and we know that AB resistance of waterlogged chickpeas is compromised. Further the genetic purity of the variety could not be determined. Generally, however, good management and dry conditions through Aug – Oct kept AB under control and no major yield losses were reported.

Details of chickpea diseases and a review of the 2015 chickpea season are in another paper in these Proceedings (Chickpeas – what we learnt in 2015 and recommendations for 2016).

Latest research on variability in the Ascochyta pathogen

Is the pathogen changing? Yes, and as a population of living individuals (isolates), we should expect it to change.

Has the pathogen changed in response to selection pressure such as the widespread cultivation of varieties with improved resistance or other factors? We don't yet know. To know if something has changed, you need to track it over a suitable time period. Detailed studies on molecular variability in the AB fungus commenced in 2008 and have shown that the overall population variation hasn't changed much. However, pathogenicity studies that began in 2013 indicate that there are differences in pathogenicity among isolates and that highly pathogenic isolates are causing disease on PBA HatTrick⦶. This paper provides key results from a range of research groups working on this combined project to better understand the chickpea AB population and its threat to the resistance sources through potential adaptation and selection.

Latent period

The incubation period is the time from infection to the appearance of symptoms. The latent period (LP) is the time from infection to the development of pycnidia (the small dark fruiting bodies that develop in the leaf and stem lesions), the LP is important because it determines how fast the disease can cycle in a crop. Determining these characteristics is thus another way of measuring variability in the pathogen population.

Three experiments were conducted in 2015. In each experiment, five isolates representing a sub-set of the pathogen population in Eastern Australia plus a 6th control isolate (obtained in 2014 from PBA HatTrick⦶ at Yallaroi, TR6415) were evaluated in a growth cabinet (20°C/15°C 12h day/12h night) on four chickpea genotypes. There were eight replicates (pots) for each of the 24 genotype by isolate combinations. At the 3 leaf stage plants were grouped by isolate and inoculated with a conidial suspension of 100,000 conidia/mL (sprayed to run-off). Plants were examined daily for symptoms and pycnidia. The mean LP was estimated by survival analysis with the status of a pot based on whether pycnidia had or had not developed. For each genotype-isolate, the data is the last day that pycnidia had not developed.

The four genotypes, their AB rating and abbreviation are: 1) ICC3996 (rated R, coded ICC), 2) Genesis™ 090 (rated R, coded GEN), 3) PBA HatTrick⦶ (rated MR, coded HAT), 4) Kyabra⦶ (rated S, coded KYB).

For each experiment, LP varied significantly between some isolates and genotypes (LP range 6-8 days). Furthermore, all isolates had the shortest LP on the most susceptible entry, KYB and the longest LP on the most resistant entry, ICC or the second most resistant entry, GEN (see example findings, Figure 1). Within an experiment, no single isolate had the shortest LPs on all genotypes, we interpret this as indicating there are no clear differences among isolates in the contribution of LP to isolate aggressiveness.

These experiments complement the pathogenicity work and confirm variability does exist in the pathogen population

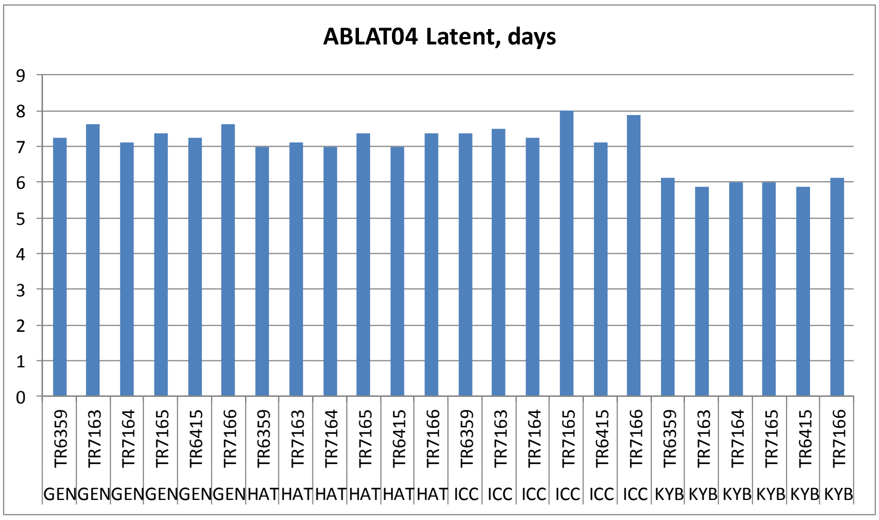

Figure 1. Latent period results for experiment ABLAT04 grouped by genotype (ICC3996 (ICC), Genesis 090 (GEN), PBA HatTrick⦶ (HAT), Kyabra⦶ (KYB)) for inoculation with six isolates listed by isolate no, source and variety: TR6359 2014 North Star NSW, Flipper⦶; TR7165 2014 Horsham VIC; Genesis425, TR7163 2014 Donald VIC; Slasher⦶; TR6415 2014 Yallaroi NSW, HatTrick⦶; TR7164 2014 Donald VIC, Slasher⦶; TR7166 2014 Salter Springs SA, Monarch⦶.

Histopathology experiments

A range of preliminary histopathology experiments have been completed, see Figure 2 for summary spore germination and germ tube length results. Key findings from a range of work in this area are that:

- Spore germination begins much faster on the susceptible Kyabra⦶ and on PBA HatTrick⦶ than on the resistant Genesis090
- Spore germination is consistently slower and lower on the resistance source ICC3996 than on any other chickpea genotype tested
- There is significant variation in germination time among different isolates and this correlates with their level of pathogenicity
- After germination, germ tube length prior to invasion is significantly shorter on ICC3996 than any other chickpea genotype tested

These differential fungal responses may be indicative of host recognition and defence strategies, which are being further investigated.

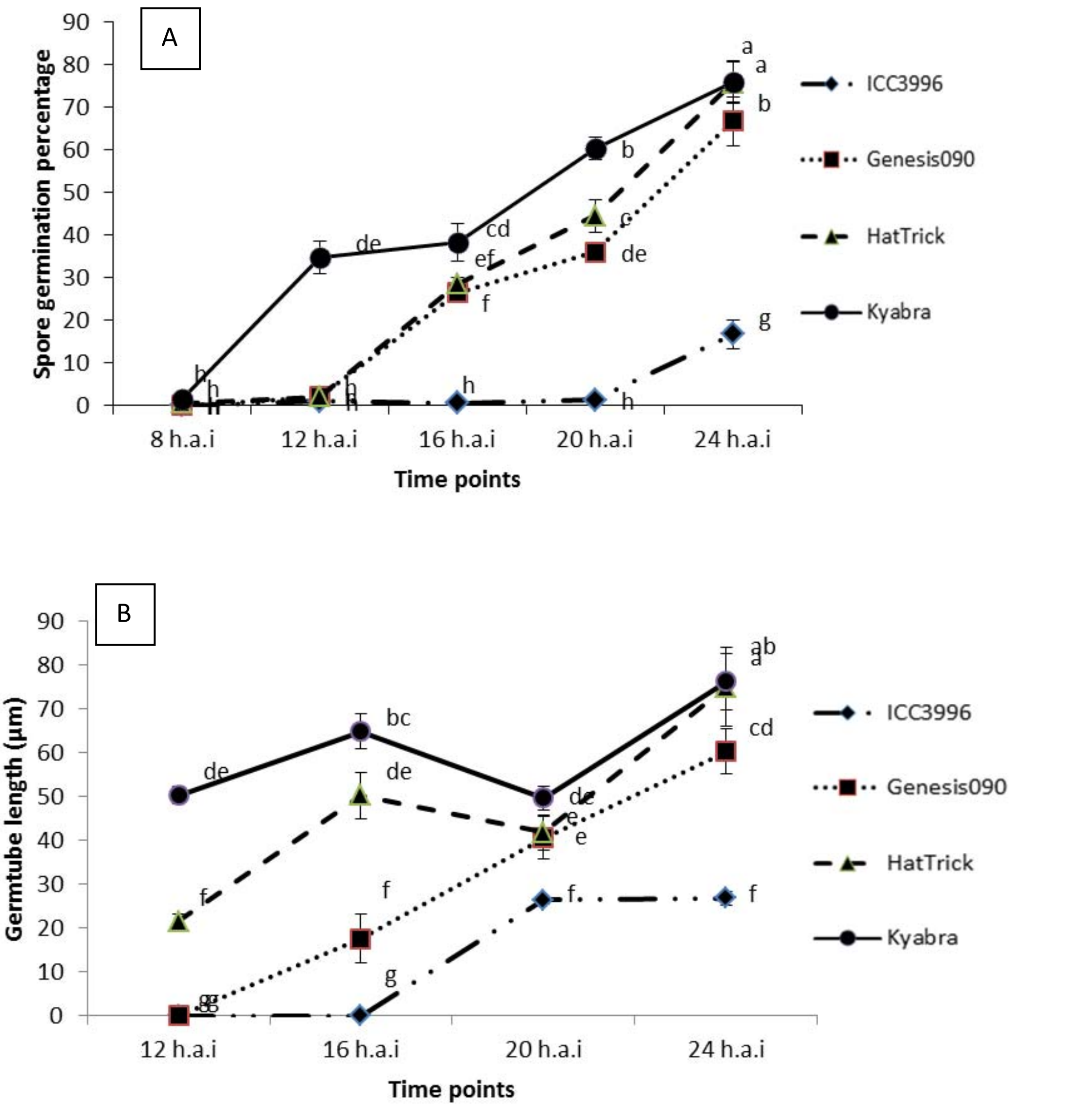

Figure 2. Significant differences were observed among the physiological traits of a highly pathogenic isolate FT13092-1 from Kingsford, SA when inoculated onto chickpea genotypes that are resistant (ICC3996 and Genesis090), moderately resistant (PBA HatTrick(b)) or susceptible (Kyabra(b)). Where A = the percentage of germinated spores and B = the germtube length over time after inoculation.

How is this information used by the PBA Chickpea program?

In 2014 and 2015 two aggressive isolates identified by the pathogen variability project were screened on the national Stage 3 desi and kabuli entries in a controlled environment by SARDI. In 2015 the two isolates tested were collected in 2013; FT13092-1 from South Australia on Genesis 090 and TR5919 from northern NSW (Tooraweenah) on PBA HatTrick(b). Of the 154 entries tested, 62 breeding lines significantly differed in their resistance (% of main stem broken) to the two isolates (subset of lines presented in Table 1). The northern isolate was found to be more aggressive than the South Australian isolate. There was no significant difference in the response of PBA HatTrick(b) to the two isolates, but PBA Boundary(b), CICA0912 and CICA1007 had significantly higher disease with TR5919. Conversely, the kabuli variety Genesis Kalkee had significantly lower disease with the TR5919 isolate compared to the SA isolate. The desi CICA1521 and kabuli CICA1156 had very low levels of disease from both isolates. The 2014 research examined two isolates collected in 2010 and a much smaller number of entries 8 (out of 137) had a significantly different response to the two isolates.

To complement this information, molecular markers have been screened across the 154 entries. A total of 5 flanking molecular markers (3 SNPs and 2 SSRs) for AB resistance (resistance sources S95362 (kabuli) and ICC3996 (desi)) were identified within “DAV00098 - Molecular markers for the pulse breeding programs” led by DEDJTR, Victoria. These markers have been validated across a diverse set of chickpea lines as part of DAV00126 program. By combining the phenotypic and genotypic information, the breeding program will gain a greater understanding of the genetic resistance in each breeding line. The wider implementation of AB molecular markers across the PBA Chickpea program has identified breeding material which may contain alternative resistance genes. Research into alternative genetic resistance genes is continuing in DAV00126. The use of alternative resistance genes in the breeding program will be essential to ensure new chickpea varieties have adequate levels of AB resistance.

Table 1. Ascochyta blight ratings, response of varieties and breeding lines (% main stems broken, lsd 29.2) to two *Phoma rabiei* isolates in a controlled environment and presence/absence (+/-) of molecular marker and source of resistance.

	AB	% of main stems broken		
Name	Field rating	Isolate FT13092-1	Isolate TR5919	Marker genotype
Kyabra⌽	S	100	100	-
PBA HatTrick⌽	MR	0	20	+, desi
PBA Boundary⌽	MR	35	75	+, desi
Genesis 836	MS	8	28	Not conclusive
CICA0912	R*	0	42	+, desi
CICA1007	MR*	0	50	+, desi
CICA1521	R*	0	8	+, desi
Almaz⌽	MS	8	8	-, suggests other genes
Genesis 090	R	0	8	+, kabuli
Genesis 425	R	8	17	+, kabuli
Genesis Kalkee	MS	50	20	--, suggests other genes
PBA Monarch⌽	MS	3	42	+, kabuli plus others
CICA1156	R*	0	0	+, kabuli

*Advanced breeding lines, putative AB rating

While research into variability of the AB pathogen continues, it seems prudent to adopt a conservative approach to AB management

Further information

http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management

www.pulseaus.com.au

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- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/northern-guide#Diseasemanagement
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/idm-strategies
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/botrytis-grey-mould
- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

- http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/sclerotinia
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Phytophthora in chickpea varieties HER15 trial –resistance and yield loss

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Key words

Phytophthora root rot, variety, risk management

GRDC code

DAN00176, DAN00151, DAQ00186, DAS00137

Take home message

- In a wet season, substantial (94%) yield losses from PRR occur in susceptible varieties such as PBA Boundary. Do not grow PBA Boundary if you suspect a PRR risk
- Varieties with improved resistance to PRR (PBA HatTrick and Yorker) can also have large yield losses (68-79%) in a very heavy PRR season
- Although yield losses will occur in very heavy PRR seasons, crosses between chickpea and wild *Cicer* species such as the breeding line CICA1328 offer the best resistance to PRR
- Avoid paddocks with a history of lucerne, medics or chickpea PRR

Varietal resistance to phytophthora root rot

Phytophthora medicaginis, the cause of phytophthora root rot (PRR) of chickpea is endemic and widespread in southern QLD and northern NSW, where it carries over from season to season on infected chickpea volunteers, lucerne, native medics and as resistant structures (oospores) in the soil. Although registered for use on chickpeas, metalaxyl seed treatment is expensive, does not provide season-long protection and is not recommended. There are no in-crop control measures for PRR and reducing losses from the disease are based on avoiding risky paddocks and choosing the right variety.

Detailed information on control of PRR in chickpea is available at:
http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

Current commercial varieties differ in their resistance to *P. medicaginis*, with Yorker and PBA HatTrick having the best resistance and are rated MR (historically Yorker has been slightly better than PBA HatTrick), while Jimbour is MS - MR, Flipper and Kyabra are MS and PBA Boundary has the lowest resistance (S). PBA Boundary should not be grown in paddocks with a history of PRR, lucerne, medics or other known hosts such as sulla.

From 2007 to 2015 PRR resistance trials at the DAF Qld Hermitage research Facility, Warwick QLD have evaluated a range of varieties and advanced PBA breeding lines. Each year the trial is inoculated with *P. medicaginis* at planting. There are two treatments, (i) seed treatment with thiram + thiabendazole and metalaxyl and regular soil drenches with metalaxyl (Note: soil drenches with metalaxyl not currently registered) and (ii) seed treatment with thiram + thiabendazole only with no soil drenches. The first treatment has prevented infection by the PRR pathogen in all of these trials. The difference in yield between the metalaxyl-treated plots and untreated plots are used to calculate the yield loss caused by PRR i.e. % loss = 100*(Average yield of metalaxyl-treated plots – Average yield of nil metalaxyl plots)/ Average yield of metalaxyl-treated plots.

Yields in metalaxyl-treated plots were close to seasonal averages for the 2015 season with the lowest yielding breeding lines and varieties (CICA1328, Yorker⸙ and PBA HatTrick⸙) yielding close to 2.5 t/ha (Table 1).

In 2015 the level of PRR in the trial was considerably higher than those previous seasons such as 2014 (Table 2). For example yield losses were greater than 40% for CICA1328 in 2015 but only 1.8% in 2015 and yield losses for PBA Boundary⸙ were 94% in 2015 and 74% in 2014. However, the 2015 trial again confirmed that Yorker⸙ and PBA HatTrick⸙ had better resistance than PBA Boundary⸙ (Table 1), which has been consistent across previous trials.

Results for the high PRR disease season of 2015 showed that susceptible varieties sustain substantial yield loss from PRR and that varieties with moderate resistance have reduced losses. The 2015 trial again confirmed the superior PRR resistance of the PBA breeding line CICA1328 which is a cross between a chickpea (*Cicer arietinum*) line and a wild *Cicer* species.

CICA1007 was included in the 2015 trial because it has high yield and large seed size in a Yorker⸙ background. In the absence of PRR it was the second highest yielder in the trial (2.93t/ha) and its yield loss to PRR was similar to Yorker⸙.

Table 1. Yields of commercial chickpea varieties and breeding lines protected from Phytophthora root rot, and % yield losses from PRR in a 2015 trial at Warwick QLD. (P Yield<0.001; lsd Yield = 0.46)

Variety/line[A]	Yield (t/ha) in absence of *Phytophthora* infection	Yield (t/ha) in presence of *Phytophthora* infection	% yield loss due to *Phytophthora* infection
CICA1328[A]	2.64	1.54	41.7
D06344>F3BREE2AB027[A]	2.52	1.05	58.4
PBA HatTrick⸙	2.50	0.81	67.7
Yorker⸙	2.61	0.57	78.7
CICA1007	2.93	0.71	75.9
CICA0912	2.76	0.37	86.6
PBA Boundary⸙	2.88	0.17	94.0

[A] These lines are crosses between chickpea (*C. arietinum*) and a wild *Cicer* species

Table 2. Yields of commercial chickpea varieties and breeding lines protected from Phytophthora root rot, and % yield losses from PRR in a 2014 trial at Warwick QLD. (P Yield<0.05; lsd Yield = 0.80)

Variety/line[A]	Yield (t/ha) in absence of *Phytophthora* infection	Yield (t/ha) in presence of *Phytophthora* infection	% yield loss due to *Phytophthora* infection
CICA1328[A]	2.76	2.71	1.8
Yorker⸙	3.01	2.69	10.4
CICA1211	3.01	2.66	11.6
D06344>F3BREE2AB027[A]	2.93	2.13	27.4
PBA HatTrick⸙	2.94	1.98	32.8
CICA0912	3.23	1.79	44.6
PBA Boundary⸙	2.79	0.73	73.8

[A] These lines are crosses between chickpea (*C. arietinum*) and a wild *Cicer* species

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A new DNA tool to determine risk of chickpea Phytophthora root rot

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Key words

Phytophthora root rot, risk management, inoculum measurement, PreDicta B®

GRDC code

DAS00137, DAN0172, DAN0176

Take home message

- Increasing level of inoculum (oospores/plant) of *Phytophthora medicaginis* (Pm) was strongly correlated with decreasing yield of the moderately resistant variety Yorker
- An inoculum level of 660 oospores/plant (PreDicta B® > 5000 Pm copies/g soil) at sowing significantly reduced yields compared with lower inoculum levels under both dryland and irrigated conditions
- Testing soil samples from growers' 2015 paddocks confirmed the results of testing 2014 samples that the PreDicta B® soil Pm test can identify Pm in growers paddocks in NSW and QLD
- These findings provide further evidence that the PreDicta B® Pm test will be a useful tool for growers to determine their risk of Phytophthora root rot

Note: the SARDI PreDicta B® test for *Phytophthora medicaginis* is under development and is not yet available commercially

Phytophthora medicaginis **detection in soil**

Phytophthora medicaginis (*Pm*), the cause of chickpea Phytophthora root rot (PRR) is endemic and widespread in southern QLD and northern and north central NSW. Under conducive conditions, PRR can cause 100% loss. The pathogen survives from season to season on chickpea volunteers, lucerne, native medics, sulla and as resistant structures (oospores) in roots and soil.

A PreDicta B® soil DNA test has been developed by the South Australian Research and Development Institute (SARDI) to quantify the amount of Pm DNA in soil samples and so provide a measure of the amount of Pm inoculum (infected root tissue and oospores) in paddocks. We report on the second season of studies to assess the capability of this test to:

1. detect Pm inoculum in soil from commercial paddocks
2. predict the risk of PRR disease and potential yield losses in chickpea

Pm **inoculum level, PRR disease and yield**

It would be useful if the Pm DNA test could predict the amount of PRR disease and potential losses. For example, would paddocks with nil, low and high Pm inoculum levels have nil, low and high PRR disease and yield losses? Our 2014 Pm inoculum concentration field trial (Tamworth) using the PRR susceptible variety Sonali (rating S) showed that yield losses were greatest at the highest soil Pm concentrations but that even at low soil concentrations (100 oospores/plant) substantial yield loss occurred. Pm is able to multiply quickly under high soil water conditions. The 2014 trial showed that following a saturating rain event, the amount of disease and extent of yield loss with medium levels of inoculum (500 and 1000 oospores/plant) caught up with those of higher levels of inoculum (2000 and 4000 oospores/plant)

The aim of the 2015 field trial (DAF Qld Hermitage Research Station, Warwick, QLD) was to relate the Predicta B® Pm test to PRR level and yield loss for low inoculum levels (<1000 oospores/plant) using the most PRR resistant variety Yorker⫯ (rating MR), under dryland and irrigated conditions. Irrigation was included to specifically test if low inoculum treatments would have similar effects on disease and yield loss to those of high inoculum treatments under disease conducive conditions. On 10 June 2015, a range of Pm inoculum levels was established by applying, at sowing, different rates of oospores in-furrow. On 10-11 Jun, thirty soil samples (150 mm depth cores) per plot (5 reps) were pooled and tested for soil Pm concentration by PreDicta B®. The trial was also sampled for end-season DNA Pm concentrations on 15 December (data not available at time of writing).

Irrigation was applied on 10-11 Sep and on 16-17 Oct following 2 weeks with low rainfall (< 3mm). Winter rainfall was similar to long term average values for July (22mm) and August (25mm) but September and October both had below average rainfall totals. November was wet with 97mm of rain.

Soil Pm DNA values at sowing differed significantly among oospore treatments but not between irrigation treatment (Table 1). Three of ten Nil (0) oospore plots had positive but low Pm DNA results, indicating background Phytophthora in some plots.

On 13 Oct (end of flowering), the irrigated 130 and 660 oospores/plant treatments had significantly more PRR than the dryland 130 and 660 oospores/plant treatments (Table 1). By 12 Nov (dryland treatments senescing), the irrigated 40, 130 and 660 oospores/plant treatments had significantly more PRR than the dryland 40, 130 and 660 oospores/plant treatments.

The interaction of irrigation and oospore treatments on grain yield was complex as indicated by (Table 1, Figure 1):

(i) at low inoculum levels (zero and 40 oospores/plant), irrigation increased yield compared with dryland

(ii) for medium inoculum (130 oospores/plant), irrigation had no significant effect on yield

(iii) for the highest inoculum level (660 oospores/plant) irrigation reduced yield compared with the dryland treatment.

These interactions suggest that at low PRR levels, the primary effect of irrigation is on yield, but at high PRR levels the primary effect is on disease. However, the shape of these relationships are likely to vary from season to season due to differences in seasonal rainfall (Figure 1).

Furthermore multiple processes will affect outcomes. For example, although yields did not differ between the irrigated and dryland 130 oospores/plant treatments (~3000 P.med DNA seq no/g soil) there was more disease in the irrigated treatment. In this 2015 trial, the uninfected irrigated plants in a plot will have had grain yield benefits from irrigation and so probably compensated for the yield loss of infected plants. However, for seasons with above average early-season rainfall there may be greater early-season disease development and hence greater impacts on yield at this same 3000 P.med DNA seq no/g soil inoculum level.

Under PRR conducive conditions, can low initial levels of inoculum catch up to high initial levels with regard to disease severity and yield loss? This is not clear from the current experiment and further research is required.

Can the Pm DNA soil test predict risk of Phytophthora? Based on the results of this trial with Yorker⫯ (MR) and the 2014 Tamworth one with Sonali (S), the answer is YES. For Yorker⫯ significant yield loss can be expected with starting (pre-sow sampling) inoculum levels above ca 3000 Pm DNA sequences/g soil (ca 130 oospores/plant).

However, these values may need to be interpreted with some caution as seasonal conditions will modify outcomes, for instance in a dry season less disease may develop from the same amount of inoculum.

Table 1. Irrigation-oospore treatment, soil Pm DNA concentration, PRR assessment and yield of Yorker⊕ in 2015 Pm inoculum trial at Warwick, QLD (Soil Pm concentration: P < 0.001; LSD 1092.6; 13 Oct PRR rating: P = 0.038; LSD = 0.58; 12 Nov row cm of PRR stunted plants: P = 0.035; LSD 46.4; Grain yield: P<0.001; LSD = 480.7)

Treatment, dryland (D), irrigated (I), no. oospores per plant	Soil Pm DNA concentration at sowing no. Pm sequences/g soil	13 Oct PRR rating (1= no disease, 9 = all plants dead)	12 Nov. cm of row of PRR stunted plants	Grain yield, kg/ha
D-0	342	1.1	16	3198
D-40	1986	1.7	18	2961
D-130	3051	2.0	88	3038
D-660	5357	3.1	203	2402
I-0	169	1.2	6	3914
I-40	1765	1.8	78	3631
I-130	2996	2.8	185	2966
I-660	5925	4.2	395	1764

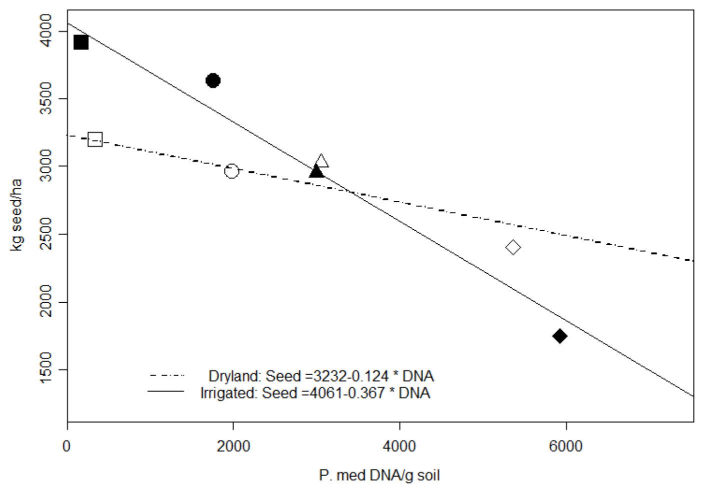

Figure 1. Multiple regression for plot soil Pm concentrations at sowing vs. grain yield for dryland (black symbols) and irrigated (white symbols) treatments (model R^2 = 0.745), treatment means presented.

Pm DNA detection in soil samples from commercial paddocks

We evaluated the ability of the Pm DNA test to detect Pm in soil samples from growers' paddocks.

Over the winter-spring period of 2014, soil samples were collected from fields in central (16) and south-western Queensland (10), and Victoria (7). Most paddocks included chickpeas in the rotation but not all had chickpeas in 2014. There were eight perimeter sample sites per paddock, one near each corner and one near the midpoint of each side. At each of the eight sample sites, a W collection pattern was walked towards the centre of the paddocks and 10 soil cores (150 mm depth PreDicta B® soil corer) collected every 20 – 25 paces along the sample path (total distance 200 – 250 m per sample site), giving a total of 80 soil cores.

Samples (9) were also collected from southern NSW, in this case most paddocks included either lucerne or lupins in the rotation. For these sites a diagonal collection pattern across low lying and weedy areas of paddocks was used and 80 150mm PreDicta B® cores collected per site.

Soil samples were stored in sealed plastic bags at 5°C. Samples were homogenised by cutting up cores and mixing, following which a 400g sub sample was sent to SARDI for DNA analysis. The remainder of each sample was then restored at 5°C until the baiting experiment was setup.

Samples from 43 paddocks were prepared for DNA analysis and a Pm baiting experiment. Subsamples of soil were dried at 105°C for 24h to determine soil moisture content, then non-dried soil was mixed with sand (dry weight basis, 55g soil + 154g sand), placed in a plastic cup (70mm width, 75mm height). There were five reps; soil from a Pm inoculated field trial (MET14) served as a control. Three Sonali seeds were sown in each cup, the cups placed in a glasshouse (RCB design). The cups were watered to 21% soil moisture content three times a week. After 18 days the cups were flooded for 48h then drained. Seedlings were assessed for disease (chlorosis, stem cankers, death) three times a week. Stem canker tissues were plated to isolate Pm. Cultures with Phytophthora like growth on cornmeal agar were plated on low strength V8 agar and colony morphology, oospore production and oospore size used to identify Pm like cultures. The isolation of Pm was attempted from all treatments that produced chlorosis followed by the appearance of Pm like stem cankers, in addition, the isolation of Pm was also attempted from any treatments where there were disease symptoms or seedlings with poor growth. After eight weeks the experiment was terminated.

Ten of the 43 paddock soil treatments produced PRR like cankers on plants, Pm like cultures were isolated from eight samples from growers paddocks; Pm like cultures were also isolated from the MET14 control soil, giving a total of nine Pm isolates. One of the samples (NIE1) produced cankers that were not caused by Pm.

Of the 43 paddock soil treatments (including the MET14 control soil), 9 had positive Pm DNA results. Comparing the DNA results to the isolation results showed that most (8/9, 89%) samples which had positive DNA results also yielded Pm cultures and that most (33/34, 97%) samples which had negative DNA results also did not yield Pm cultures (Table 2).

Notably, one sample (LOU2) which yielded a Pm culture was negative for Pm DNA.

One sample (A) was positive for Pm DNA but did not yield Pm cultures, seedlings in all 5 cups remained healthy. This sample that did not produce any PRR symptoms had a lower Pm DNA value (1,234 Pm copies/g soil) than other samples (range 2,443-813,436 Pm copies/g soil). Possible explanations for this result is: (i) more time may be required for symptoms to develop, or (ii) that the pathogen had died but some DNA had been detected.

Table 2. Comparison of *Phytophthora medicaginis* (Pm) DNA detection in 43 paddock soil samples and isolation success of Pm from Sonali chickpeas grown in these samples

		43 samples analysed for Pm DNA	
		9/43 + Pm DNA	34/43 nil Pm DNA
43 soil samples baited with chickpeas for Pm	9/43 + Pm isolates	8/9 (positives)	1/34 (false negatives)
	34/43 nil Pm isolates	1/9 (false positives)	33/34 (negatives)

These second season of results for the capability of the soil Pm DNA test are again generally promising, with most samples with positive and negative Pm DNA results corresponding to expected Pm isolation results. However, results for some samples indicate that further work is required to a) identify what factors may contribute to false negative results and b) determine if false positives are due to the presence of dead or inactive Pm DNA.

Pm DNA sampling in paddocks and disease risk determination

The DNA result for a soil sample from a paddock can only provide an indication of inoculum concentration and disease risk for the areas of the paddock which were sampled. Therefore, the spread and locations of sampling across a paddock will affect how representative DNA results are for a paddock. Because of the risk of rapid PRR disease build up following wet conditions it may be appropriate to treat a negative Predicta B® test result as indicating a low risk rather than a nil risk, as the pathogen could still be in areas of the paddock that were not sampled and so still cause PRR and reduce yield.

To maximise the probability of determining the PRR risk of a paddock, target those areas of the paddock where Pm is more likely to occur. The pathogen thrives in high soil moisture contents and so often occurs in low lying regions of paddocks where pooling following rain may occur. The pathogen also carries over from season to season on infected chickpea volunteers, lucerne and, native medics. Including low lying areas and weedy areas of paddocks during PreDicta B® soil sampling may provide the best strategy to identifying a paddocks disease risk of PRR in chickpea.

Detailed information on control of PRR in chickpea is available at:
http://www.pulseaus.com.au/growing-pulses/bmp/chickpea/phytophthora-root-rot

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Recent insect pest management research findings and the application of results in the field

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Key words

Scarabs, Helicoverpa, thresholds, green mirid, faba beans, canola

GRDC code

DAQ00196

Take home message

1. Green mirids do cause spotting on faba bean seed. Both adults and late instar nymphs are damaging and warrant control in faba bean crops. No threshold is available yet.
2. Preliminary thresholds for Helicoverpa in canola are proposed, based on research that showed the consumption rate per larva to be 2.4g of grain.
3. Knockdown products currently used for Rutherglen bug (RGB) are either more effective, or as effective, as a range of 'new' products screened. Residual activity still being investigated.
4. Cultivation shows promise as an option for reducing high densities of scarab larvae.
5. The interaction between scarab density and efficacy of seed dressings and in-furrow treatments (IFT's) needs further investigation.

Recent research outcomes

Confirmation of green mirid damage potential in faba beans

A replicated trial that caged mirid adults and nymphs on developing and maturing pods was conducted in 2015. The purpose of the trial was to establish conclusively whether mirid feeding caused spotting on the seed, and whether mirids warranted further research as a pest of faba beans.

Pods at two development stages were included in the trial, 1) fully filled, but still green and 2) immature, seed approximately 30% filled. Either 2 adult mirids, or 2 late instar nymphs were confined on a pod for 10 days, and there were control pods on which there were no mirids. At the end of the 10 days the mirids were removed from the 'cages' and the cages replaced to protect the pods from being damaged by any other insect or weather. Cages remained on the pods until the pods were mature and dried down (harvestable). During this time cages were checked, and treated where necessary for small nymphs that hatched from eggs laid by the mirids in the trial.

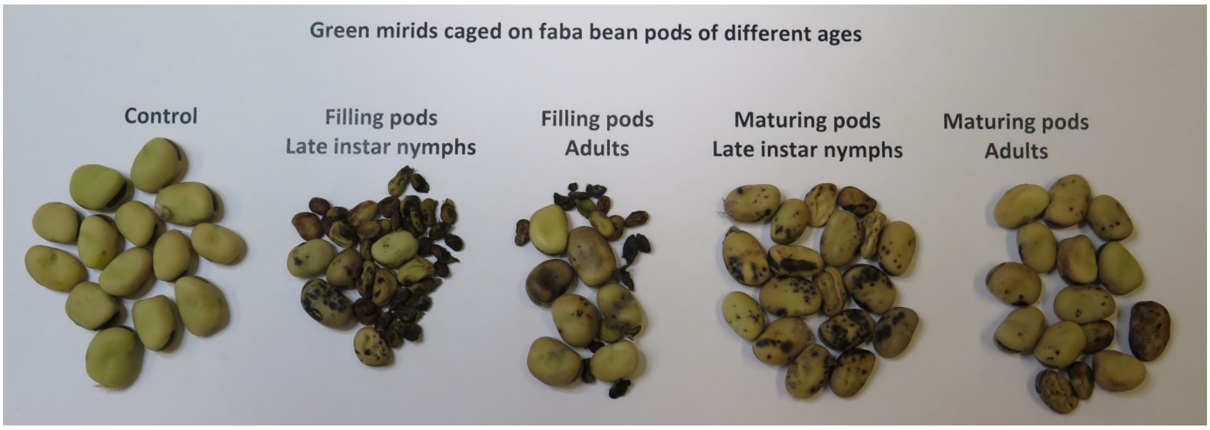

Figure 1. Effect of green mirids caged on faba bean pods of different ages

As shown in the figure above, mirids did consistently cause spotting on the seed coat. Adult and late instar mirids caused similar damage. When filling pods were exposed to mirids, a significant proportion of seed did not develop. This trial result clearly demonstrates the damage potential of mirids in faba beans, both in terms of quality (spotting) and yields (small seed).

This trial was not designed to address the question of threshold. We cannot extrapolate from these data to estimate how many mirids will cause significant seed spotting or screenings. These are areas of research that will be addressed next winter.

Preliminary threshold for helicoverpa in canola

To date, thresholds available for managing helicoverpa in canola have been based on 'best guesses'. In 2015 we conducted a replicated trial to determine the consumption rate of helicoverpa larvae in canola. A consumption rate is a vital component of an economic threshold, and is an estimate of the yield and crop loss likely to occur. It is calculated from the lifetime consumption of a larva. In other words, it is a reflection of the amount of yield loss that would occur if the larva was not controlled.

The trial involved confining individual larvae on canola racemes and allowing them to feed until they pupated. These data were compared with data from racemes that had no helicoverpa feeding. In summary, results of the trial are:

i) The consumption rate of a helicoverpa larva is estimated to be 2.4 grams of grain per larva.

ii) On average a larva damaged 10.5 pods and consumed 124 seeds.

iii) Larvae showed no preference for pod size/maturity

If we use the following equations, we can calculate the potential yield loss and economic thresholds for a range of crop and cost of control values – presented in the tables below.

Potential yield loss (t/ha) per larva = D x P x V

Where D = estimated yield loss per larva (t/ha)

P = pest density per sampling unit (e.g. per m^2)

V = crop value ($/t)

Economic threshold (larvae/m2) = C / (V x D)

Where C = cost of control ($/ha)

V = crop value ($/t)

D = estimated yield loss per larva (t/ha)

Table 1. Potential yield loss ($/ha) from helcoverpa larvae in canola

Crop value ($/t)	Number of larvae per m^2			
	1	2	3	4
400	9.60	19.20	28.80	38.40
450	10.80	21.60	32.40	43.20
500	12.00	24.00	36.00	48.00

Table 2. Economic threshold (larvae per m^2) of helicoverpa in canola

Cost of control ($/ha) (application + insecticide)			
	400	450	500
20	2.1	1.9	1.7
25	2.6	2.3	2.1
30	3.1	2.8	2.5
35	3.6	3.2	2.9
40	4.2	3.7	3.3

These thresholds are preliminary, and as it usual in the development of thresholds, the next stage is to repeat the trial as well as to evaluate the effectiveness of the proposed thresholds in adequately preventing economic yield loss in commercial crops. It is expected that we will have greater confidence and firm thresholds within 1-2 seasons.

The other aspect of helicoverpa management that has not yet been addressed, and is critical to the use of economic thresholds, is a reliable sampling method. This will be addressed this coming winter.

Rutherglen bug in canola stubble

Despite their apparent hardiness in the field, Rutherglen bug (RGB) have proven to be very difficult to maintain in laboratory bioassays. We have conducted a number of bioassays to evaluate the efficacy of a range of insecticides that we considered useful either as knockdown products, or with potential as barrier treatments to limit movement into summer crops from canola stubbles. To date we have screened 11 products for knockdown efficacy, and none of the 'new' products were superior to those currently used.

Problems with keeping RGB alive for more than 4 days in the lab, has limited our ability to evaluate the residual efficacy of the products. We will pursue this again in 2016.

What is now clear from agronomist observations and our monitoring of canola fields is that the RGB are present in the canola crops as they are filling pods and maturing. The RGB lay eggs in the soil (up to 400 eggs per female), resulting in an explosion of nymphs in 2-4 weeks after the adult RGB are seen. Although not typical, nymphs will move up the plants and onto the pods. More commonly they remain on the soil and base of plants. Where canola is windrowed, the nymphs may move to shelter under the windrows and feed on the shed seed. The risk of RGB damage to seed through direct feeding is not well understood and warrants research. Overseas research suggests that the risk of impact on grain (oil content/quality) decreases as the crop matures and dries down.

Scarabs damaging summer and winter crops

Scarab damage to establishing crops has been reported from the Darling Downs to Northern NSW. The highest number of reports of scarab infestation, and crop loss caused by scarabs, has been from the eastern Downs, but this may be a result of a higher level of awareness in these areas. Sorghum is the crop most frequently reported with crop loss, but crop loss has also been confirmed in sunflower, maize, mungbean, and wheat.

Species and lifecycle

At least 4 species of larvae have been collected from fields. In the majority of cases, there is a predominance of one species in affected fields. Whilst a definite identification is still not available (identification can only be made from beetles, and the beetles are only active for a short period between Oct-Mar), we believe the most common species is *Othnonius batseii*, the black soil scarab.

Other species of beetle are currently with a scarab taxonomist for identification.

Scarabs generally have a 1-2 year lifecycle, which can be longer if the larvae do not have suitable growing conditions (too dry, inadequate food source). This means larvae can be present in fields 12 months of the year. The larvae feed on roots, impacting on plant growth and ability to tolerate moisture stress. The impact of scarab feeding is visible as slowed crop growth, plant death (often in patches), delayed maturity and lodging.

Damaging densities

Whilst we do not yet have a defined threshold, observations of crop loss and infestations indicate that densities above 15 larvae per sqm (to 15 cm depth) are associated with significant crop loss. This tentative threshold is influenced by a number of conditions including crop, scarab species, soil moisture, cultivation, sowing equipment, use of seed dressings and in-furrow treatments. At present, we think that at densities below 15 per sqm, seed dressings and in-furrow treatments may provide some protection. At higher densities, particularly those above 25 larvae per sqm, observations suggest that even at-sowing treatments do not prevent significant crop loss.

Management options

<u>Cultivation</u>

Two replicated trials have been conducted, comparing the impact of a single offset disc and chisel plough on scarab larvae densities. The results from these trials showed that cultivation, either with disc or chisel plough, reduced larvae numbers significantly (Figure 2). In these trials the cultivation resulted in a full disturbance of the soil surface and correspondingly high reductions in soil moisture. Subsequent sorghum planting at the Cecil Plains site did not establish well in the cultivated plots. We have monitored the impact of several commercial fields where the growers have cultivated infested patches in the field. The results from these fields have shown similarly large decreases in the larval populations.

The impact of cultivation on soil moisture is a major impediment to the potential uptake of cultivation to manage high density infestations. However, it may be possible to be more targeted with cultivation and achieve the same outcome. Examination of the distribution of larvae across the plant row and inter-row shows a concentration of larvae on the plant row in the majority of fields (Figure 3). This pattern of distribution opens up the possibility of more targeted tillage, with reduced disturbance. This area of work clearly requires further research and development.

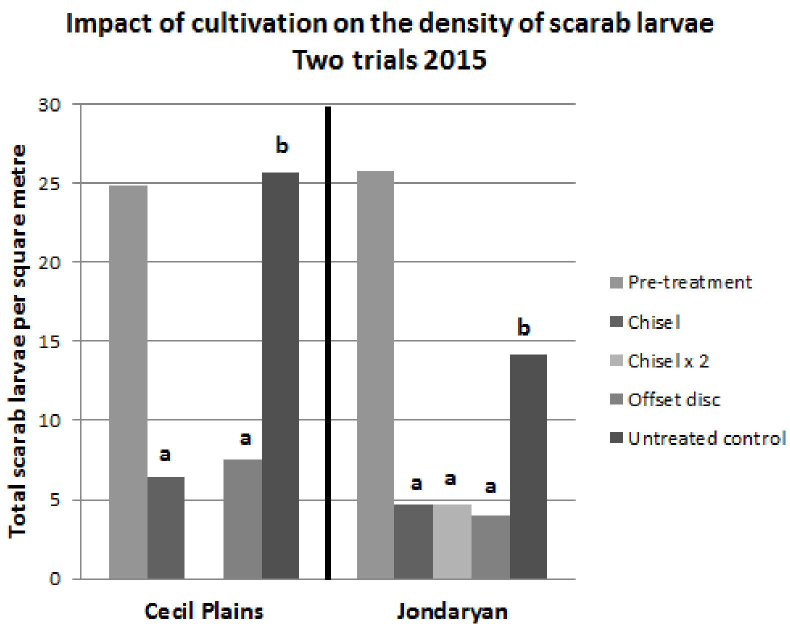

Figure 2. Cultivation with an offset disc or chisel plough reduced scarab larvae densities significantly. Two passes with the chisel plough (Jondaryan only) did not further reduce larval numbers. Means with the same letter above the bar are not significantly different from each other.

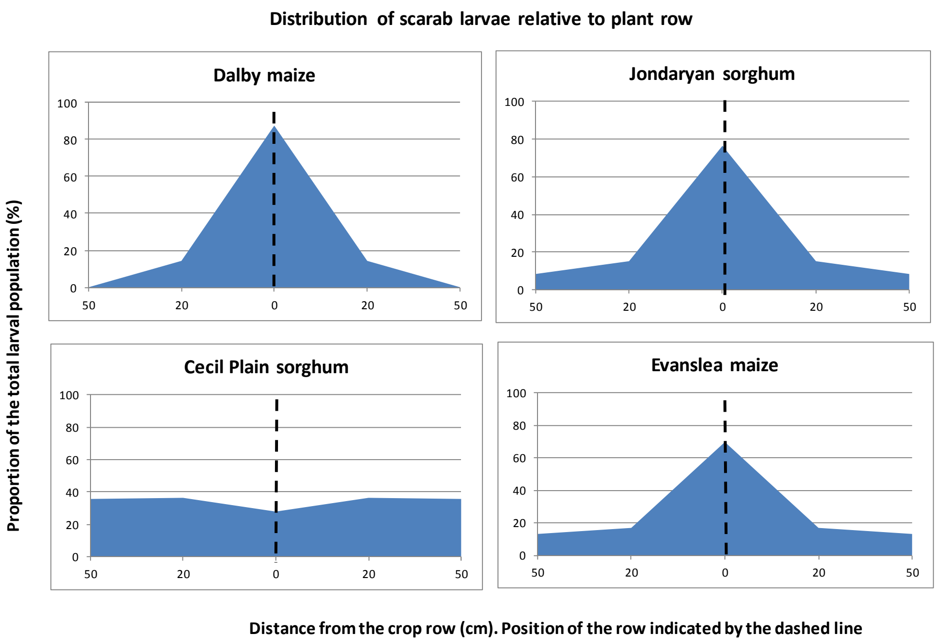

Figure 3. Distribution of scarab larvae in crops on 1m row spacing, showing the concentration along the plant row in three of the four examples

Insecticide treatment

Once a crop is planted, there are no insecticide options for controlling scarab larvae. Consequently, any attempt to mitigate the impact of larvae either by killing them or repelling them from the root zone must be implemented at sowing.

In 2015 we evaluated a range of in-furrow treatments (IFT) and seed treatment options to see what benefit they may be in establishing sorghum in a heavily infested field (average of 26 larvae per square metre). As discussed above, it is likely that there are larval densities at which even effective seed treatments and IFT will not provide adequate protection. However, the trial results (Figure 4) show significant increases in seedling biomass at 53 days after sowing (DAS) with a number of treatments. At the time of writing, no in-furrow or seed treatments have registered label claims for the control of scarabs. The plots treated with two seed dressings (C and D) showed significant increases in biomass compared with the untreated controls. In combination with IFT, there was a further increase in biomass with some treatments.

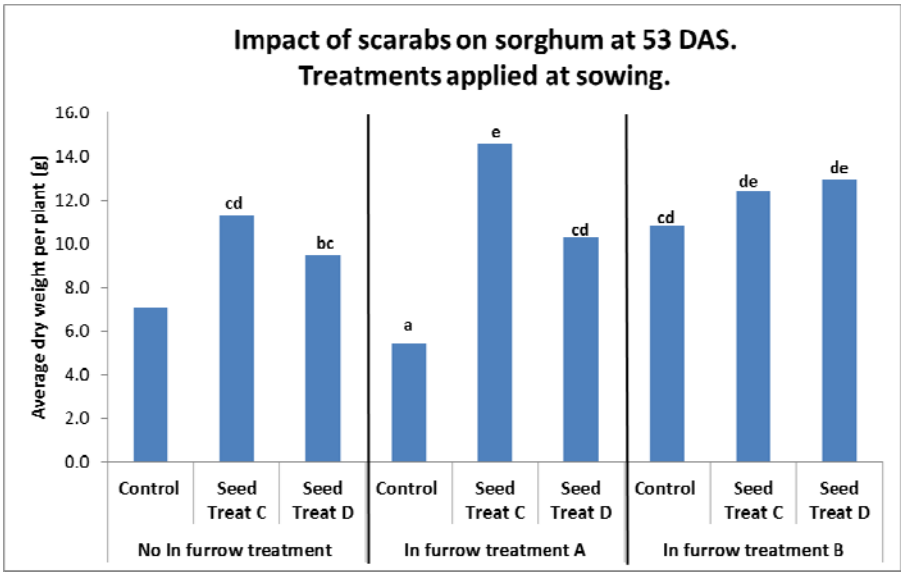

Figure 4. Scarab larva impact on seedling sorghum (to 53 DAS) was significantly reduced with the application of some in-furrow and seed treatment combinations.

We also saw a significant yield increase in wheat, in the same field, in a trial evaluating the efficacy of seed treatments in winter crops.

The use of IFT and seed dressings for a long-lived pest like scarab larvae is not simple. It is probable that the insecticides will deter larvae from the zone in which they are active, but as roots grow out of the treated zone they may then be damaged by larvae. These interactions need investigation.

Acknowledgements

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

We are extremely grateful for the generous support of many growers and agronomists who have allowed us to sample their field or undertake trial work, and made us aware of insect pest issues affecting them. In particular, we acknowledge the assistance and opportunity for field work and discussion provided by James Ryder, John and Paul Griffiths, Glenn Milne, Belinda Chase, Mike Balzar, Steven Hegarty (Vanderfield), Graeme Sutton (Bayer) and Trevor Philp (Pacific Seeds). Much of our field work would not be possible without the assistance of the field staff at the Hermitage Research Station and the Regional Research Agronomist network. The DAF Biometry team, in particular Kerry Bell, has provided valuable assistance with the analysis of trial data.

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Root-lesion nematodes (*Pratylenchus thornei*): how long does it take to reduce their population within the soil?

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Key words

Root-lesion nematode (*Pratylenchus thornei)*; modelling population decline

GRDC code

CSE00055

Take home message

- Know your soil's Root-lesion nematode (*P. thornei*) population size
- Test your soil for Root-lesion nematodes. *P. thornei* populations greater than 40,000 per kg at harvest will requires a double break of around 40 months free of a host to reduce the population below the accepted threshold of 2000 Pt/kg. *P. thornei* populations greater than 10,000 per kg at harvest will requires a single break of around 30 months free of a host to reduce the population below the accepted threshold of 2000 Pt/kg.
- Weeds can be a host so fallows must be weed free and free of volunteers

Background

The root-lesion nematode *Pratylenchus thornei* (Pt) is a major pest of cereal and pulse crops on the heavy clay textured soils of the northern grains region of eastern Australia. *P. thornei* has a broad host range covering many cereals and pulses (Castillo and Vovlas, 2007; Nicol and Rivoal, 2008) highlighting its economic importance as a major pathogen of grain production worldwide. In Australia, yield losses in intolerant wheat varieties as a result of *P. thornei* have been estimated at between 44 and 80% (Thompson, 2008; Thompson et al., 2012), resulting in an estimated annual cost to the industry of $38 million (Murray and Brennan, 2009). Genetic control by breeding tolerant and resistant varieties has been considered the best long-term approach for this pathogen (Thompson et al., 1999). Wheat lines with superior tolerance have been developed, which has meant the regional wheat yield potential has continued to be achieved. However, tolerant varieties can continue to increase the nematode population, creating high pathogen levels in the soil and posing a serious risk to other host crops that do not have tolerant or resistant lines available.

How long does it take a *P.thornei* population to decline in the absence of a host.

Fallowing or the use of consecutive non-host crops such as sorghum(O'Brien, 1983) has the potential to significantly reduce *P. thornei* populations (Owen et al., 2014; Thompson et al., 2012) . However, this can take a long time and never completely eliminate the pest as low numbers of *P. thornei* were still present in soils fallowed continuously for 8 years (Peck et al., 1993). This is in contrast to another *Pratylenchus* species (*P. coffeae*) where an 11-month absence of a host reduced the population to zero (Trinh et al., 2011). To understand the rate of decline in a nematode population we monitored different starting populations for a 30 month host free period in a Vertosol on the Darling Downs at Formartin.

What we did

Following two consecutive wheat crops using wheat cultivars with different levels of tolerance and resistance a range of nematode populations were created in the soil. At the harvest of the second wheat crop the nematode population from each plot was recorded and characterised as high, (H >20,000Pt/cm^2/1.2m profile), medium (M >10,000Pt/cm^2/1.2m profile), low (L >5,000Pt/cm^2/1.2m profile) and very low populations (VL <5,000Pt/cm^2/1.2m profile) calculated as the sum of nematodes across the whole profile. Over the next 30 months, soil samples were collected from these plots to monitor the change in nematode population over time. Two 1.8 m soil cores were collected from each plot and divided into 8 layers (the top four being of 15 cm and the bottom four of 30 cm) Nematodes were extracted from the soil and manually counted to give a live nematode population estimate for each soil layer. The rotation over the 30 months was, long fallow from wheat to sorghum then long fallow from sorghum to wheat. In the fallow commencing in 2011 no sorghum was sown due to drought.

Our results

In this experiment, the majority of nematodes resided in the soil surface layers. Over the 30 months without a host crop the bulk of the populations reduced to below the damage threshold of 2000/kg or ~2/cm^3. The majority of the reduction occurred in the surface layers (Figure 1). The 0-15 cm layer at the surface showed the fastest decline in population numbers (Figure 2).

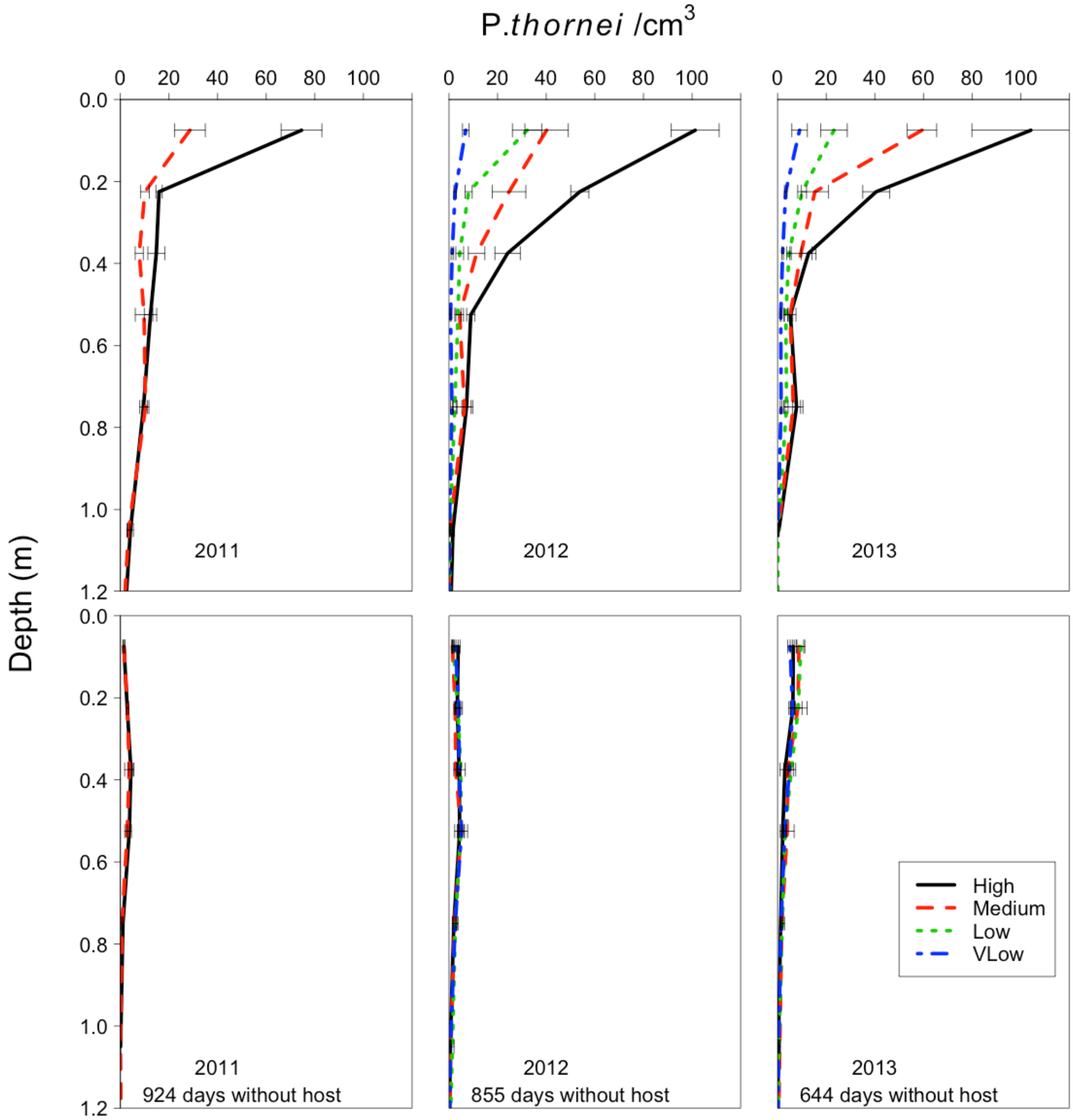

Figure 1. Distribution of *Pratylenchus thornei* at the start (top row) and end (bottom row) of the three non-host long fallows. The different lines indicate the different starting population classes (High,H >20,000Pt/cm^2/1.2m profile), medium (M >10,000Pt/cm^2/1.2m profile), low (L >5,000Pt/cm^2/1.2m profile) and very low population (VL <5,000Pt/cm^2/1.2m profile) calculated as the sum of nematodes across the whole profile. Standard errors are indicated for each sampling point.

To understand the rate of decline or how many nematodes died per day a negative exponential function was applied to the data (Figure 2) which went part way to describe the observed data. Note how a sharp drop occurs in the surface layer but not in the second or third layer population densities.

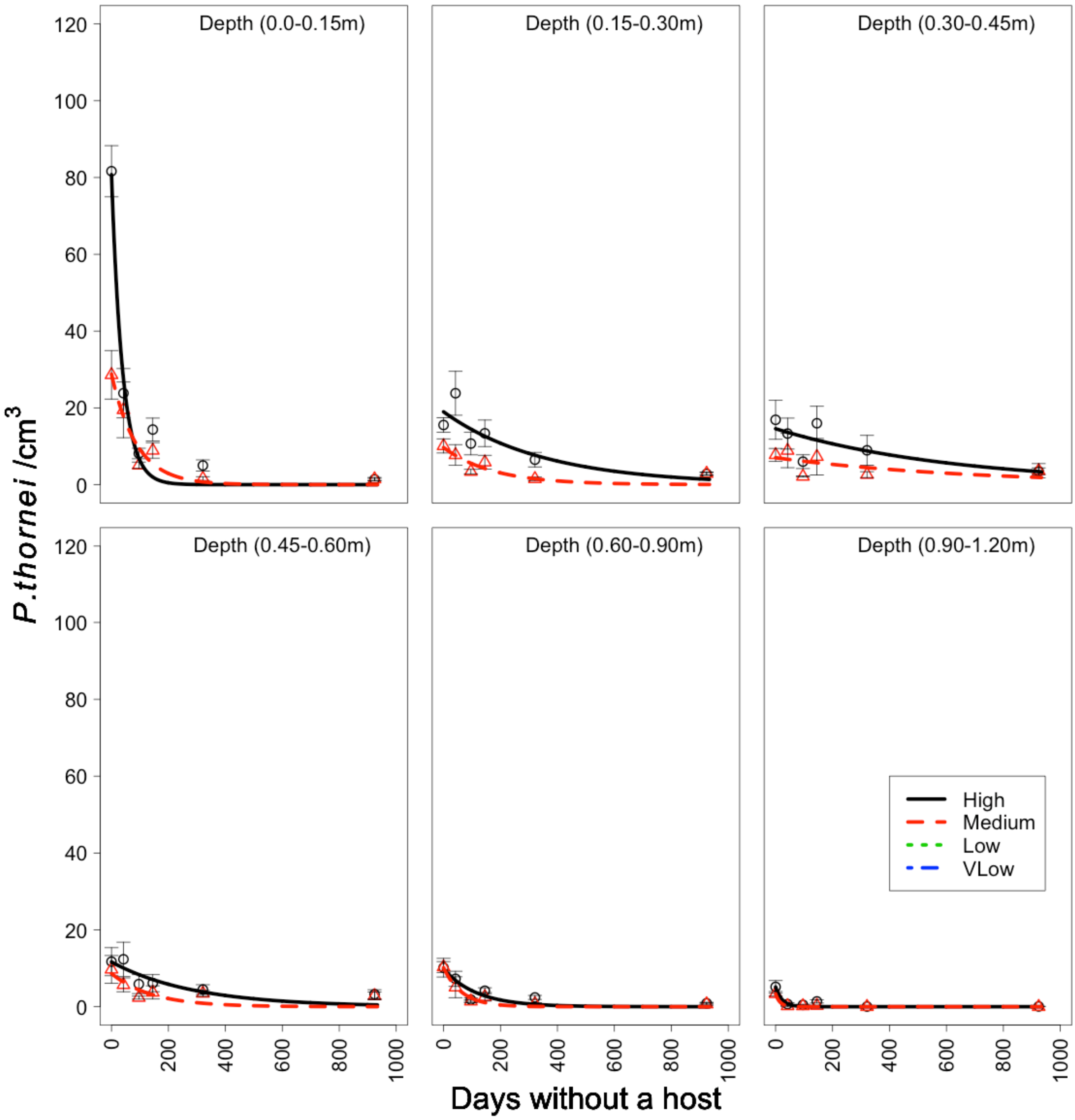

Figure 2. The negative exponential function Y=ae-bt, where y = nematode density per soil layer, t = time in days , a = the intercept and b = the slope parameter, fitted to the high and medium population data at each soil layer over the 30-month fallow commencing in November 2011. Standard errors are presented for each of the observed population measurements.

A similar rate of decline was found in each of the non-host periods for each layer. This information was combined with knowledge of temperature and moisture to build a dynamic nematode decline model that worked with APSIM. The completed model was tested against the observed data. The observed predicted regression (Figure 3) shows the model accounted for 95% of the error. The predicted model curves highlight how the inclusion of dynamic modelling or temperature and moisture combined with age class mortality rates of the different nematode life stages improved the prediction in the early stages of the fallow (Figure 4).

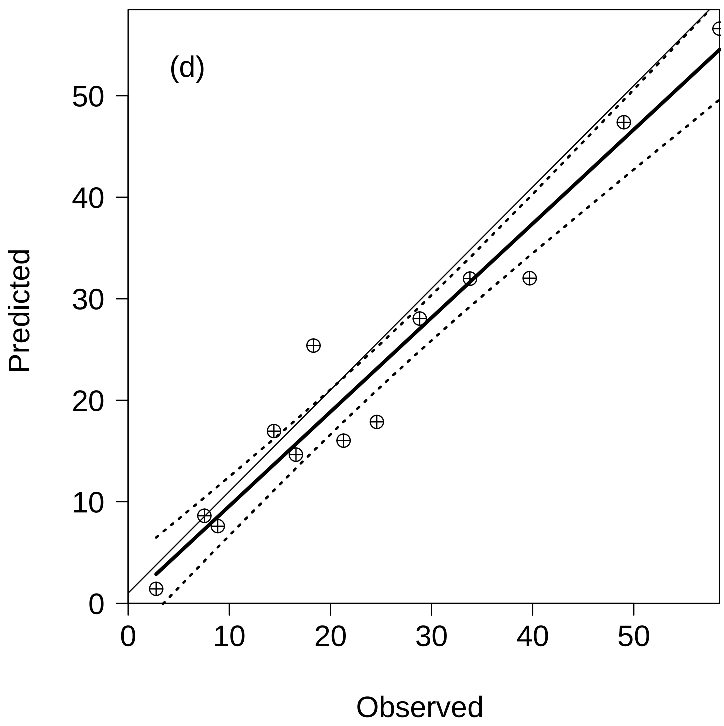

Figure 3. The observed predicted regression (Fig. 1d) shows good correlation between the observed and predicted data, y = 0.93x + 0.28, R2=0.94.

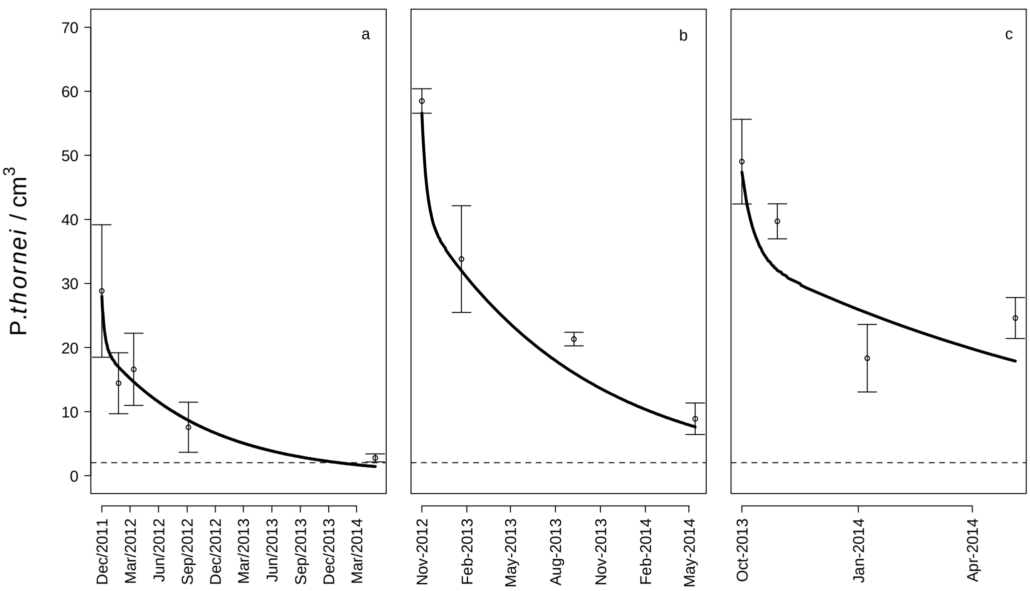

Figure 4. The observed (points) and predicted (line) population data declining from maximum population at harvest of the preceding wheat crop and the decline over the break. The longest decay curve (a) included a non-host sorghum crop sown in October 2012. The shorter curve (b) commenced in November 2012 and there was no sorghum crop planted due to drought. The final curve (c) commenced in 2013 and had a sorghum crop planted in October 2014. The dashed horizontal line represents the damage threshold below which minimal yield loss will occur in a susceptible wheat crop.

Using the developed model, the time taken to reduce different sized nematode populations to below the damage threshold of 2000 nematodes per kg was calculated (Figure 5).

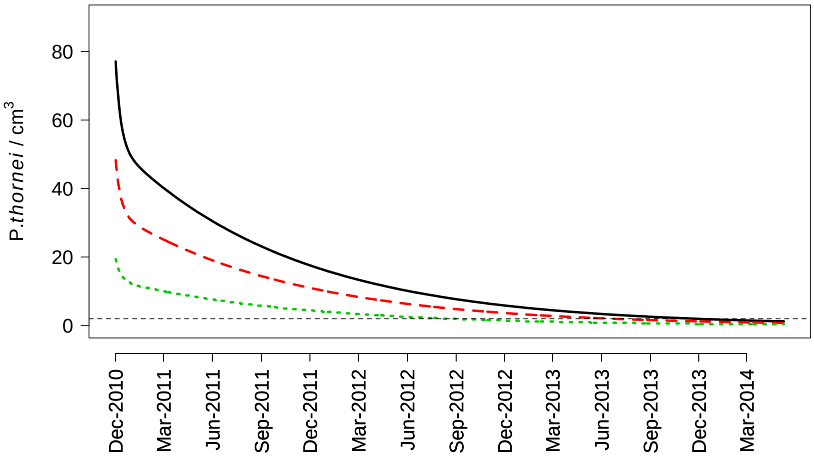

Figure 5. The effect of starting population (80 Pt/cm^3 ~80,000/kg, solid black line; 50 Pt/cm^3 ~50,000/kg, dashed red line; 20 Pt/cm^3 ~20,000/kg , dotted green line) on the time taken for the *P. thornei* population to reduce below the economic threshold.

So what?

The scenario analysis (Figure 5) highlighted the importance of the initial population when reducing nematode populations below the damage threshold. High population of 80 nematodes per cm^3 (~80,000 Pt/kg) took four years to reduce below the threshold. This would require 2 non host crops such as sorghum and fallows to reduce the population. A moderate initial population of 50 nematodes per cm^3 took three and a half years (Figure 6), requiring the equivalent of a single non host summer crop and fallows. A population of 20 nematodes per cm^3 took 24 months. The long survival mechanisms of root-lesion nematodes highlight the importance of knowing the size of the population at the end of each season. Once a population increases, non-host, resistant crops or fallows are required to reduce the population below the damage threshold. Planting susceptible or tolerant crops within this time period will increase populations to higher levels that will take longer to reduce, thereby limiting cropping options, and potentially reducing the profitability of the overall farming system. As resistant wheat varieties are released they can be used to provide a winter decline option to increase non-host periods within the rotation.

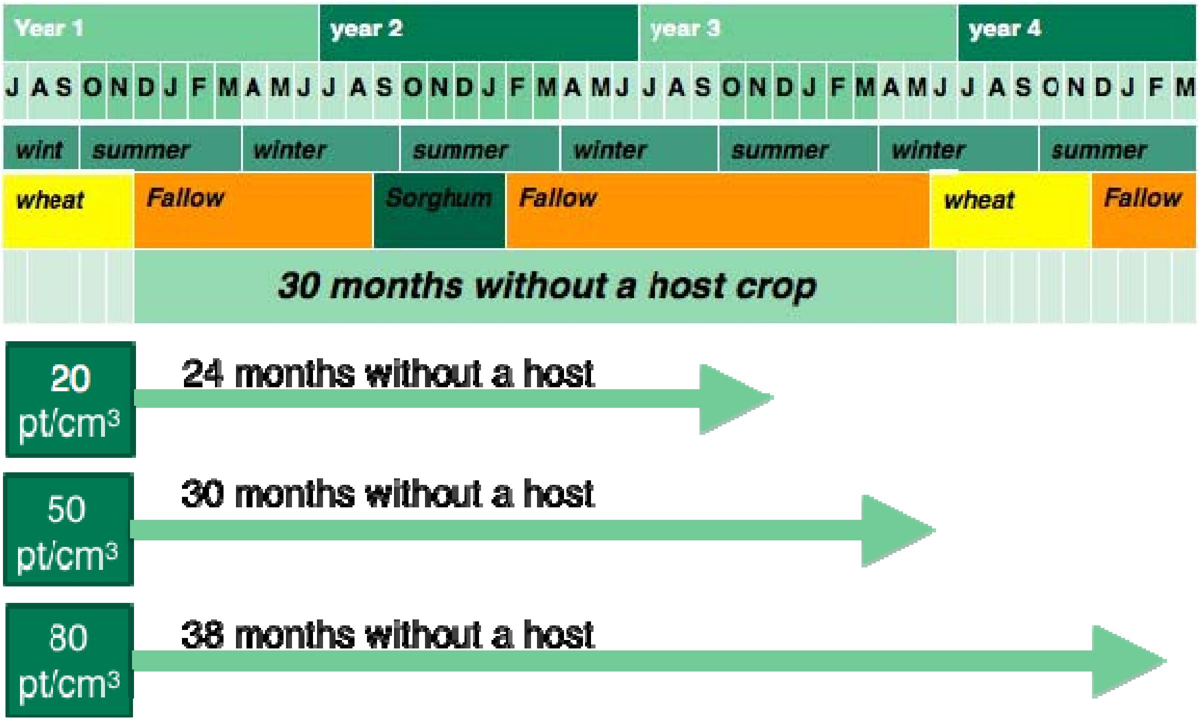

Figure 6. An example of a non-host fallow showing the time required to reduce different starting populations of root-lesion nematode.

Where to next

Further testing of the model is required to ensure it captures the influences of different soils, soil temperatures and moisture conditions. Understanding the survival mechanisms of *P. thornei* and what causes the initial sharp decline may provide some insight into tactical ways to reduce populations faster and maintain low populations for longer

References

Castillo P., Vovlas N. (2007*) Pratylenchus* (Nematoda: Pratylenchidae): Diagnosis, biology, pathogenicity and management. Chapter 7. In *Biology and ecology of* Pratylenchus. Nematology Monographs and Perspectives Series 6. pp. 305–324 Eds D.J. Hunt, R.N. Perry, Leiden-Boston:Brill,.

Murray, G.M., Brennan, J.P., 2009. Estimating disease losses to the Australian wheat industry. Austral. Plant Pathol. 38, 558–570. doi:10.1071/AP09053

Nicol, J.M., Rivoal, R., 2008. Global Knowledge and its Application for the Integrated Control and Management of Nematodes on Wheat, in: Mukerji, K.G. (Ed.), Integrated Management and Biocontrol of Vegetable and Grain Crops Nematodes. Springer, pp. 251–283.

O'Brien, P., 1983. A Further Study on the Host Range of *Pratylenchus thornei*. Austral. Plant Pathol. 12, 1. doi:10.1071/APP9830001

Owen, K.J., Clewett, T., Bell, K., Thompson, J.P., 2014. Wheat biomass and yield increased when populations of the root-lesion nematode (*Pratylenchus thornei*) were reduced through sequential rotation of partially resistant winter and summer crops. Crop Pasture Sci. 65, 227–15. doi:10.1071/CP13295

Peck, D.M., Thompson, J.P., Clewett, T., Haak, M.I., 1993. The root lesion nematode *Pratylenchus thomei* survives extended clean fallows and build up quickly with wheat cropping, in:. Presented at the th Biennial APPS Conference Hobart, July -th,, pp. 29–32.

Thompson, J.P., 2008. Resistance to root-lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) in synthetic hexaploid wheats and their durum and *Aegilops tauschii* parents. Aust. J. Agric. Res. 59, 432. doi:10.1071/AR07222

Thompson, J.P., Brennan, P., Clewett, T., Sheedy, J.G., Seymour, N., 1999. Progress in breeding wheat for tolerance and resistance to root-lesion nematode (*Pratylenchus thornei*). Austral. Plant Pathol. 28, 45–52.

Thompson, J.P., Zwart, R.S., Butler, D., 2012. Inheritance of resistance to root-lesion nematodes (*Pratylenchus thornei* and *P. neglectus*) in five doubled-haploid populations of wheat. Euphytica 188, 209–219. doi:10.1007/s10681-012-0689-x

Trinh, P.Q., Wesemael, W.M.L., Nguyen, C.N., Moens, M., 2011. Decline of *Pratylenchus coffeae* and Radopholus arabocoffeae populations after death and removal of 5-year-old arabica coffee (*Coffea arabica* cv. Catimor) trees. Nematology 13, 491–500. doi:10.1163/138855410X528505

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Soil health, soil biology, soilborne diseases and sustainable agriculture

Graham Stirling

Key words

Soil organic carbon, disease suppression, soil food web, grain cropping, pasture.

Take home message

- Healthy soils contain a myriad of beneficial organisms that suppress soilborne pathogens through competition for habitat and food; production of antibiotics and toxins; or via predation or parasitism.
- Organic carbon is the single most important soil health indicator. Increases in soil organic carbon (particularly biologically-available forms) are intimately linked to the size, composition and activity of the soil microbial community; enhanced retention and cycling of nutrients; improved aggregate stability; and increased water-holding capacity.
- Key management practices to promote healthy soils are continuous inputs of organic matter; permanent plant residue cover; a diverse rotation sequence; minimum tillage; and avoidance of compaction through traffic control.
- Once good farming systems are in place, incremental improvements can be made through cover crops and legumes in the rotation; integration of crop and livestock production; organic amendments and mulches; improved nutrient-use efficiency; optimised water management; site-specific management of inputs and integrated pest management.
- Pastures can play an important role in improving soil health, reducing losses from soilborne diseases, and managing risk in Australia's broadacre cropping systems. There are many benefits to be gained by integrating crop and animal production, but the extent of the gains will be determined by the level of management inputs and the skill and passion of the land manager.
- While livestock may be detrimental to soil health, negative impacts can largely be overcome with best-practice management: Grazing must be carefully monitored to maintain soil cover (at least 50-70%); Rotational grazing can assist to more evenly distribute nutrient returns across a paddock and minimise soil compaction from grazing; Another option is to convert the herbage from pastures into hay or silage and use it to feed animals off-site.

Introduction

Our capacity to feed the world's ever-increasing human population is dependent on the thin layer of soil covering the earth's surface. It not only provides a physical support for plants but also filters water, detoxifies pollutants and provides a home for a huge range of beneficial organisms that decompose organic matter, supply nutrients to plants and compete with the fungal, bacterial and nematode pathogens that cause disease. However, this non-renewable resource is continually subject to water and wind erosion, is further degraded by compaction and tillage, is rendered unproductive by salinisation and desertification, and is easily ruined by mismanagement.

This paper explains the inextricable link between soil health and sustainable agriculture: agriculture can only survive in the long-term if soils are farmed in ways that not only repair historical damage but also improve their physical, chemical and biological properties. It argues that a soil cannot be considered healthy unless it contains an active and diverse soil biological community and then goes on to provide a list of the management practices that can be used to improve a soil's biological status. These and many other topics are covered in much greater detail in a new publication, '**Soil**

health, soil biology, soilborne diseases and sustainable agriculture. A guide', details for which can be found at the end of the paper.

Organisms in the soil food web and their function

A teaspoon of a fertile agricultural soil will contain tens of millions of bacterial cells, more than 10 km of fungal hyphae, thousands of protozoa, hundreds of nematodes and numerous insects, mites and small animals. Some of these organisms will damage the roots of plants but the main role of the soil biological community is to provide the following ecosystem services:

- improve the soil's structural characteristics
- fix nitrogen from the atmosphere
- help plant roots take up water and nutrients
- minimise losses of nutrients to the environment
- mineralise nutrients from organic matter
- degrade pollutants, pesticides and other contaminants
- produce compounds that promote plant growth
- protect plants from attack by pests and pathogens

Unfortunately, some of the organisms that provide these services have disappeared from our agricultural soils. Thus, many soils now retain water and nutrients less efficiently and are affected by structural problems such as hard setting and surface sealing. Also, pests and pathogens rather than beneficial organisms tend to dominate the soil biological community, and this means that crops often fail to reach their yield potential.

The key role of carbon in maintaining soil health and sustaining the soil biological community

One of the main reasons growers face root disease and soil health problems is that the amount of organic matter in their soil has declined to unacceptable levels. Since the carbon in soil organic matter stabilises soil structure, promotes aggregation of mineral particles, increases water infiltration rates, improves water holding capacity, stores and releases nutrients and contributes to cation exchange, it has a huge impact on soil properties. It is also important from a biological perspective, as it nourishes the organisms that cycle nutrients and compete with pests and pathogens.

In agriculture, organic carbon is obtained from four sources:

1) crop residues that accumulate on the soil surface;

2) root exudates and the decomposing remains of old roots;

3) manure from grazing animals and

4) amendments such as compost that are imported from elsewhere.

Although organic inputs to soil should ideally come from a range of sources, the above sources all play a vital role, individually and collectively, in sustaining the soil food web. Bacteria and fungi multiply rapidly when a new food source becomes available and they commence the decomposition process. A myriad of litter transformers and ecosystem engineers (arthropods, earthworms and enchytraeids) then break up this material and incorporate it into soil, increasing the rate of decomposition. Provided carbon inputs are regular and the decomposition process is allowed to proceed unhindered, the end result is higher soil carbon levels and an active and diverse biological community capable of providing a huge range of benefits (see the figure below).

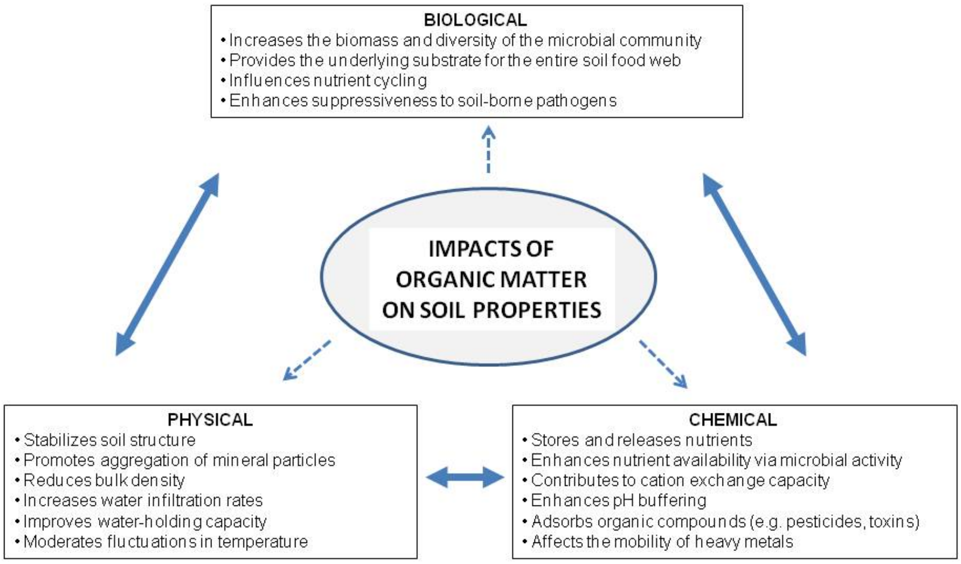

Figure 1. Impacts of soil organic matter on soil properties

Impact of natural enemies on soilborne pathogens

The fungi, bacteria and nematodes that cause soilborne diseases do not exist in isolation. They live in a complex and dynamic environment and are associated with an enormous number of other organisms that interact with them in many different ways.

- **Competition.** This is a universal phenomenon within the soil food web, as a huge range of microbes and small animals are continually competing for habitable space, or for food sources. When a competing soil organism accesses a resource before it can be acquired by a pathogen (e.g. it utilises root exudates that may be required to stimulate spore germination or enhance the infection process), it diminishes the capacity of the pathogen to cause disease.
- **Antibiosis**. Many soil bacteria and fungi produce soluble or volatile antibiotics that kill, inhibit or repel other organisms. These antibiotics may act against plant pathogens, with one of the best-studied examples being suppression of the take-all pathogen of cereals by a group of antibiotic-producing bacteria known as the fluorescent pseudomonads.
- **Toxin production and lysis**. Some soil organisms produce toxins that immobilise or kill neighbouring organisms, while others produce enzymes that digest the cell wall or cuticle of their prey. Both these mechanisms are thought to contribute to the biological control of soilborne fungal pathogens.
- **Predation**. This occurs when one organism (the prey) is killed by another, often larger, organism (the predator). Protozoans, nematodes and microarthropods all have the capacity to consume other soil organisms. Some predators feed indiscriminately on a wide range of organisms while others have quite specific food preferences.
- **Parasitism.** Parasites are highly adapted species that live in or on another organism (the host) and obtain all or part of their nutritional resources from that host. Bacteria and viruses

are known to parasitize protozoans and nematodes, but fungi are probably the most important parasitic organisms in soil. Numerous fungal parasites of arthropods and nematodes are known, and mycoparasitism (parasitism of one fungus by another) is also relatively common.

In a healthy soil, all the above mechanisms will be operating, and this means that the soil has some capacity to suppress the pathogens that cause disease. The most common form of disease suppression (usually referred to as **'general', 'non-specific'** or '**organic matter-mediated'** suppression) is most likely to be observed in soils with high levels of organic matter. Numerous organisms are involved, and they act collectively through the mechanisms listed above.

A second form of disease suppression (usually known as '**specific' suppression**) results from the activities of a limited number of relatively specific antagonists, and typically develops in situations where pest populations have remained high for some time. Parasites that are adapted to using the pest as a food source take advantage of the situation and multiply rapidly, causing high levels of mortality.

Enhancing suppression of soilborne diseases in grain crops

Rhizoctonia is an important pathogen of Australian cereal crops, but on-farm observations in South Australia over the last 30 years have shown that when the soil is managed appropriately, naturally-occurring antagonists will keep it under control. Although the organisms responsible for suppressing the disease have not been identified, recent studies using DNA-based techniques have shown that the bacterial and fungal communities in disease- suppressive and non-suppressive soils are quite different. A range of bacterial taxa and several groups of fungi known to exhibit antifungal activity are found in higher frequencies in suppressive soils. What is clear from this work is that disease suppression is not due to a single microbial group. It almost certainly involves many different biocontrol microbes and it is likely that they interact synergistically to suppress the pathogen.

Field and glasshouse trials have shown that soils become suppressive to Rhizoctonia root rot when practices such as cultivation and stubble burning are removed from the farming system and replaced with full stubble retention, limited grazing, more frequent cropping, limited or no cultivation and nutrient inputs that are sufficient to meet crop demand. Thus, a combination of practices that increase inputs of biologically available carbon are required to enhance levels of disease suppression.

Another example of general disease suppression occurs in the northern grain-growing region, this time against root lesion nematode (*Pratylenchus thornei*), a widely distributed pest. Nematode population densities are particularly high at depths below about 25 cm but are usually much lower in surface soils, partly because organic carbon levels in this zone are high enough to support a diverse range of natural enemies, including nematode trapping fungi and predatory nematodes. The challenge of the future is to increase soil carbon levels down the soil profile, thereby enhancing predatory activity at depth.

The best known Australian example of specific disease suppression is the natural control of root-knot nematode (*Meloidogyne* spp.) on grapevines by a bacterial parasite (*Pasteuria penetrans*). A closely related species of this bacterium has been found on root-lesion nematodes in the northern grain-growing region. Although levels of parasitism are relatively low at present, the proportion of parasitised nematodes is expected to increase with time, provided the host-parasite relationship is not disturbed by tillage. However, continuing research is required to determine whether *Pasteuria* will eventually provide some control of this important pest.

Improving soil health in grain farming systems

If an agricultural soil is to provide a full range of ecosystem services, the following crop and soil management practices must be integrated into the farming system. Benefits will be limited if only some of these practices are adopted.

- Continuous inputs of organic matter
- Permanent plant residue cover
- A diverse rotation sequence
- Minimum tillage
- Avoidance of compaction through traffic control

Once the above practices are integrated into a farming system, incremental improvements can then be made by focusing on the following:

- Biomass-producing cover crops
- Inclusion of legumes in the rotation
- Integration of crop and livestock production
- Organic amendments and mulches
- Improved nutrient-use efficiency
- Optimised water management
- Site-specific management of inputs
- Integrated pest management

Although the practices listed above provide farmers with a range of management options, the actual practices that can be integrated into a farming system will be influenced by climatic factors, production goals and the economic realities of farming. Thus, it is impossible to be prescriptive about best-practice farming systems to improve soil health. Many potentially useful technologies and practices are available, and it is up to the land manager to adapt them to local conditions and constraints.

Pastures as a tool to improve soil health in grain cropping systems

One of the most effective ways of increasing levels of soil organic matter and improving the health of soils used for cropping is to integrate a pasture phase into the farming system. Carbon inputs into the soil will increase under pasture, as perennial plants have a higher root to shoot biomass ratio than annual crops, and grow for a longer proportion of the year. Because pasture soils are not regularly disturbed by tillage implements, this carbon tends to remain in the soil rather than being lost to the atmosphere as CO_2.

Although research has shown that pastures increase soil microbial biomass and enhance biodiversity, it is important to recognise that the livestock which graze them may impact negatively on soil health. Their most important effects are listed below.

- **Soil structural degradation**. Trampling by sheep and cattle can impact negatively on soil structure. However, compaction effects are mainly limited to the upper 15 cm of soil and tend to be concentrated in animal traffic areas such as gateways, camps, and around troughs. Recent research indicates that crops which follow a well-managed pasture are usually not markedly affected by the shallow surface compaction caused by livestock.

- **Ground cover and soil erosion**. Livestock contribute to soil erosion by removing ground cover and loosening the soil surface, so stocking rates need to be carefully managed.
- **Drying of the soil profile***.* In rain-limited environments, pasture will utilise stored soil water that could otherwise be used by the following crop.
- **Spatial relocation of nutrients**. Grazing animals excrete most of the nutrients ingested from pasture, but in the absence of appropriate management, they tend to be concentrated in stock camps and/or lost from urine patches.
- **Redistribution of weed seeds**. Livestock spread weed seeds when they graze, and bury them by trampling.

The conclusion that can be drawn from the points made above is that livestock may be detrimental to soil health, but their negative impacts can largely be overcome with best-practice management. Grazing must be carefully monitored so that a minimum level of soil cover (at least 50-70%) is always maintained, while practices such as rotational grazing can be used to more evenly distribute nutrient returns across a paddock, and to minimise the soil compaction effects of grazing animals. Another option is to convert the herbage from pastures into hay or silage and use it to feed animals off-site.

The take-home message is that pastures can play an important role in improving soil health, reducing losses from soilborne diseases, and managing risk in Australia's broadacre cropping systems. There are many benefits to be gained by integrating crop and animal production, but the extent of the gains will be determined by the level of management inputs and the skill and passion of the land manager.

Further reading and information:

A new book targeted to growers and advisers explains how to build an active and diverse soil biological community capable of improving soil structure, enhancing plant nutrient uptake and reducing losses from soilborne diseases. Written by soil biologists with experience in a wide range of farming systems, the book cited below provides an overview of the management practices that can be used to restore the health of agricultural soils, enhance plant resilience to stress and improve profitability and sustainability.

Stirling GR, Hayden, HL, Pattison AB, Stirling AM (2016) Soil health, soil biology, soilborne diseases and sustainable agriculture. A guide. CSIRO Publishing, Melbourne. 280 pp. ISBN 9781486303045

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Herbicide residues in soils – are they an issue?

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Key words

herbicide, soil functions, sustainability, plant-back periods

GRDC code

DAN00180

Take home message

- A national soil survey found that residues of certain herbicides, including; glyphosate and its metabolite AMPA, trifluralin and diflufenican, frequently persist at agronomically significant levels in soils prior to the winter cropping season
- Analysis of international literature suggests that soil biological functions are generally resilient to short term impacts of herbicide application at recommended label rates
- However, longer term impacts of herbicide residues, especially after repeat applications, are less well understood. There is evidence that residues at levels found in the soil survey could reduce crop performance, most likely through direct phytotoxicity. The lack of readily available, soil-specific threshold values for herbicide residues causing damage to i) soil biological functions and ii) plant growth is a key knowledge gap to be addressed by future work in this project.
- Strategies to avoid herbicide residue accumulation and potential damage to soil functions and crops include: routine rotation of pre-emergent herbicides, reliable record keeping to help identify potential residue issues and organic matter addition to help tie-up bioavailable residues and stimulate microbial activity

Background

The move to conservation tillage and herbicide-tolerant crop cultivars means that many farmers are relying on herbicides for weed control more than ever before. Despite the provision of plant-back guidelines on herbicide product labels, site-specific factors such as low rainfall, constrained soil microbial activity and non-ideal pH may cause herbicides to persist in the soil beyond usual expectations. Because of the high cost of herbicide residue analysis, information about herbicide residue levels in Australian grain cropping soils is scarce.

In addition, little is known about how herbicides affect soil biological processes and what this means for crop production. This is especially the case for repeated applications over multiple cropping seasons. In Australia, herbicides undergo a rigorous assessment by the Australian Pesticides and Veterinary Medicines Association (APMVA) before they can be registered for use in agriculture. However, relatively little attention is given to the on-farm soil biology – partly because we are only now beginning to grasp its complexity and importance to sustainable agriculture. Although a few tests are mandatory, such as earthworm toxicity tests and effects on soil respiration, functional services provided by soil organisms such as organic matter turnover, nitrogen cycling, phosphorus solubilisation and disease suppression are usually overlooked.

GRDC recently co-funded a 5-year project (DAN00180) to better understand the potential impacts of increased herbicide use on key soil biological processes. This national project, co-ordinated by the NSW Department of Primary Industries with partners in WA, SA, Vic and Qld, is focused on the effect of at least 6 different herbicide classes on the biology and function of 5 key soil types across all three grain growing regions.

Here we report on the results of a field survey of herbicide residues in 40 cropping soils prior to sowing and pre-emergent herbicide application in 2015. We discuss the relevance of these residues to soil biological processes and crop health, with a focus on those herbicides most frequently detected. Recommendations are given to minimise potential impacts of herbicide residues on productivity and soil sustainability. We also detail plans for future research and the development of management tools for growers to monitor and predict herbicide persistence in soils.

Methods

- Farm survey data from the GRDC Focus Paddocks project (DAW00213) was collated and analysed to understand herbicide use practices in the WA grain growing regions. The Focus Paddocks project monitored the farming practices, soil properties and crop yields of 180 paddocks spanning the WA wheat-belt for 5 years. Spray records were converted to quantity (as kg of active ingredient) per hectare and ranked in terms of frequency of application for different crops;
- A soil survey was undertaken to provide a representative snapshot of herbicide residue levels in cropping soils at the beginning of the 2015 growing season (April-May), prior to the application of pre-emergent herbicides. Soil samples were taken from 40 paddocks around Australia, including 12 in WA, 15 in SA, 10 in NSW and 3 in Qld. Composite samples (12 subsamples) were taken from a randomly chosen 50 m by 50 m grid in each paddock, at two depths (0-10, 10-30 cm). Samples were analysed for 15 commonly used herbicides using advanced analytical techniques developed and validated specifically for this project;
- Herbicide impacts to soil biology were reviewed by searching the literature using the search terms herbicide AND soil AND (microb* OR function*). Over 300 peer-reviewed publications were analysed for potential impacts of herbicides on soil organic matter turnover, nutrient cycling and disease interactions;
- The potential for direct phytotoxicity to crops was assessed by comparing herbicide residue to literature thresholds for herbicide sensitivity. Because such data are lacking for glyphosate residues in soil, we also conducted a bioassay to determine the effect of soil-borne glyphosate residues on wheat, lupin and canola growth in a sandy (tenosol) soil from Wongan Hills, WA. This soil has low phosphorus buffer index (for Colwell P) of 15 L kg^{-1}, indicating a low potential for P sorption. Glyphosate (as Roundup CT ®) was thoroughly mixed through topsoil (5 cm) at rates equivalent to 0.33, 1, 3, 9 and 27 times the label rate, and aged for 1 month in the glasshouse prior to sowing. In addition, we tested whether the application of 20 kg ha^{-1} of P (as potassium phosphate) would alter the toxicity thresholds by remobilising soil-bound glyphosate. Root and shoot biomass was measured after a 6-week growth period.

Exposure – which herbicides are being applied?

Despite farmers and advisers keeping spray records for individual paddocks, aggregated (i.e. industry-wide) data for herbicide use practices are not readily accessible. Information collected in the Focus Paddock Project provides a useful snapshot of which herbicides are being used frequently in different crops (Figure 1). Information is also being collected through the National Paddock Survey Project and will be analysed over the coming year.

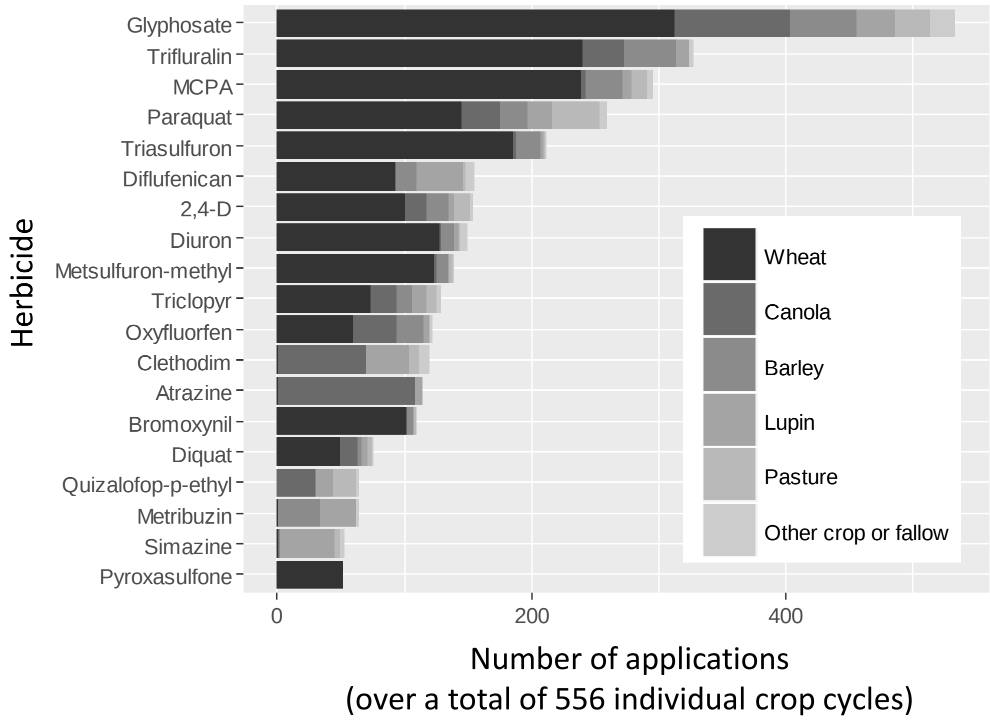

Figure 1. Herbicide use patterns for WA cropping systems. A total of 556 paddock records were obtained in the Focus Paddock survey over the 5 year period.

Glyphosate is the most frequently applied herbicide product in the WA Focus Paddocks, and in all likelihood, other Australian grain cropping regions as well. Glyphosate was used in all crop types/sequences in the WA Focus Paddocks. Given that glyphosate was applied over 500 times to 556 individual crop cycles, this equates on average to almost 1 application per crop. Other commonly used herbicides included those from Group D (trifluralin), Group I (MCPA; 2,4-D; triclopyr), Group L (paraquat), Group B (triasulfuron; metsulfuron-methyl), Group F (diflufenican) and Group C (diuron). Atrazine and glyphosate were the most common herbicides used for weed control in canola. The use of pyroxasulfone (Sakura®) has increased in response to herbicide-resistance.

Exposure – which herbicides are remaining in soil?

The soil survey of 40 different paddocks from around Australia (12 in WA, 15 in SA and 13 in NSW-Qld) detected residues of 11 chemicals out of the 15 analysed (Figure 2). Glyphosate and its primary metabolite, aminomethylphosphonic acid (AMPA) were the most commonly detected residues, with AMPA residues present in every topsoil sample taken. Trifluralin residues were also detected in over 75% of the paddocks surveyed, both in topsoil and in the 10-30 cm soil layer, indicating some vertical movement despite the strong tendency of trifluralin to remain close to the site of application. This is possibly the result of cultivation, however, leaching or movement of particle-bound trifluralin may also occur on lighter textured soils with low organic matter content. Diflufenican and diuron residues were frequently detected in samples from WA paddocks, but less so in NSW-Qld and SA.

Interestingly, despite known application of triasulfuron and metsulfuron-methyl in many of the surveyed paddocks, neither of these residual herbicides was detected in any of the samples tested. This is probably a reflection of their low rates of application, close to the limit of analytical detection. It should be noted that sulfonylurea (SU) herbicides may still have some residual activity at levels below the limit of (currently available) analytical detection. By contrast, the lack of positive detections of frequently applied MCPA reflects its relatively short persistence.

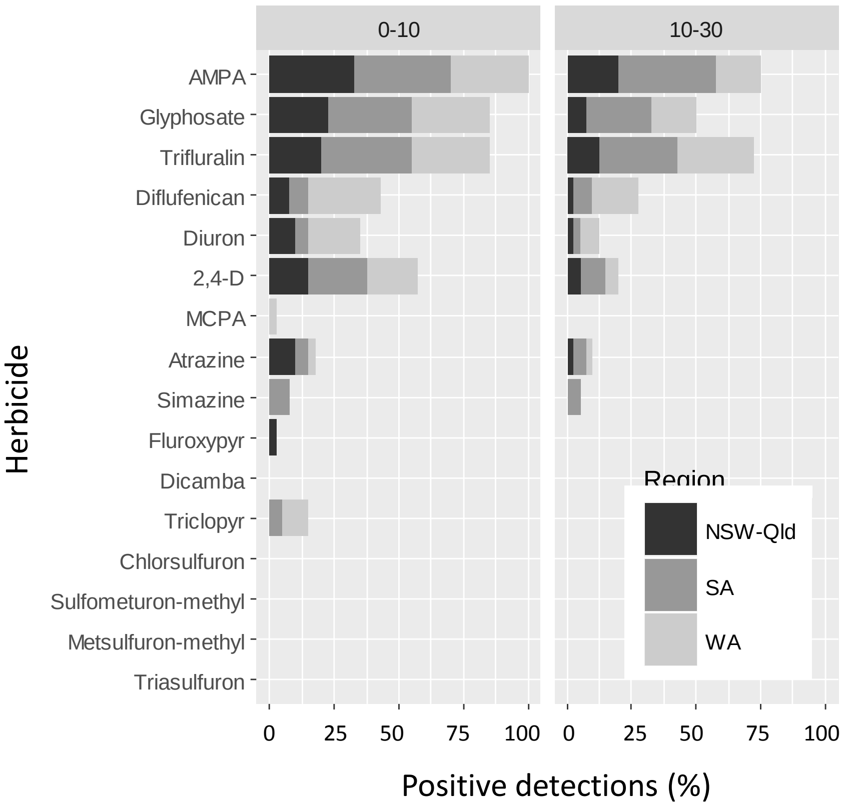

Figure 2. Number of positive detections of herbicides and the glyphosate metabolite AMPA in soil samples from 40 grain cropping paddocks around Australia.

By multiplying herbicide concentrations (mg/kg) by soil bulk density (kg/dm) and area, we estimated the total load of herbicide in the 0-30 cm soil profile for each paddock (Table 1). The average and maximum estimated loads of glyphosate, trifluralin, diflufenican and diuron were all significantly higher in paddocks in WA compared with those in SA, NSW and Qld. This likely reflects the lighter soil types, lower organic matter, dry summers and cool winters, which contributes to lower microbial activity and constrained herbicide breakdown. The higher load of atrazine in SA paddocks is probably a consequence of the higher persistence of s-triazine herbicides in alkaline soils; whilst the higher values for 2,4-D in the NSW-Qld soil profiles was due to a high value in a single paddock which had recently been sprayed.

Notably, in a number of paddocks (especially in WA but also in other states), we found glyphosate in quantities greater than expected from a single spray. This demonstrates a degree of accumulation of glyphosate and its metabolite AMPA over time. Although the half-life of glyphosate is relatively rapid (10-40 days), a significant portion of the glyphosate (and AMPA) is bound to soil and is much less accessible for continued degradation. This, combined with the high frequency of glyphosate use, can lead to a build-up of glyphosate and AMPA in soil. Accumulation of trifluralin was also apparent in a number of paddocks in WA. It should be reiterated that these levels represent the *total* loads, accessible by aggressive chemical extraction, rather than the bio-available fraction. Aging of residues in soil results in stronger binding over time, and a reduction in bioavailability, so any biological effect can be difficult to predict. This is discussed in more detail in the following sections.

Table 1. Residue loads (average and maximum) of herbicide active ingredients (a.i.) in the 0-30 cm soil profile of paddocks by region.

Herbicide	Estimated average load across all sites (kg a.i./ha)*			Estimated maximum load detected (kg a.i./ha)*		
	NSW-Qld	SA	WA	NSW-Qld	SA	WA
AMPA	0.91	0.95	0.92	1.92	1.97	2.21
Glyphosate	0.56	0.48	0.79	2.05	1.05	1.75
Trifluralin	0.08	0.11	0.53	0.14	0.26	1.34
Diflufenican	0.01	0.03	0.04	0.02	0.05	0.09
Diuron	0.14	0.05	0.17	0.16	0.05	0.29
2,4-D	0.20	0.02	0.01	1.00	0.05	0.02
MCPA	0	0	0	0	0	0
Atrazine	0.02	0.03	0.02	0.03	0.05	0.02
Simazine	0	0.04	0	0.00	0.05	0
Fluroxypyr	0.03	0	0	0.03	0	0
Dicamba	0	0	0	0	0	0
Triclopyr	0	0.04	0.01	0	0.07	0.01
Chlorsulfuron	0	0	0	0	0	0
Sulfometuron-methyl	0	0	0	0	0	0
Metsulfuron-methyl	0	0	0	0	0	0
Triasulfuron	0	0	0	0	0	0

*Calculated by multiplying mass concentration (mg/kg) detected by area and average bulk density (derived from soilquality.org) for each soil layer

Toxicity – how do soil functions respond?

A literature review of over 300 published studies identified common themes with respect to herbicide impacts on soil function (Rose et al., 2016). The majority of papers reported negligible impacts of herbicides on beneficial soil functions when applied at recommended rates. Even in the cases where negative effects were observed, they were usually minor and only lasted for periods of less than one month.

However, some exceptions were apparent, especially regarding the effects of repeated herbicide application. For example, there is evidence that the accumulation of some SU herbicides after repeat application can reduce plant-available N, by slowing down the processes controlling N-cycling. Persistence of SUs in soil has also been linked with increased incidence of *Rhizoctonia* diseases in cereals and legumes. These effects are more likely to occur in alkaline soils, where SU herbicides are significantly more persistent. There are also cases in which other herbicides (e.g. glyphosate) can increase the incidence of disease, but these interactions appear to be site-specific and often occur under stressful growing conditions.

Based on this information and the herbicide residues detected in the soil survey, it is unlikely that SU residues are having ongoing negative impacts to soil functions in the paddocks surveyed. However, the high residue loads of glyphosate, its metabolite AMPA and trifluralin may be altering some soil functions or plant-pathogen interactions. The localised nature of interactions with glyphosate, and the lack of specific data on trifluralin, means that firm conclusions cannot yet be made with respect to the residues detected.

Toxicity – how do plants respond?

Because the potential for each herbicide to damage crops varies according to soil, agroclimate and crop, comprehensive phytotoxicity thresholds (given as soil residue concentrations) for assessing plant-back risk are not readily available. Here we focus only on the potential for glyphosate (+AMPA) or trifluralin residues to cause seedling damage, given their high frequency of application and detection in the residue survey.

It is generally accepted that glyphosate is deactivated when it reaches the soil and poses little risk to crops. However, recent research has shown that under certain circumstances glyphosate can be remobilised and become plant bioavailable, including:

1. In the event of P fertilisation, which can compete with glyphosate for binding sites on soil and remobilise bound glyphosate residues (Bott et al., 2011)
2. In the event of glyphosate applied to a high density of weeds soon before sowing, such that dying weeds translocate glyphosate into the soil and act as a more soluble pool of glyphosate to the germinating crop (Tesfamariam et al., 2009)

We used a sandy, low organic matter soil from Wongan Hills, WA, to construct dose-response curves for wheat and lupin encountering glyphosate residues applied one month prior to sowing. To demonstrate circumstance (1), half the test pots received a one-off application of 20 kg/ha P fertiliser (as soluble potassium phosphate) at sowing.

As can be seen in Figure 3, in soil not receiving P fertiliser, wheat biomass was not affected by levels of glyphosate in soil resulting from a 27 kg/ha application rate, whilst lupin biomass was only significantly reduced at rates above 12 kg/ha (when upper 95% confidence level falls below 100% biomass). When P fertiliser was added at 20 kg P/ha, both wheat and lupin showed signs of phytotoxicity at lower glyphosate concentration – for lupin this occurred at levels of glyphosate > 3.5 kg/ha (Figure 3, visual growth shown in Figure 4); and for wheat > 12.5 kg/ha (Figure 3). Previous research has shown that increasing levels of P fertiliser application will continue to lower the phytotoxicity threshold to glyphosate/AMPA residues in soil. We are currently analysing the soil samples from this experiment to determine the residue level of both glyphosate and AMPA in soil. This will give us a more accurate understanding of whether the residues found in the field survey are likely to cause crop growth impacts following P fertilisation.

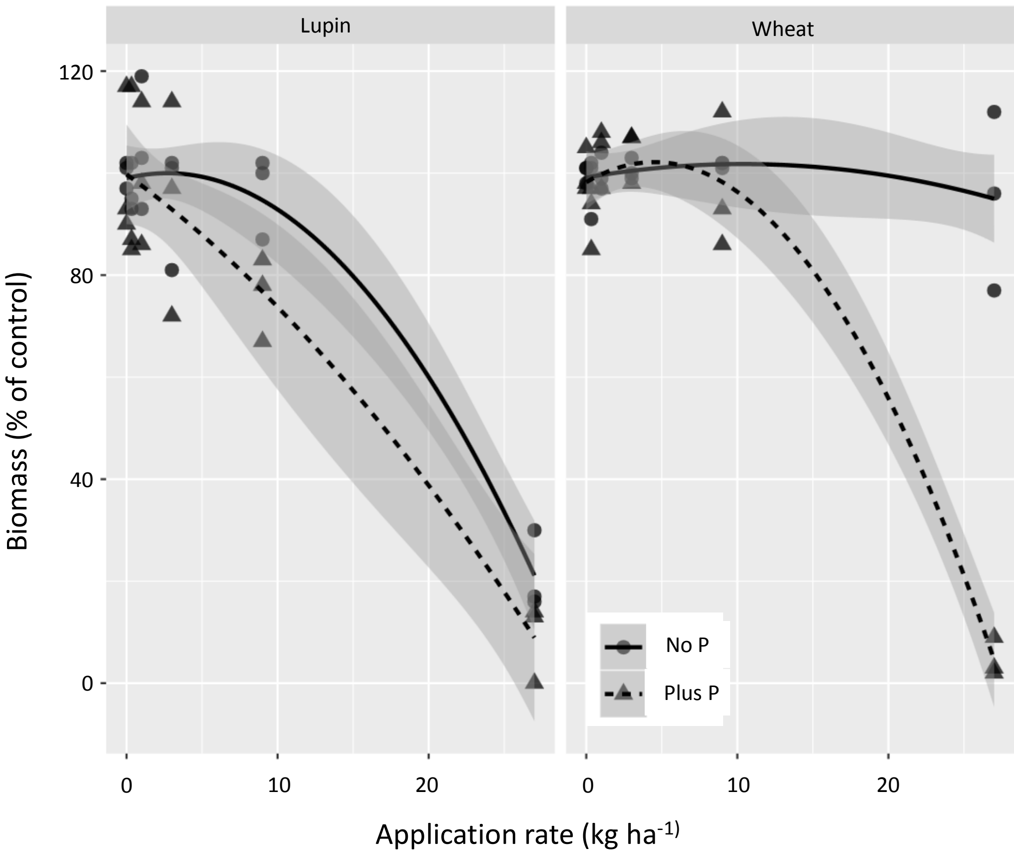

Figure 3. Growth response of lupin and wheat to glyphosate applied to soil one month prior to sowing. P fertiliser (20 kg/ha) was added at sowing to half the pots.

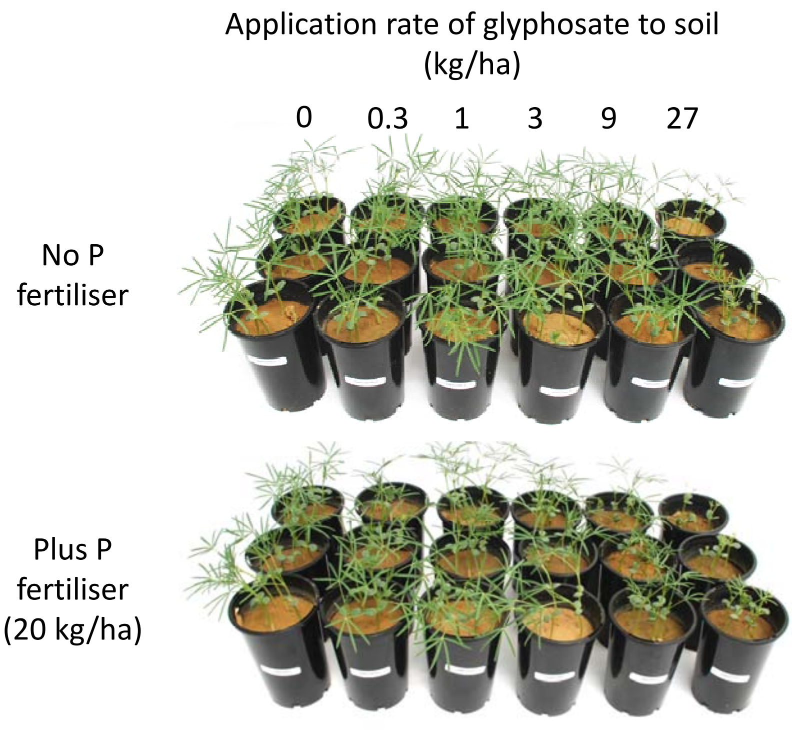

Figure 4. Growth response of lupin to glyphosate applied to soil one month prior to sowing. Note the impact of P fertiliser on lupin growth at glyphosate application rates 9 kg/ha.

With respect to trifluralin, phytotoxicity thresholds for oats vary from 0.1 – 0.2 mg/kg and wheat vary from 0.2 – 0.4 mg/kg depending on the soil type (Hager and Refsell, 2008). Table 2 shows the number of paddocks in which the topsoil trifluralin residue concentration exceeds the lower threshold for oats and wheat, respectively. Again, it must be stressed that the residues detected in our field survey constitute "aged" residues which are likely to be less bioavailable and hence less phytotoxic to crops. Nevertheless, considering that some of these paddocks will receive a pre-emergent application of trifluralin in 2016, the risk of some phytotoxicity is tangible.

Table 2. Number of paddocks exceeding trifluralin lower phytotoxicity thresholds for oats (0.1 mg/kg) and wheat (0.2 mg/kg) in topsoil (0-10 cm)

Region	Trifluralin > 0.1 mg/kg	Trifluralin > 0.2 mg/kg	Number of paddocks surveyed
WA	10	5	12
SA	2	0	15
NSW-Qld	0	0	13

Where to from here?

Ideally, growers and advisers would have tools available for rapid diagnosis of herbicide residues in soil, together with information of the biological relevance of these residues. Our current work is testing rapid in-field dipstick technology (similar to pregnancy test-kits) that can give a semi-quantitative indication of herbicide residue levels in soil within 30 minutes. We are also formulating improved models that can account for the effects of weather and soil type on herbicide persistence, to give growers and advisers the ability to estimate soil residue concentrations in a given paddock at a certain time after herbicide application. Output from current and future glasshouse dose-response experiments on herbicide impacts to soil functions and plant growth will be linked to model output in a handheld, 'App' format for quick reference.

Conclusions

- Glyphosate, trifluralin and diflufenican are routinely applied in grain cropping systems and their residues, plus the glyphosate metabolite AMPA, are frequently detected at agronomically significant levels at the commencement of the winter cropping season
- The risk to soil biological processes is generally minor when herbicides are used at label rates and given sufficient time to dissipate before re-application
- However, given the frequency of glyphosate application, and the persistence of trifluralin and diflufenican, further research is needed to define critical thresholds for these chemicals to avoid potential negative impacts to soil function and crop production.

Acknowledgements

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Crown rot and weeds concurrent session (Day 2)

Crown rot – does cereal crop or variety choice matter?

Steven Simpfendorfer, NSW DPI Tamworth

Key words

Yield benefit, inoculum load, resistance, crown rot, variety

GRDC codes

DAN00175 – National crown rot epidemiology and management program

Take home message

- Barley and bread wheat varieties do vary in their yield response to crown rot infection.
- Variety choice can provide a 20-50% yield benefit over growing the susceptible variety EGA Gregory⫯ in the presence of high levels of crown rot infection.
- However, all varieties are **susceptible** to crown rot infection and will **not** significantly reduce inoculum levels for subsequent crops. Variety choice is **NOT** a sole solution to crown rot.
- Crown rot tolerance should not be the only consideration in variety choice, impacts on other pathogen populations, especially *Pratylenchus thornei*, resistance to other pathogens, grain quality and delivery should all be considered along with relative grain prices.

Background

Crown rot, caused predominantly by the fungus *Fusarium pseudograminearum* is a significant disease of winter cereal crops in the northern NSW and southern Qld. All winter cereal crops host the crown rot fungus. Yield loss varies between crops and the approximate order of increasing loss is oats, barley, triticale, bread wheat and durum. Barley is very susceptible to crown rot infection and will build up inoculum but tends to suffer reduced yield loss through its earlier maturity relative to wheat. Late planted barley can still suffer significant yield loss especially when early stress occurs within the growing season.

Yield loss trials conducted across 11 sites in northern NSW in 2007, in collaboration with the Northern Grower Alliance (NGA), found that the average yield loss from crown rot was 20% in barley (4 varieties), 25% in bread wheat (5 varieties) and 58% in one durum (EGA Bellaroi⫯). In 2007, a yield benefit of only around 5-10% could be demonstrated in bread wheat varieties between choosing the best and the worst entries in the presence of high levels of crown rot infection. However, recent research highlights that some newer bread wheat varieties appear to differ significantly in their level of yield loss to crown rot with some in the northern region (Sunguard⫯, Suntop⫯, LRPB Spitfire⫯, LRPB Lancer⫯ and Mitch⫯) appearing to suffer less yield impacts compared to the widely grown EGA Gregory⫯. NSW DPI trials from a total of 23 sites conducted across the northern region in 2013 and 2014 indicate that this can represent a yield benefit of around 0.50 t/ha in the presence of high levels of crown rot infection. In a relatively short period of time the yield benefit associated with bread wheat variety choice in the presence of high crown rot infection has grown to around 20-30% with some of these newer varieties.

Continued research in 2015

A further 12 replicated crown rot yield loss trials were conducted across northern NSW and southern Qld in 2015 with sites spread from Wongarbon in the south to Macalister in the north (Figure 1).

There were two barley, 13 bread wheat and one durum entry evaluated across the trials in 2015 (Figure 2). The trials used an inoculated versus uninoculated trial design to evaluate the relative yield response of varieties to crown rot infection at each site. Each site was soil cored at sowing (separate bulk samples across each range) to determine background pathogen levels using the DNA based soil test PreDicta B®. Post-harvest soil cores were also collected from all plots at Wongarbon and Macalister in December and analysed by PreDicta B to determine the impact of varieties on the build-up of populations of the root lesion nematode, *Pratylenchus thornei* (*Pt*) and crown rot inoculum over the 2015 season. These two sites were targeted for post-harvest assessment based on PreDicta B analysis of all 12 sites at sowing.

Yield impact – site effects

Background crown rot inoculum levels existed at half of the 12 sites with medium background crown rot levels at Mullaley, Macalister and Merriwa while high background levels were measured at Coonamble, Wongarbon and Mungindi. All trials were conducted in grower paddocks and generally co-located with GRDC funded National Variety Trials (NVT). One criterion for selecting sites is that they are generally paddocks with a good crop rotation, with all 12 sites having a non-winter cereal break (chickpea, canola or sorghum) as the previous crop within the rotation sequence. The medium to high background crown rot inoculum levels still evident at half of the sites highlights the continuing difficulty of managing stubble-borne inoculum levels of the crown rot fungus across the region. Background crown rot levels potentially underestimate the yield impact associated with crown rot infection as varying levels of infection would have occurred in the no added crown rot (CR) treatment plots at these sites.

Yield varied across the sites which, when averaged across the 16 winter cereal entries, ranged from 4.60 t/ha at Mullaley down to 2.87 t/ha at Mungindi in the no added CR treatments (Figure 1). The addition of crown rot inoculum at sowing (added CR) significantly reduced yield at all 12 sites in 2015 when averaged across entries. Average yield loss (difference between no added CR and added CR treatments) ranged from 7% (0.29 t/ha) at Trangie up to 43% (1.22 t/ha) at Mungindi (Figure 1).

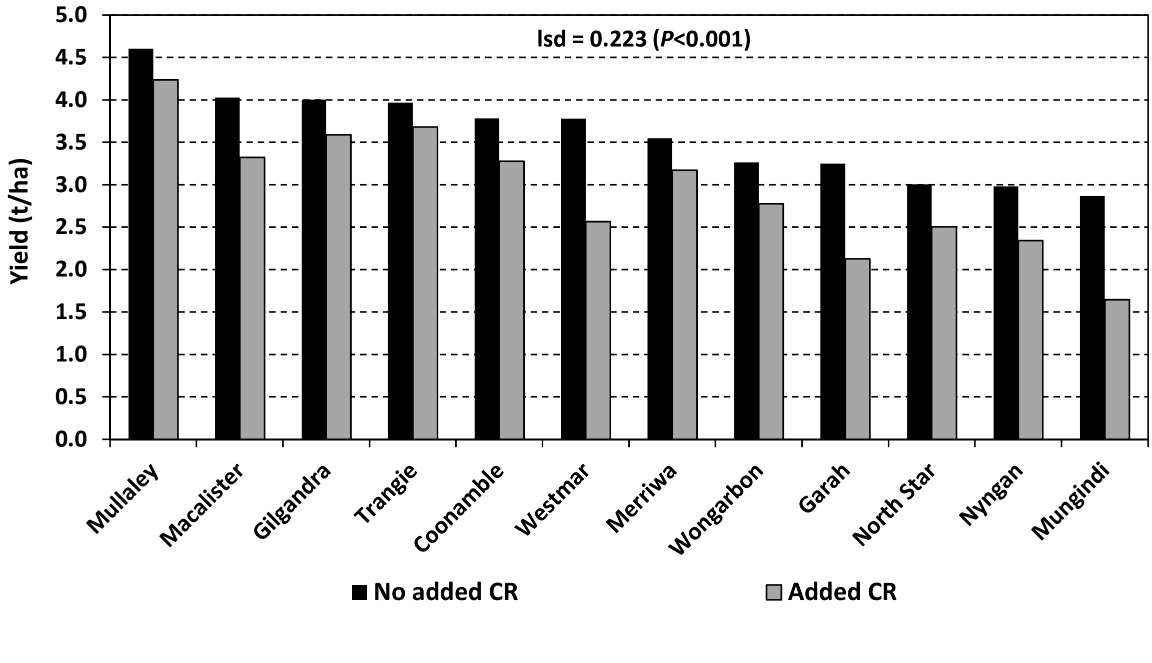

Figure 1. Average yield of 16 winter cereal entries in the absence and presence of added crown rot (CR) inoculum at 12 trial sites in 2015

Did cereal crop type and/or variety make a difference?

An across site analysis was conducted to assist in summarising the general trends in varietal performance across the 12 sites in 2015. Only yield results from the barley variety Commander⚖ at Mungindi were excluded from the analysis due to severe damage from the herbicide Topik® which was applied across the predominantly wheat trial site. Significant lodging of both barley varieties occurred at North Star due to delayed harvest of the trial site waiting for some of the bread wheat entries to mature. Unfortunately a significant rain event occurred during this period which severely lodged the barley and caused some sprouting which differentially impacted on barley yield at this site with La Trobe⚖ appearing to be more disadvantaged than Commander⚖. Barley yellow dwarf virus (BYDV) was evident in the Merriwa trial site with the yield impact appearing to be greater in La Trobe⚖ (2.78 t/ha) than in Commander⚖ (3.44 t/ha). Based on Western Australian data Commander⚖ is rated MR-MS to BYDV while La Trobe⚖ has a provisional rating of S. The impact of BYDV on yield is generally greater in barley than in wheat, but as appears to have occurred at Merriwa, varieties can differ significantly in their levels of resistance. It is notable that the NVT trial conducted at this site was all treated with the seed treatment Hombre which contains a fungicide and the insecticide imidicloprid. Imidicloprid has been shown to provide early season control of aphids which transmit BYDV. No BYDV symptoms were evident in the NVT trial while interveinal yellowing/reddening of leaves characteristic of BYDV infection was obvious throughout the crown rot trial which was all treated with the same fungicide as a seed treatment (Dividend® M). However, yield results from the two barley varieties at both North Star and Merriwa were still included in the across site analysis.

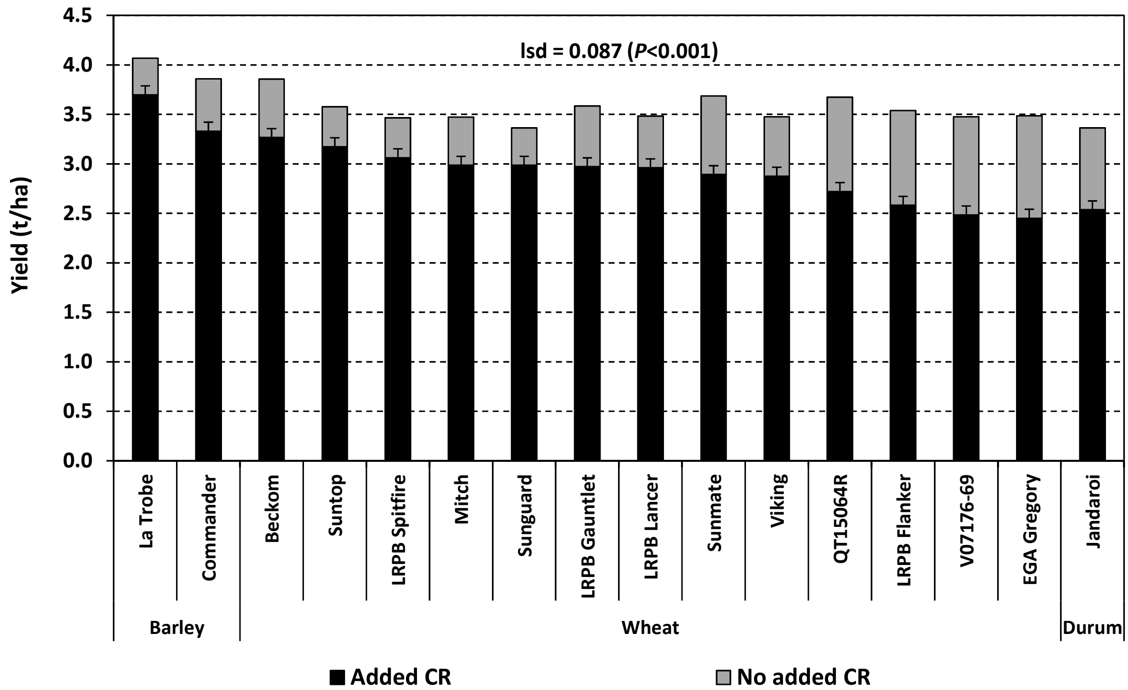

Figure 2. Impact of crown rot on the yield of two barley, 13 bread wheat and one durum entry averaged across 12 trial sites in 2015

Averaged across sites, yield in the no added CR treatments (grey bars) ranged in the barley from 4.07 t/ha (La Trobe⚖) to 3.86 t/ha (Commander⚖), in the bread wheat from 3.86 t/ha (Beckom⚖) to 3.36 t/ha (EGA Gregory⚖) and was 3.36 t/ha with Jandaroi⚖, the only durum variety included in the trial series (Figure 2). Remember, yield in the no added CR treatments was potentially impacted by background crown rot inoculum levels at half of the sites. The addition of crown rot inoculum at sowing (black bars) significantly reduced the yield of all entries compared to the no added CR treatments (grey bars). Yield loss associated with high levels of crown rot infection when averaged across the sites was 9% (0.37 t/ha) in La Trobe and 14% (0.53 t/ha) in Commander. In bread wheat, yield loss ranged from 11% (0.38 t/ha) in Sunguard up to 30% (1.04 t/ha) in EGA Gregory (Figure 2). Yield loss averaged 25% (0.83 t/ha) in the durum variety Jandaroi.

Another way of comparing the relative impact of crown rot on the yield of varieties, which is not complicated by differential background inoculum levels present at the different sites, is to concentrate on the absolute yield achieved under high disease pressure in the added CR treatments (black bars; Figure 2). Under high crown rot pressure average yield ranged from 3.70 t/ha in the barley variety La Trobe down to 2.45 t/ha in the widely grown bread wheat variety EGA Gregory. Only the advanced bread wheat line V07176-69 and the durum variety Jandaroi were not significantly higher yielding than EGA Gregory when averaged across the 12 sites. The average yield benefit over growing EGA Gregory under high crown rot infection ranged from 1.25 t/ha (51%) with the barley variety La Trobe down to 0.13 t/ha (5%) with the recently released bread wheat variety LRPB Flanker. However, the relative yield benefit compared to EGA Gregory was considerably greater with other bread wheat varieties such as LRPB Lancer (0.51 t/ha; 21%), LRPB Gauntlet (0.52 t/ha), Sunguard (0.54 t/ha), Mitch (0.54 t/ha), LRPB Spitfire (0.61 t/ha), Suntop (0.72 t/ha) and Beckom (0.82 t/ha; 33%). Commander, the second barley variety in the trials, averaged a 0.88 t/ha (36%) yield benefit over EGA Gregory under high levels of crown rot infection across the 12 sites in 2015 (Figure 2).

Varietal impact on final soil populations of *Pratylenchus thornei*

The root lesion nematode, *Pratylenchus thornei* (*Pt*), has been demonstrated in repeated studies to be widespread across the northern region and at moderate to high populations it appears to interact with the expression of crown rot which can exacerbate yield loss from both pathogens. While consideration needs to be given to the relative yield of cereal type and variety in the presence of crown rot infection in the current season, potential consequences of these choices on the build-up of *Pt* for subsequent crops within the rotation should not be overlooked. Final *Pt* populations developed by the 16 different winter cereal entries was determined after harvest at two sites (Wongarbon and Macalister) in 2015 to determine potential residual impacts on the differential build-up of *Pt* populations within a rotational sequence.

Both sites had similar average starting *Pt* populations across the trial area at sowing of around 5.5-5.6 *Pt*/g soil in the 0-30 cm soil layer. This level is generally considered a medium risk for yield loss in intolerant wheat varieties (low = <2.0, medium = 2-15 and high =>15 *Pt*/g soil). Final populations established by the varieties during the 2015 season varied markedly between the two sites but significant differences between varieties were evident. Final *Pt* populations varied from 0.9 *Pt*/g soil after Suntop, up to 19.8 *Pt*/g soil after Mitch at Wongarbon.At Macalister populations varied from 11.8 *Pt*/g soil after Commander up to 105.0 *Pt*/g soil after Mitch (Table 1). There was generally a fair consistency between the ranking of varieties between the two sites with Mitch clearly being at the more susceptible end and Suntop at the more resistant. Both barley varieties and the durum variety Jandaroi were generally towards the mid to lower end of final *Pt* populations relative to the bread wheat entries. The two barley varieties appear to vary in their resistance to *Pt* with La Trobe leaving approximately double the *Pt* population of Commander at Macalister. The difference between the barley varieties at Wongarbon was not significant even though La Trobe similarly trended towards a higher final *Pt* population than Commander (Table 1).

Further research across sites is required to confirm differences in resistance of barley and wheat varieties to *Pt* as this can have significant implications for the build-up of *Pt* populations within a paddock and hence following rotational choices. For instance, while it appears that Mitch has a useful level of tolerance to crown rot (average 0.54 t/ha higher yielding than EGA Gregory in 2015), its increased susceptibility to *Pt* resulted in it taking nematode populations from a medium risk level at sowing to a high risk level (arguably extreme at Macalister) by harvest at both Wongarbon and Macalister in 2015 (Table 1). Hence, MitchⓅ should only be considered for production in paddocks known to be free of *Pt* as its increased susceptibility to *Pt* is likely to override the yield gain in the presence of crown rot when considering the whole rotational sequence.

Table 1. Impact of selected barley, bread wheat and durum entries on final post-harvest soil populations of the root lesion nematode, *Pratylenchus thornei* (Pt/g soil) at two sites in 2015

Crop	Variety	Wongarbon		Macalister	
Barley	CommanderⓅ	2.7	cde	11.8	a
	La TrobeⓅ	4.5	efg	24.5	cde
Wheat	SuntopⓅ	0.9	a	13.7	ab
	Sunmate	4.6	fg	17.9	bc
	LRPB VikingⓅ	3.2	cdef	22.1	cd
	LRPB GauntletⓅ	1.0	ab	31.9	def
	LRPB LancerⓅ	1.9	bc	34.4	efg
	BeckomⓅ	3.8	defg	38.0	fgh
	SunguardⓅ	5.3	g	43.4	fghi
	QT15064R	5.0	fg	45.9	fghi
	V07176-69	2.4	cd	48.4	ghi
	LRPB SpitfireⓅ	4.6	fg	52.0	hi
	LRPB FlankerⓅ	4.4	efg	52.5	hi
	EGA GregoryⓅ	4.4	efg	59.6	i
	MitchⓅ	19.8	h	105.0	j
Durum	JandaroiⓅ	3.2	cdef	21.0	c

Values within sites followed by the same letter are not significantly different (P=0.05) based on transformed data (ln (x+1)). Back transformed values presented in table. Sowing *Pt* soil populations averaged across ranges were 5.6 *Pt*/g soil at Wongarbon and 5.5 *Pt*/g soil at Macalister at 0-30 cm. Final *Pt* numbers post-harvest were from 0-30 cm at Wongarbon and due to drier soil conditions 0-15 cm at Macalister.

What about the build-up of crown rot inoculum?

Post-harvest soil cores collected from all plots at Wongarbon and Macalister were also analysed using PreDicta B for residual crown rot inoculum levels established by the different varieties. Crown rot risk is a sum of the DNA levels of all three *Fusarium* species known to cause crown rot expressed on a log scale where <0.6 is below detection, 0.6-1.4 is low, 1.4-2.0 is medium and >2.0 is high risk. At Wongarbon all entries left low inoculum levels (0.6 to 1.4) in the uninoculated plots and high levels (2.0 to 3.0) in the inoculated plots with no significant difference between entries. A similar outcome occurred at Macalister with crown rot inoculum levels across entries in uninoculated plots lower (0.5 to 1.8) but a high risk (2.0 to 3.0) remained with all inoculated plots with no significant difference between entries. Although varieties appear to significantly differ in their yield in the presence of crown rot infection, differences in the levels of partial resistance, which limits the rate of spread of the crown rot fungus through the plant during the season, do not appear to result in significant variation in inoculum levels at harvest. Partial resistance does not actually prevent the plant from being infected but rather slows the rate of fungal growth in the plant arguably delaying expression of the disease which can translate into a yield and grain quality (reduced screenings) benefit. However, the crown rot fungus, while being a pathogen when the winter cereal plant is alive, is also an effective saprophyte once the plant matures and dies. This saprophytic colonisation of infected tillers late in the season as the crop matures is the likely reason why limited practical differences in residual inoculum levels are created between varieties and winter cereal crop types.

Barley is ***very*** susceptible to infection by the crown rot fungus. It ***does not*** have improved resistance to crown rot infection. Barley tends to yield better in the presence of crown rot infection due to its earlier maturity relative to bread wheat, providing an escape mechanism which reduces its exposure to moisture stress during the critical grain filling stage. This is often referred to as tolerance. It is **CRITICAL** that growers **do not** continue to confuse tolerance with resistance when considering crown rot. Barley is likely to provide a yield advantage over wheat in the presence of high crown rot infection but it **will not** reduce inoculum levels for subsequent crops. This is similarly true with any bread wheat variety choice. Variety selection can improve yield in the presence of crown rot, though all varieties still suffer yield loss, which can maximise profit in the current season but this **will not** reduce inoculum levels for subsequent crops.

Implications

Interestingly, the better options across sites in 2015 appeared to be the reduced biomass plant types La Trobe⦸ barley and the new bread wheat variety Beckom⦸. These reduced growth habits may provide a yield advantage under lower yielding situations in the northern region as they potentially conserve soil water usage for grain-fill. This may also reduce the expression of crown rot and the impact of this disease on yield. Variety maturity and consequently sowing date can also have a large impact on the expression and therefore yield loss associated with crown rot infection. Earlier sowing or quicker maturity can result in grain-fill occurring under reduced evapotranspiration stress relative to delayed sowing or longer season varieties sown on the same date. This interacts with the expression of crown rot which is strongly influenced by moisture/heat stress during grain filling.

The barley variety La Trobe⦸ appeared quite promising for maximising yield in the presence of high crown rot infection across the 12 sites conducted in 2015. La Trobe⦸ on average had a significant yield benefit over Commander⦸ barley (0.37 t/ha) and the best bread wheat varieties Beckom⦸ (0.43 t/ha) and Suntop⦸ (0.53 t/ha) in the presence of high crown rot infection in 2015. La Trobe⦸ is malt accredited but relative grain price (malt vs feed barley; wheat vs barley), the increased susceptibility of La Trobe⦸ to BYDV, impact on *Pt* populations, segregation by grain accumulators and performance of other barley and bread wheat varieties not included in these trials (www.nvt.online.com.au) should be considered as part of potential variety choices. Unfortunately, grain quality data was not available at the time of writing this update paper which should also be a consideration in variety choice.

If forced into planting a cereal crop in a high crown rot risk situation then some barley varieties may provide a yield advantage over bread wheat in that season, as long as early stress does not occur. Some of the newer bread wheat varieties do appear to be closing this gap to some extent. However, a key message is that this decision is only potentially maximising profit in the current season. Growing barley over bread wheat will **not** assist with the reduction of crown rot inoculum levels as barley is **very susceptible** to infection. Significant yield loss is still occurring in the best of the barley and bread wheat varieties in the presence of high crown rot infection. Crop and variety choice is therefore **not** the sole solution to crown rot but rather just one element of an integrated management strategy to limit losses from this disease.

Acknowledgments

The research undertaken as part of project DAN00175 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The project is co-funded by the NSW state government through the NSW DPI who are also thanked for their support in fully funding my position and laboratory and other infrastructure costs. Technical assistance provided by Robyn Shapland, Tim O'Brien, Finn Fensbo, Patrick Mortell, Carla Lombardo, Chrystal Fensbo, Kay Warren, Karen Cassin and Rachael Bannister is gratefully acknowledged. Soil-borne pathogen levels were determined using the DNA based soil test service PreDicta B provided by the South Australian Research and Development Institute. We are also extremely thankful to NVT operators Peter Matthews (NSW DPI), Douglas Lush (DAF Qld) and Research Agronomist Rick Graham (NSW DPI) and their staff for sowing, managing and harvesting the trials and co-operating growers for use of their paddocks.

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Reviewed by: Dr Guy McMullen, NSW DPI

Crown rot – do seed treatments have a place?

Steven Simpfendorfer, NSW DPI Tamworth

Key words

Establishment, yield, Rancona® Dimension, crown rot

GRDC codes

DAN00175 – National crown rot epidemiology and management program

Take home message

- Treating EGA Gregory seed with Rancona® Dimension reduced establishment losses associated with the addition of crown rot inoculum to 6% compared to 23% when no seed treatment was used.
- In this instance, Rancona Dimension did not provide a significant or consistent yield benefit in the presence of high levels of crown rot infection across the 12 trial sites in 2015.
- Growers should not expect Rancona Dimension to provide a significant and consistent reduction in yield loss from crown rot infection when used as a standalone management strategy.
- Growers considering the use of Rancona Dimension should follow the manufacturer's advice and only consider it as part of an integrated management strategy against crown rot.

Background

Crown rot, caused predominantly by the fungus *Fusarium pseudograminearum* is a significant disease of winter cereal crops in the northern NSW and southern Qld. Rancona® Dimension (ipconazole + metalaxyl) was recently registered in Australia as a fungicidal seed treatment with good activity against cereal bunts and smuts, pythium and suppression of rhizoctonia. Rancona Dimension is also the first seed treatment to be registered (at 320 mL/100 kg seed) for the suppression of crown rot. Suppression by definition indicates that the seed treatment reduces growth of the pathogen for a set period of time early in the season. This is distinct from control which Rancona Dimension and other seed treatments provide against bunts and smuts of wheat and barley in that they prevent infection throughout the season. It is recommended by the manufacturer that Rancona Dimension is used as part of an integrated disease management strategy for crown rot and not as a standalone option. However, growers may still be tempted to try and use Rancona Dimension under medium to high crown rot risk situations where other management strategies have not sufficiently reduced inoculum levels. This is not uncommon following seasons with low in-crop rainfall which limits the effectiveness of break crops such as chickpea, faba bean, canola and sorghum in decomposing cereal stubble which harbours the crown rot fungus. Under this scenario growers are often forced into sowing another winter cereal within the rotation sequence and may be tempted to resort to a seed treatment as their main option in trying to reduce yield loss associated with crown rot infection. Replicated research therefore appears warranted to determine the impact of Rancona Dimension on yield loss from crown rot infection across sites in the northern region. This will hopefully ensure that growers have a realistic expectation of what this seed treatment can achieve if used in isolation of other management strategies.

Research in 2015

Twelve replicated trials were conducted across northern NSW and southern Qld in 2015 with sites spread from Wongarbon in the south to Macalister in the north. Background crown rot inoculum levels existed at half of the 12 sites with medium background crown rot levels at Mullaley, Macalister and Merriwa while high background levels were measured at Coonamble, Wongarbon and Mungindi in PreDicta B soil cores collected across the sites at sowing. All trials were conducted in grower paddocks and generally co-located with GRDC funded National Variety Trials (NVT). One criterion for selecting sites is that they are generally paddocks with a good crop rotation, with all 12 sites having a non-winter cereal break (chickpea, canola or sorghum) as the previous crop within the rotation sequence. The medium to high background crown rot inoculum levels still evident at half of the sites highlights the continuing difficulty of managing stubble-borne inoculum levels of the crown rot fungus across the region. The trials used an inoculated versus uninoculated trial design to evaluate the relative impact of seed treatments on the yield impact associated with crown rot infection at each site. High levels of crown rot infection were induced in inoculated plots (added CR) by incorporating non-viable durum seed colonised by at least five different isolates of *Fp* into the seeding furrow (2.0 g/m of row) at sowing. The crown rot susceptible bread wheat variety EGA Gregory⦶ was used across all sites at a target plant population of 100 plants/m^2 with seed treatments evaluated being:

1. Nil seed treatment
2. Rancona® Dimension (ipconazole 25 g/L + metalaxyl 20 g/L) at 320 mL/100 kg seed
3. Dividend® M (difenoconazole 92 g/L + metalaxyl-M 23 g/L) at 260 mL/100 kg seed
4. Jockey® Stayer® (fluquinconazole 167 g/L) at 450 mL/100 kg seed

Dividend M and Jockey Stayer are NOT registered for suppression of crown rot but were included to represent a commonly used wheat seed treatments for bunt and smut control or early control of the leaf disease stripe rust, respectively. Inclusion of four treatments across each site ensured statistical rigour of yield outcomes.

Impact on crop establishment

An across site analysis was conducted to assist in summarising the general trends in the performance of Rancona Dimension across the 12 sites in 2015. In the no added crown rot (CR) treatments, Rancona Dimension and Dividend M had no signficant impact on plant establishment compared to the nil fungicide treatment (Figure 1). However, establishment was slightly reduced with Jockey Stayer compared to the Rancona Dimension and nil treatments.

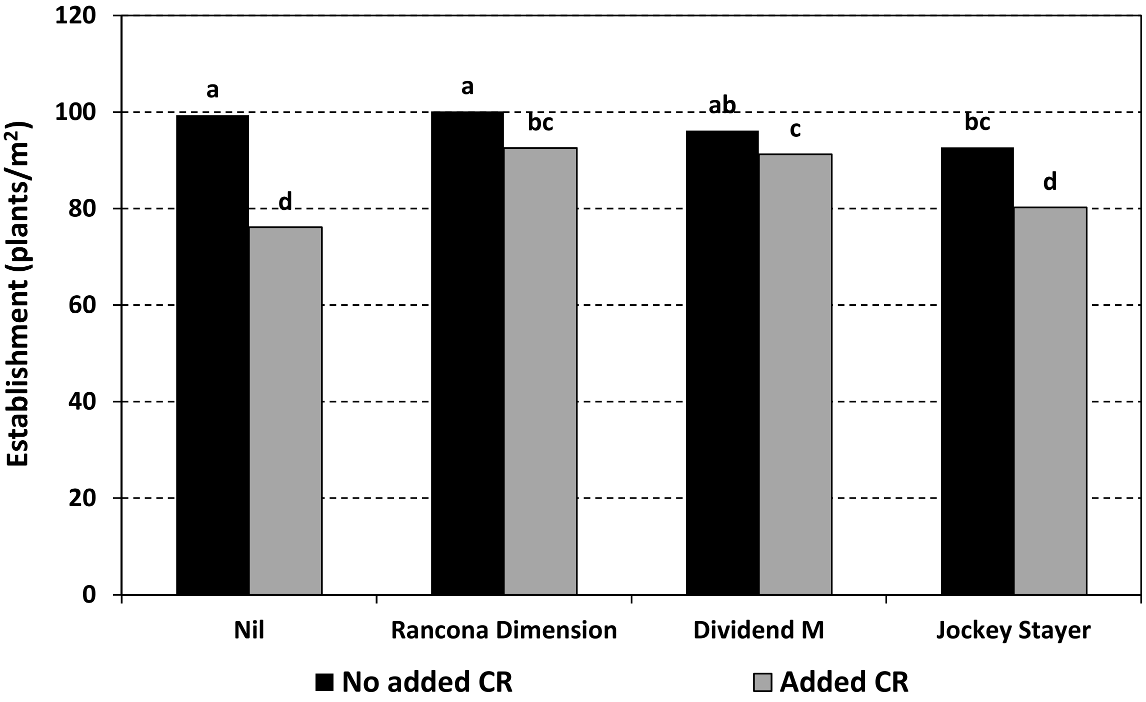

Figure 1. Impact of fungicide seed treatments on establishment of EGA Gregory⟮D⟯ in the absence and presence of added crown rot inoculum – average 12 sites in 2015

The addition of CR inoculum at sowing significantly reduced the establishment of EGA Gregory⟮D⟯ by 23% averaged across sites when no seed treatment was applied (Nil; Figure 1). Rancona Dimension and Dividend M significantly improved establishment in the presence of added CR with losses reduced to only 6% and 8%, respectively compared to the Nil – No added CR treatment. Jockey Stayer did not significantly improve establishment in the presence of added CR. Severe early infection from crown rot, as can occur with the addition of CR inoculum in the furrow at sowing, may result in seedling blight which reduces crop establishment. Rancona Dimension may provide a useful level of protection against seedling blight associated with severe early *Fusarium* infections but further research is required to prove this.

What does it mean in terms of yield?

An across site analysis of the 12 trials conducted in 2015 found that Dividend M had a minor yield reduction (0.07 t/ha) compared to using no seed treatment (Nil) in the no added CR treatment (Figure 2). Rancona Dimension did not have a significant impact on yield in the absence of added CR over the Nil treatment but was only slightly (0.09 t/ha) higher yielding than Dividend M. Across sites, yield loss in the added CR treatment was 28% with Dividend M, 31% with Rancona Dimension and 32% with Jockey Stayer. The extent of yield loss was unaffected by the seed treatments with none significantly different from what was measured in the Nil treatment (31%; Figure 2). Rancona Dimension® unfortunately did not provide a consistent yield benefit in the presence of high levels of crown rot infection across the 12 trial sites in 2015.

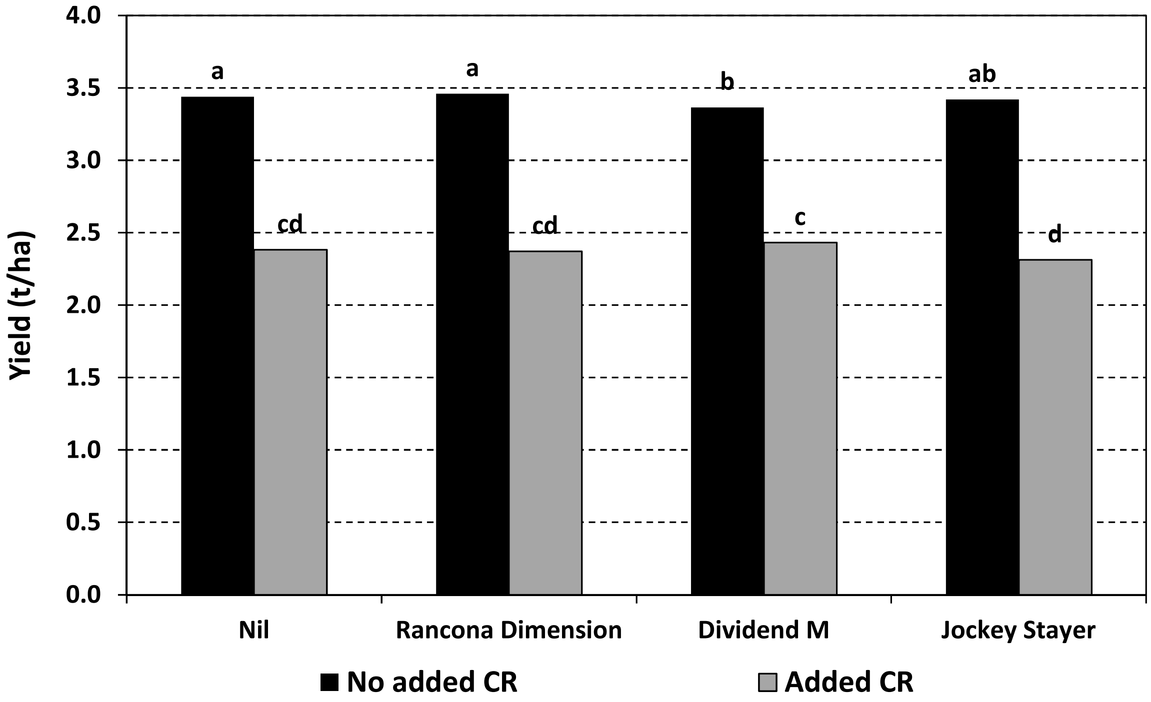

Figure 2. Impact of fungicide seed treatments on the yield of EGA Gregory⦼ in the absence and presence of added crown rot inoculum – average 12 sites in 2015

Implications

Rancona Dimension is registered in Australia for the suppression of crown rot infection. Rancona Dimension reduced establishment losses associated with severe early infection, created by the addition of crown rot inoculum to the seed furrow at sowing, to 6% compared to 23% in the absence of a seed treatment. Further research is required to determine if this improvement in establishment is associated with reduced *Fusarium* seedling blight. It should also be established whether such severe establishment losses are an artefact of the inoculation process used in the trials or occurs naturally in paddocks with high stubble-borne inoculum loads. In a separate larger trial conducted at Tamworth in 2015 in which infected stubble at the surface was the inoculum source Rancona Dimension did not have a significant impact on the establishment of EGA Gregory⦼ compared to the Nil seed treatment (data not presented). Establishment benefits apparent in the 12 trials unfortunately did not translate into any improvement in grain yield. Rancona Dimension did not provide a significant yield benefit over the use of no seed treatment or the two other commonly used seed treatments examined in this study under high crown rot pressure across 12 sites in 2015.

Although Rancona Dimension is registered for the suppression of crown rot, with activity against early infection and potential establishment losses evident in this study, growers should not expect this to translate into a significant and consistent reduction in yield loss from crown rot infection when the product is used as a standalone management strategy. Integrated management remains the best strategy to reduce losses to crown rot. Growers may like to consider including Rancona Dimension (320 mL/100 kg seed) as one additional component in their integrated management of crown rot.

Acknowledgments

The research undertaken as part of project DAN00175 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The project is co-funded by the NSW state government through the NSW DPI who are also thanked for their support in fully funding my position and laboratory and other infrastructure costs. Technical assistance provided by Robyn Shapland, Tim O'Brien, Finn Fensbo, Patrick Mortell, Carla Lombardo, Chrystal Fensbo, Kay Warren, Karen Cassin and Rachael Bannister is gratefully acknowledged. Soil-borne pathogen levels were determined using the DNA based soil test service PreDicta B provided by the South Australian Research and Development Institute. We are also extremely thankful to NVT operators Peter Matthews (NSW DPI), Douglas Lush (QDAF) and Research Agronomist Rick Graham (NSW DPI) and their staff for sowing, managing and harvesting the trials and co-operating growers for use of their paddocks.

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Reviewed by: Dr Guy McMullen, NSW DPI

Integrated management of crown rot in a chickpea – wheat sequence

Andrew Verrell, NSW Department of Primary Industries, Tamworth

Key words

row placement, row spacing, wheat, stubble, chickpea

GRDC code

DAN00171 - Winter pulse agronomy project

Take home message

- Sow chickpea crops between standing wheat rows
- Sow the following wheat crop *directly* over the row of the previous year chickpea crop
- Keep wheat stubble intact and do not spread it across the surface

Introduction

Crown rot, caused by the stubble-borne fungus *Fusarium pseudograminearum* (*Fp*), remains a major limitation to winter cereal production across the northern grains region of Australia. Crop sequencing with non-host crops, has proven to be one of the best means of reducing the impact of crown rot (CR) infection (by 3.4-41.3%) and increasing wheat yield (by 0.24-0.89 t/ha) compared to a cereal-wheat sequence (Kirkegaard *et al.* 2004, Verrell *et al*. 2005). While inter-row sowing has been shown to reduce the impact of CR and increase yield, by up to 9%, in a wheat-wheat sequence (Verrell *et al* 2009). Verrell *et al.* (2014) showed that using mustard-wheat and chickpea-wheat crop sequencing resulted in a 40-44% increase in wheat yield over a continuous wheat system under zero-tillage and adding inter-row sowing increased wheat yield by a further 11-16% depending on the row placement sequences.

Chickpea are the most prevalent break crop grown in sequence with wheat in the northern NSW region. Chickpea crops are reliant on the use of post-sow pre-emergent residual herbicides (Group C and H) for broadleaf weed control and a common commercial practice is to level the seeding furrow after sowing, usually with Kelly chains, to avoid the risk of herbicide residue concentrating in the furrows and causing damage. The consequence of leveling the seed furrow to avoid possible herbicide damage is that any standing wheat residue, under a zero-tillage system, is shattered and spread across the entire soil surface. If this wheat residue is infected with *Fp* then CR inoculum is no longer confined to the standing wheat rows.

There was a need to examine whether integrating row placement, stubble management, chickpea row spacing and ground engaging tool would affect the incidence of *Fp* and grain yield in wheat in a chickpea– wheat sequence grown under a zero-tillage system.

What did we do?

A three year crop sequence experiment (wheat-chickpea-wheat) was established at Tamworth in 2012 to examine the effect of ground engaging tool, chickpea row spacing, row placement and wheat residue management on the incidence of *Fp* and grain yield of a wheat crop.

In 2012, durum wheat (EGA Bellaroi⚘) was sown into a cultivated paddock using a Trimble® RTK auto-steer system fitted to a New Holland TL80A tractor with narrow row crop tyres. The crop was sown with a disc seeder on 40 cm row spacing and bulk harvested with the residue cut at a uniform height of 24 cm.

In 2013, chickpea (cv. PBA HatTrick⍉) was sown at 80 kg/ha and treatments consisted of; main-plot was row placement; (between or on 2012 wheat rows), sub-plot was stubble management; (standing or slashed and spread), sub-sub plot was row spacing; (narrow 40 cm or wide 80 cm) and sub-sub-sub plots were ground engaging tool; (Barton® single disc opener or Janke® coulter-tyne-press wheel parallelogram). The stubble management treatments was applied after the plots were sown.

In 2014, wheat (cv. EGA Gregory⍉) was sown over the chickpea plots and treatments consisted of; sub-sub plots as row placement; (between or on 2012 wheat rows) and sub-sub-sub plots were ground engaging tool; (Barton single disc opener or Janke coulter-tyne-press wheel parallelogram).

What did we find?

Chickpea grain yield increased when sown with a disc opener (by 6%), on narrow rows (by 22%) and sown between the 2012 wheat rows (by 7%) but stubble management did not have a main effect on chickpea yield. However, stubble management had a significant interaction with row spacing where sowing chickpeas on narrow rows (40 cm) into standing residue out yielded narrow rows where the residue had been slashed (by 6%) (see Figure 1). There was no significant yield effects with chickpeas sown on wide rows (80 cm) whether the wheat residue was left standing or slashed.

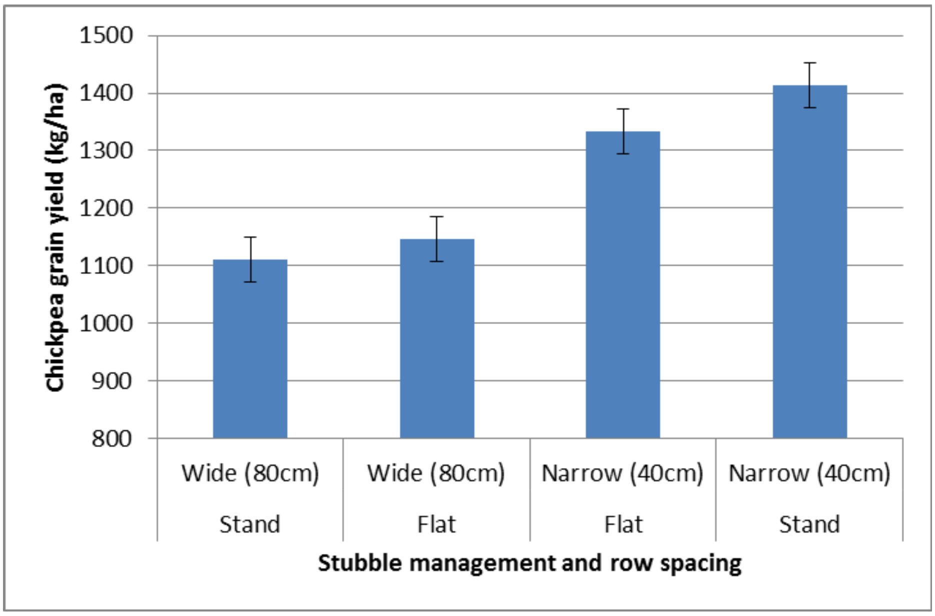

Figure 1. Effect of row spacing and wheat stubble management on chickpea grain yield (kg/ha)

In the 2014 wheat crop, sowing with a coulter-tyne-press wheel out yielded the disc opener (by 6.3%). Row placement of the wheat (relative to the 2012 wheat crop) had a significant interaction with the stubble treatment in the 2013 chickpea crop. Where wheat was sown into the space between the old wheat rows (2012) and the stubble was left standing in the 2013 chickpea crop resulted in the highest grain yield (3718 kg/ha) (see Fig. 2). This was significantly higher than the other row x stubble combinations; on-row x flat, on-row x standing and between-row x flat which yielded, 3585, 3515 and 3487 kg/ha, respectively, which were not significantly different from one another.

The incidence of *Fp* at harvest, as main effects, was lower where chickpeas had been sown between wheat rows (6.6%) compared to on the row (10.0%) and lower when stubble was left standing (6.4%) compared to spreading (9.9%). The type of ground engaging tool, row spacing in the previous chickpea crop or row placement of the 2014 wheat crop had no significant main effect on the incidence of *Fp* at harvest. For the narrow row (40 cm) chickpea system; sowing on the old wheat row led to a significant increase in the incidence of *Fp* at harvest in the following wheat crop (11.8%) compared to sowing between the old wheat rows (5.8%).

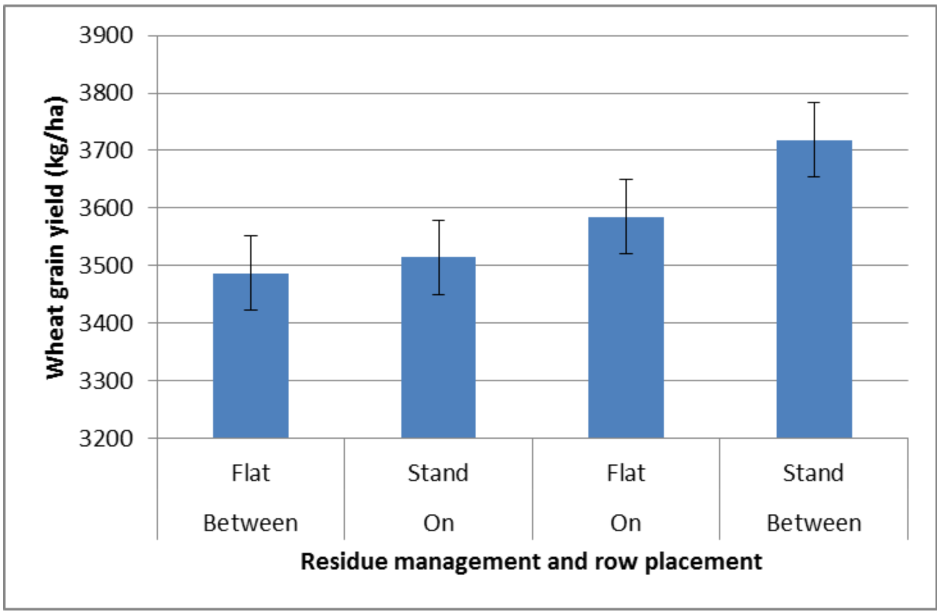

Figure 2. Effect of row placement (relative to the 2012 wheat crop) and stubble management in the 2013 chickpea crop on grain yield (kg/ha) in the 2014 wheat crop

Under the wide row (80 cm) chickpea system; row placement had no effect on the incidence of *Fp* (mean 7.5%). Sowing the 2013 chickpea crop between standing wheat rows and the following wheat crop directly over the previous chickpea row and between the old wheat rows resulted in the lowest incidence of *Fp* (4.6%) (see Fig. 3).

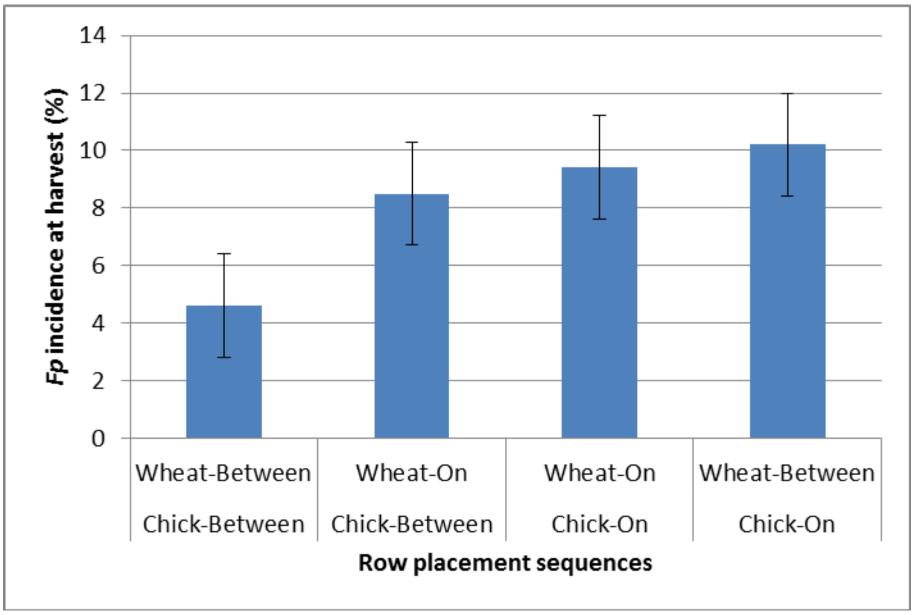

Figure 3. The interaction of chickpea row placement (2013) and wheat row placement (2014) on the incidence of *Fp* in wheat

Other row placement combinations; chickpea between wheat rows x wheat on-rows, chickpea on wheat rows x wheat on-rows, and chickpea on-rows x wheat between wheat rows resulted in *Fp* levels of 8.5, 9.4 and 10.2%, respectively.

Conclusion

At Tamworth in 2013, sowing chickpea on narrow rows (40 cm) realised a 22% yield advantage over wide rows (80 cm). Also sowing chickpeas between standing wheat rows resulted in a higher yield (by 6%) compared to sowing the crop then slashing the wheat stubble and spreading it across the surface. Growing chickpeas between standing wheat stubble has been shown to provide a yield advantage in previous studies largely by reducing the incidence of aphid transmitted viruses (Verrell and Moore 2015).

The highest wheat yield (3718 kg/ha) came from sowing the wheat into the inter row space of the old wheat crop (2 years old) and keeping the stubble standing. Using a tyne also resulted in a yield advantage over a disc opener. When stubble was left standing the incidence of *Fp* was lower (6.4%) compared to spreading stubble across the surface (9.9%). Sowing the 2013 chickpea crop between standing wheat rows and the following wheat crop directly over the previous chickpea row and between the old wheat rows resulted in the lowest incidence of *Fp* (4.6%). Any stubble management practice which spreads residues into the inter row space is likely to undo row placement benefits associated with reducing the incidence of crown rot infection, as *Fp* inoculum is no longer confined to the standing wheat rows. The perceived crop safety benefits of leveling the seeding furrow after applying post-sow pre-emergent residual herbicides (Group C and H) in chickpeas needs to be balanced against potential impacts on chickpea yield and increased incidence of crown rot infection in the following winter cereal crop.

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References

Verrell, A.G., Simpfendorfer S., Nash P. and Moore K. (2009) Can inter-row sowing be used in continuous wheat systems to control crown rot and increase yield? 13th Annual Symposium on Precision Agriculture in Australasia (2009), UNE, Armidale.

Verrell, A.G., Simpfendorfer S., Nash P. and Moore K. (2005) Crop rotation and its effect on crown rot, common root rot, soil water extraction and water use efficiency in wheat. Proceedings 2005 GRDC Grains Research Update, Goondiwindi.

Verrell A (2014) Managing crown rot through crop sequencing and row placement. GRDC. Available at: http://grdc.com.au/Research-and-Development/GRDC-Update%20Papers/2014/07/Managing-crown-rot-through-crop-sequencing-and-row-placement

Verrell A and Moore KJ (2015). Managing viral diseases in chickpeas through agronomic practices Australian Agronomy Conference, Hobart.

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Report on the 2014 GOA herbicide resistance survey

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Keywords

Herbicide, resistance, weeds, survey, testing, resistant, GOA

GRDC code

GOA0001

Take home message

- 130 annual ryegrass and 84 wild oat populations tested across the GOA region over the two seasons
- Herbicide resistance is here and it is bad. It should no longer be considered as "someone else's issues" or that "it's not that bad".
- Herbicide resistance was shown to be common place and that in the vast majority of the samples submitted multiple resistances were almost universal. In a number of cases the incidence of multiple resistances was such that there would be only a few potentially effective herbicide options left that might control those weeds.
- Testing also revealed the complexity of multiple resistances, and the lack of clear patterns make it difficult to assume that a weed population is either resistant or susceptible to a particular chemistry based on its resistance to another or herbicide history. In other words, if you are going to test for resistance, test for products that may work going forward rather than testing simply confirm the ones that you suspect do not.
- Herbicide options such as Select® (clethodim), atrazine, trifluralin and glyphosate also showed resistance.
- Attitudinal change is needed to acknowledge the issue and better manage herbicide resistance.

Background

Herbicide resistance is one of the greatest threats to the sustainability of our current grain production systems. Minimum or zero tillage systems place a heavy reliance on herbicides with, often no alternate methods of weed control used. This reliance on herbicides has already led to the development of resistance in many cropping regions of the world with Australia being a world leader!

So it leads to reason that the Central West of NSW is not immune to the development of resistance either. However, prior to a similar survey conducted by GOA at the end of 2013, the extent of resistance in the region had not been previously quantified. Before these surveys were undertaken the only formal confirmation of resistance was through ad-hoc testing by advisors or growers often only in situations where herbicides had previously failed. More informally, resistance was primarily diagnosed only by "gut feel" or an educated guess by advisors. Prior to these GOA surveys there was no publicly available data on the levels and types of resistance in this region.

In contrast, many of Australia's other main cropping regions have already conducted a number of surveys which provided a strong picture of the level and types of herbicide resistance present.

Region specific empirical evidence of the extent of the problem is seen as crucial information to help obtain grower awareness and focus on the management of this issue. Local advisors have gone so far to suggest that some growers were actively in denial to the severity of this threat and as such, often not prepared to act to prevent, slow or combat resistance.

The results from the first survey undertaken by GOA in 2013 were damning and it could be argued they showed the regions resistance situation to be much worse than expected. All of the annual ryegrass samples that were submitted were resistant to at least one herbicide tested with 54% of the populations tested expressing resistance to four or more herbicide groups or subgroups (Subgroups refer to Fop, Dim or Den herbicides which are all Group A herbicides and SUs or Imidazolinones which are both Group B herbicides). The 2013 survey also showed alarming levels of resistance to clethodim and a number of populations with resistance to glyphosate. The results on the wild oat samples also showed significant levels of resistance and cross resistance.

As a result of the positive response from growers and advisors in the GOA region, the survey was run again in 2014 to increase the size of the data set and to fill in some of the geographical sampling gaps missed in the 2013 survey. This report details the findings from the 2014 survey.

Aims

The aim of this project was to build on the findings from the 2013 herbicide resistance survey and to continue to raise awareness of the level and types of herbicide resistance in the GOA region. This will in turn motivate the growers and advisors for the GOA region to take positive action to combat the further development and spread of herbicide resistance in the region.

Methodology

In November 2014, all growers and agronomists on the GOA contacts list were offered the opportunity to submit seeds of the two main resistant weed species found in the region where GOA operates, for testing for resistance to a range of common herbicides. The two weed species were:

- Annual Ryegrass (ARG)
- Wild or Black Oats (BO)

If growers submitted two or more samples, the cost of one was met by GOA. Samples were taken from cropping paddocks with no stipulation of their suspected resistance status. That is that they could be taken from paddocks regardless of whether they were suspected resistant or not.

Samples were collected in accordance with commercially accepted sampling instructions provided by Plant Science Consulting (www.plantscienceconsulting.com/seedtest). This commercial service conducted the herbicide testing and was employed to conduct the 2013 testing. The herbicide testing was carried out to industry accepted standards in calibrated spray cabinets, with control populations introduced to ensure confidence in test results.

A range of herbicides specific to the weed species were applied and these are listed in Table 1 and Table 2 below. The herbicide types and rates used were developed with input from a number of sources with an aim to characterise the resistance status of each population to commonly used products (and a number of rates in some instances to examine any rate responsiveness). The selected herbicides are not completely exhaustive as cost would have been prohibitive but do serve to give a significant characterisation of the resistance status of the populations tested.

Table 1. Herbicides and rates tested on annual ryegrass samples

Herbicide Tested	Group	Common Trade Names	2014 Rate	2013 Rate
Trifluralin 480g/L	D	TriflurX®, Treflan®	2000mL/ha	same
Haloxyfop 520g/L	A (Fop)	Verdict™	100mL/ha	same
Clethodim 240g/L	A (Dim)	Select®, Status®	350mL/ha	same
Clethodim 240g/L	A (Dim)	Select, Status	500mL/ha	same
Butroxydim 250g/kg	A (Dim)	Factor®	180g/ha	same
Pinoxaden 100g/L	A (Den)	Axial®	300mL/ha	same
Triasulfuron 750g/kg	B (SU)	Logran 750 WG®	35g/ha	same
Iodosulfuron-methyl sodium 100g/L	B (SU)	Hussar OD®	100mL/ha	200 g/ha Hussar
Imazamox 33g/L & Imazapyr 15g/L	B (Imi)	Intervix®	750mL/ha	600 mL/ha
Atrazine 900g/kg	C (Tri)	Atrazine 900 WG, Gesaprim 900 WG®	2000g/ha	same
Glyphosate 540 g/L	M	Roundup PowerMAX®	1000mL/ha	same
Glyphosate 540 g/L	M	Roundup PowerMAX	1500mL/ha	same
Glyphosate 540 g/L	M	Roundup PowerMAX	2000mL/ha	same

Table 2. Herbicides and rates tested on wild oats samples

Herbicide Tested	Group	Common Trade Names	2014 Rate	2013 Rate
Clodinafop 240 g/L	A (Fop)	Topik®	100 mL/ha	same
Clodinafop 240 g/L	A (Fop)	Topik	210 mL/ha	Not tested
Haloxyfop 520 g/L	A (Fop)	Verdict	100 mL/ha	same
Clethodim 240 g/L	A (Dim)	Select, Status	350mL/ha	Same
Clethodim 240 g/L	A (Dim)	Select, Status	Not tested	500ml/ha
Pinoxaden 100 g/L	A (Den)	Axial	200 mL/ha	Same
Mesosulfuron-methyl 30 g/L	B (SU)	Atlantis®	330mL/ha	Same
Flamprop-M-methyl 90 g/L	Z		1800mL/ha	Same

Additional details collected when samples were submitted included; herbicide history, suspected resistance status, length of farming history and the number of herbicide applications for each mode of action applied in the last 10 years.

Following testing, test results were sent by GOA to those growers and/or agronomists that submitted the samples to allow them to make informed decisions as to the management of those populations. The combined results of all tests are the subject of this report.

Results

Industry accepted terminology for herbicide resistance is that-

1. *Survival of up to 20% of the treated population is termed to be only "Developing Resistance"*
2. *Survival of 21% or more of the treated population is termed "Resistant"*

To simplify this report a modified definition of resistance will be used for reporting. Any population with 10% or more of the population surviving the treatment will be referred to as resistant.

Ryegrass

51 samples of annual ryegrass were tested. Most samples (92%) were collected and logged by advisors and the remainder by growers.

In the 2013 survey it was thought that a reasonable cross section of the region was represented with the exception of the western area beyond Trangie and Warren and the north eastern areas around Coolah. This survey, although with fewer samples, appears to have a more even distribution of sample sites as seen in Figure 1 below.

Close to 75% of the samples submitted came from populations that the farmer or adviser indicated on submission of the samples that they were "Yes-pretty certain" the population was resistant; the remainder were from populations that were suspected "Maybe- but not certain" to be resistant with no samples submitted where no level of resistance was expected.

Examining the other answers to the survey questions around past herbicide use, there appeared to be little correlation between the patterns of past herbicide use or the length of farming history and the levels of resistance demonstrated through the testing.

That is, some populations demonstrated resistance to a particular herbicide where there has been no or very little previous use indicated, for example 15 samples were reported to have had less than two Group B herbicide applications, yet all demonstrated some level of resistance, 2 of those demonstrating 100% resistance to Hussar.

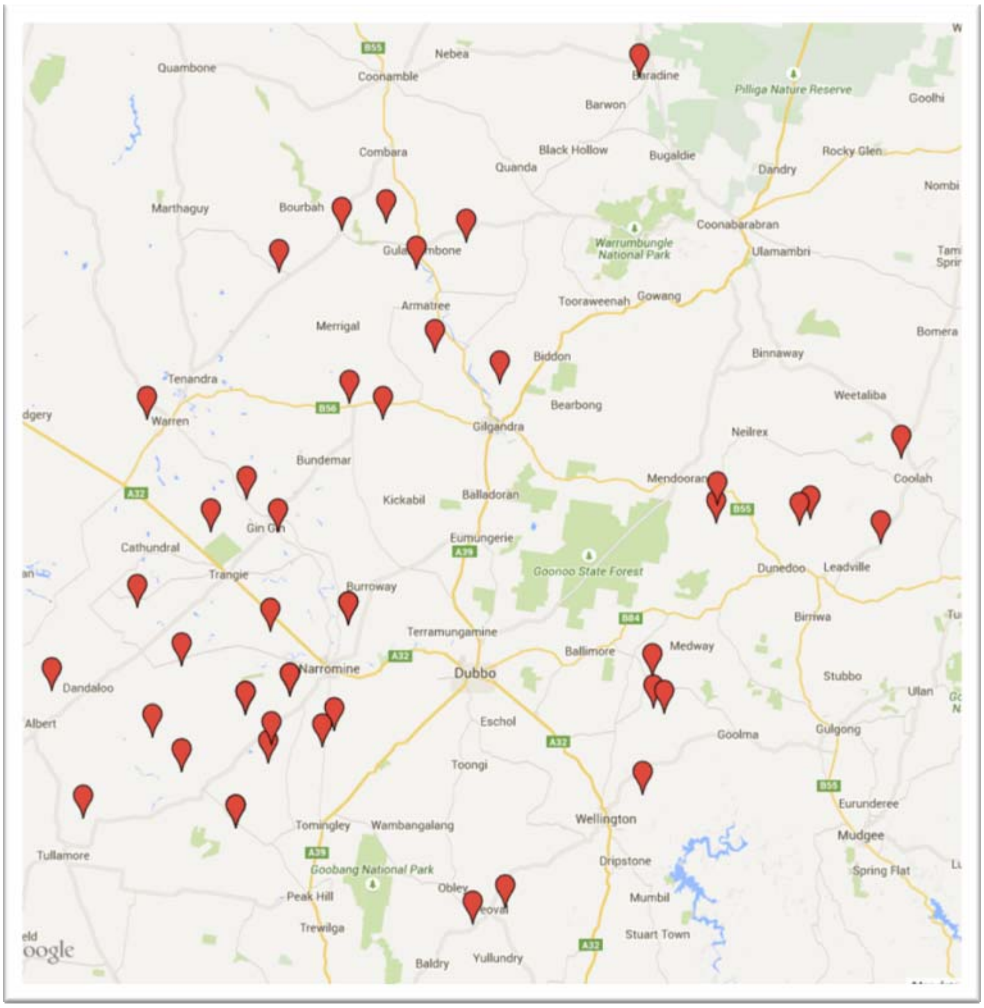

Figure 1. Approximate locations of ryegrass sample collection sites; multiple samples may have been taken from the general locality marked by a single pin.

Similar to the findings from the 2013 survey, no samples were completely susceptible to the herbicides tested and multiple resistance, (resistance to more than one herbicide type – including sub-groups of the same mode of action group), was common as detailed in Table 3 below.

Table 3. Annual ryegrass sample populations and incidence of multiple resistances to the herbicide groups or subgroups tested in 2014

No. of herbicide groups or sub groups with demonstrated resistance #	No of samples	% of samples submitted
1	3	6
2	5	10
3	3	6
4	8	16
5	14	27
6	12	24
7	6	12
Totals	51	100

Herbicides groups and subgroups considered- Fop, Dim (Select only), Den, SU, Imi, Triazines and Glycines. i.e. as weed resistant to fops, dims and dens (all Group A), would be considered as resistant to '3' group or subgroups, in the above analysis).

For this table Fops, Dims and Dens are considered as subgroups of Group A's because it has been commonly accepted that differential levels of control can often be expected when using these herbicides. Similarly, for the Group B's they are in two subgroups being the Sulfonyl urea types and the imidazolinones.

Only three samples, or 6%, demonstrated resistance to only one of the herbicides tested with the vast majority (94%) demonstrating multiple resistance to two or more herbicides tested. The largest group of samples representing 27% of the populations submitted were resistant to five herbicide groups or subgroups. A similar number (24%) were resistant to six herbicide groups, while 12% of the samples demonstrated resistance to all seven herbicide groups or sub groups tested.

By comparison, in the 2013 survey the largest group of samples (37%) demonstrated resistance to four herbicide groups tested, 15% to five and only 1% demonstrated resistance to six or seven groups tested.

The number of populations resistant to the individual herbicides and rates tested varied over a wide range as detailed in Table 4 below.

Table 4. Number of annual ryegrass samples demonstrating resistance to the various herbicides and rates tested

Herbicide and Rate	No of samples ≥ 10% Survival	% of samples with ≥ 10% survival
Trifluralin @ 2000mL/ha	1	2
Verdict 100mL/ha	44	86
Select 350mL/ha	31	61
Select 500mL/ha	13	26
Factor 180g/ha	7	14
Axial 300mL/ha	39	77
Logran 750 35g/ha	46	90
Hussar OD 100mL/ha	44	86
Intervix 750mL/ha	30	59
Atrazine 900 WG 2000g/ha	19	37
Glyphosate 540 1000mL/ha	29	57
Glyphosate 540 1500mL/ha	9	18
Glyphosate 540 2000mL/ha	4	8

Group A's- Fops, Dims & Dens

- The frequency of resistance to Verdict, a common Fop herbicide, was the second most common resistance, demonstrated in 86% of samples tested
- Resistance to Axial (pinoxaden), a Den herbicide, was the third most common resistance affecting 77% of the populations tested
- Resistance to Select (clethodim) a Dim herbicide at the lower rate of 350mL/ha was also very common affecting 61% of the samples tested. Increasing the rate to 500mL/ha improved control reducing the number of resistant populations to 26%

- Factor (butroxydim), an alternate Dim herbicide to Select, had 14% of the samples demonstrating resistance

In terms of the levels of cross resistance between the Group A herbicides;

- All populations with resistance to Select were also resistant to Verdict, however in all cases the level of resistance (% survival) was higher in Verdict than Select.
- All seven cases where resistance to Factor was demonstrated, those populations were also resistant to Verdict, Select and Axial.
- The percentage survival to Factor applications however were much lower than seen with Verdict, Select and Axial.
- All samples with resistance to Axial were also resistant to Verdict. 29 of the 39 populations (74%) resistant to Axial were also resistant to the low rate of Select, only 13 of the 39 (33%) were resistant to the high rate of Select.

In summary, Verdict and Axial are largely ineffective on the majority of these populations. The use of Select at 350 mL/ha would be effective on only 39% of the populations tested, although it was more effective at the higher rate of 500 mL/ha where it remained effective on about 74% of samples. However, even at the higher rate, 1 in 4 of these populations was not effectively controlled.

This is a different story to the 2013 testing, where more than 75% were susceptible to the lower rate of Select and increasing the rate to improved effectiveness controlling 92%.

The potential value in Factor as a Dim herbicide to control ARG is higher as it has the lowest frequency of resistance demonstrated out of any of the Group A's. However, resistance was still demonstrated in 14% of the samples tested.

Group B's- SU's and imidazolinones

- Logran was all but ineffective with 90% samples demonstrating resistance
- 86% of the samples demonstrated resistance to both Hussar and Logran
- 59% of samples tested were resistant to Intervix
- In terms of cross resistance between the three Group B herbicide tested-
    - All populations with resistance to Hussar were also resistant to Logran
    - All the cases with resistance to Intervix, were also resistant to both Logran and Hussar
    - No resistance to Intervix was found in 13 (30%) of the 44 populations that were resistant to both Logran and Hussar

In summary Logran and Hussar were largely ineffective on most of the populations tested. Intervix would still offer some value in controlling those resistant to Logran or Hussar but this data seems to suggest once resistance to Intervix is developed the other Group B's are likely to be ineffective.

Group M

- 57% of samples demonstrated resistance to Glyphosate 540 at 1000 mL/ha. This was reduced to 18% and 8% when the rate was increased to 1500 and 2000 mL/ha respectively
- 97% of the populations that demonstrated resistance at the lower rate of glyphosate demonstrated resistance to multiple alternatives. 66% of them demonstrating resistance to five or more alternates herbicide groups or sub groups

The level of resistance to Glyphosate found in the 2014 samples (57%) is much higher than that observed in the 2013 survey at 6%, but in both cases the majority of samples displayed resistance to multiple modes of action. These results clearly show that ARG Glyphosate resistance is present in the region and in many cases the number of effective alternate herbicides is limited. Using a higher rate of Glyphosate on these samples provides some benefit, with the percent of resistant populations dropping from 57 to 8% when the rate used in lab testing was doubled. It should be noted that the ideal growth conditions found in the laboratory means that lab tests usually do not translate to the same result in the paddock at the same rate used in the lab.

Wild oats

43 samples of wild or black oats were submitted. One sample failed to germinate and was not tested, and two other samples had insufficient plants to complete the herbicide test for resistance to Topik. Most samples were collected and submitted by advisors.

The distribution of the sample locations is detailed in Figure 2 below and represents a reasonable cross section of the GOA region.

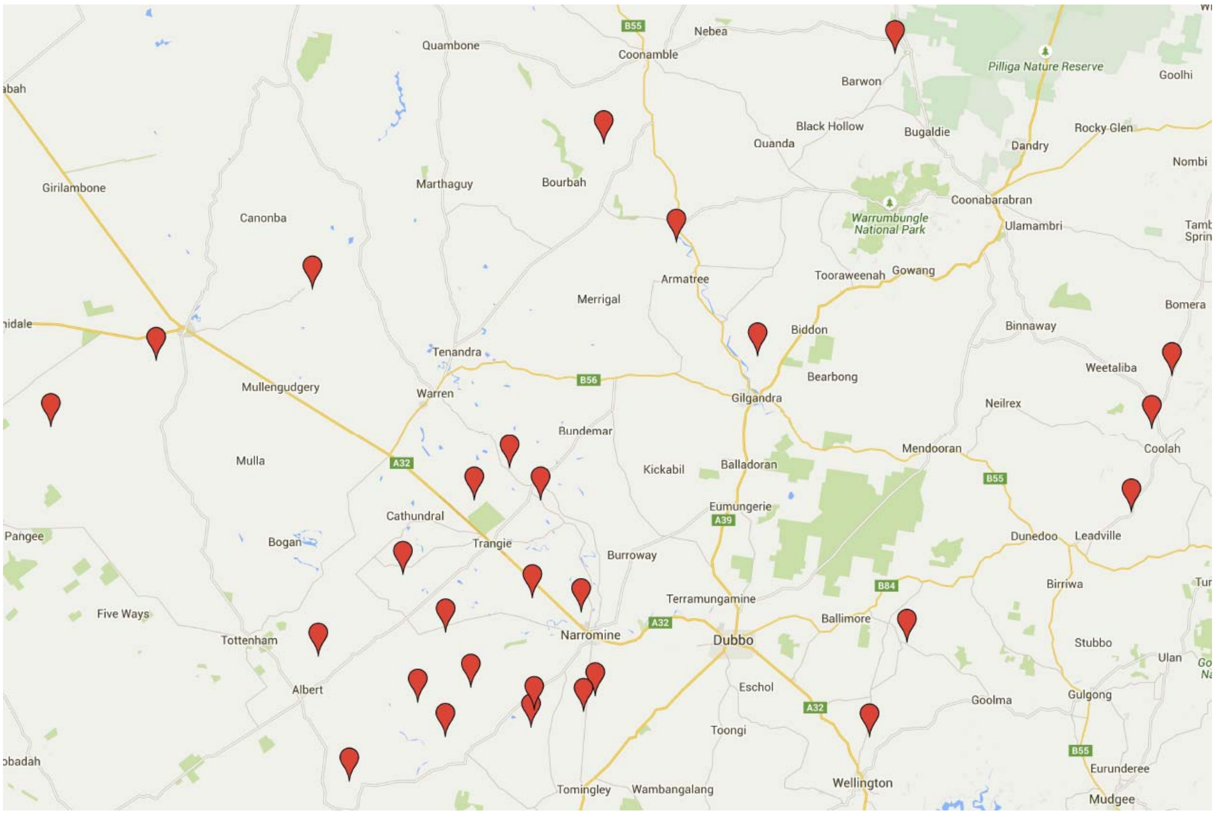

Figure 2. Approximate locations of wild oats sample collection sites; multiple samples may have been taken from the general locality marked by a single pin.

Within these samples there appeared to be little correlation to the length of cropping history and resistance. Only two samples were reported to have been cropped for less than 10 years and these showed lower incidences of resistance. Interestingly there was no resistance found in the one sample collected on the field with more than 50 years of reported cropping, and amongst the highest reported number of sprays across all groups.

There appeared little correlation between past herbicides use as indicated in the survey responses and the demonstrated resistance to those herbicides.

All samples were suspected to be either “Yes- pretty certain” of resistance or “Maybe- but not sure” of resistance and no samples were suspected to be “susceptible”.

Despite predictions that all samples being submitted were thought to be resistant at some level, 14% of the samples submitted demonstrated no resistance to the broad range of common herbicide options tested. This was similar to the 2013 survey where 29% of samples, all predicted to resistant or possibly resistant showed no demonstrated resistance to a similarly wide range of herbicides.

Multiple resistances were also common in the BO samples submitted as with the ARG samples. Table 5 below details the levels of multiple resistance. For this table both Topik and Verdict have been counted as alternate options despite both products being Fop herbicides. As is shown in Table 6 below and the findings from the 2013 survey, distinctly different levels of control have been demonstrated from the use of the two alternate options.

Table 5. Black oat sample populations and incidence of multiple resistances to the herbicide groups or subgroups tested in 2014

No. of herbicide groups or sub groups with demonstrated resistance	No of samples	% of samples submitted
0	6	14
1	2	5
2	12	29
3	9	21
4	7	17
5	6	14
Totals	42	100

Herbicides groups and subgroups tested- Fop (Topik & Verdict), Dim, Den, SU, Grp Z.

Only 5% of the samples were resistant to just one herbicide tested, 29% demonstrated resistance to two alternative herbicides. However, over 50% of samples demonstrated resistance to three, four and five groups, with no population demonstrating resistance to all six options tested.

The level of resistance to the individual herbicides tested are detailed in Table 6 below. A few key points arising from the results are highlighted below.

- Resistance to Topik was the most frequent resistance observed affecting 86% of the samples when applied at the lower rate of 100mL/ha
- Topik when applied at 210mL/ha improved control, but only marginally, reducing the number of resistant populations to 68%
- Verdict, also a Fop herbicide was not effective on 48% of the populations tested and was the third most common in term of the frequency of resistance
- 19% of the samples tested were resistant to Select at 350mL/ha.
- Axial a Group A, Den herbicide, was less effective than Select, but more effective than Verdict or Topik, but 33% of populations still demonstrated resistance
- Atlantis was the most effective of the options tested but resistance was demonstrated in 10% of the populations tested
- 69% of samples demonstrated resistance to flamprop-m-methyl, making it the second most frequent resistance demonstrated in these populations

Table 6. Number of black oat samples demonstrating resistance to the various herbicides and rates tested

Herbicide and rate	No of samples tested	Number of samples with ≥ 10% resistance	Percentage of samples with ≥ 10% resistance
Topik 100mL/ha	42	36	86
Topik 210 mL/ha	40	27	68
Verdict 100mL/ha	42	20	48
Select 350mL/ha	42	8	19
Axial 200mL/ha	42	14	33
Atlantis 330mL/ha	42	4	10
Flamprop-m-methyl 1.8L/ha	42	29	69

In terms of the observed levels of cross resistance in the populations tested-

- Verdict was still effective on 16(45%) of the 36 populations that demonstrated resistance to the lower rate of Topik
- Topik was not effective on any populations that were resistant to Verdict
- The eight cases with resistance to Select were also resistant to both rates of Topik, Verdict and Axial and only all populations bar one, were also resistant to flamprop-m-methyl. Six however were susceptible to Atlantis
- Axial was effective on 61% of populations that were resistant to the low rate of Topik and 55% of populations that were resistant to the high rate of Topik
- Flamprop-m-methyl was only effective on 19% of the populations with resistance to either rate of Topik
- Four samples tested showed low level resistance to Atlantis. These four populations also had resistance to Topik (100 mL/ha).

Discussion

It should be acknowledged that the collection method will have introduced bias to this survey. This was not a random survey of the region as highlighted in the sample questionnaire noting all samples were either suspected “resistant” or “possibly” resistant. A second bias is introduced in that most samples were taken from cropping paddocks on weed patches that had already escaped control from previous herbicide application(s).Therefore, it should be considered the outcomes and information presented from this survey may represent a “worst case scenario”. Caution should exercised when comparing results from this survey with outcomes from surveys conducted in other regions where somewhat more random sampling techniques were used. .

Given this sampling bias towards populations suspected of resistance, the finding of some levels of resistance is no surprise. However, both the ARG and BO samples submitted have overwhelmingly demonstrated a high incidence of resistance with 100% of the ARG and 86% of BO samples showing resistance to at least one of the herbicides tested. In addition, the survey showed an alarmingly high level of multiple resistances with 94% of ARG and 81% of the BO samples with resistance to two or more alternate herbicide options. An interesting observation from the BO survey is that nearly 14% of the samples showed complete susceptibility to all herbicides tested even though they had been collected from a crop situation and presumably sprayed and suspected to be resistant. This begs the question as to how these "escapes" occurred. There is number of potential explanations however no supporting evidence is available:

- Possibly the plants sampled simply germinated after the paddock was treated with herbicides
- Poor application of herbicides which has led to escapes
- Impact of plant stresses reducing the herbicide control?

This situation was also evident in the 2013 survey where 29% of the populations submitted were also found susceptible despite predictions of resistance it. Whatever the reasoning, this level of survival of weeds that could be otherwise controlled by wide range of herbicide could be perpetuating the weed seedbank unnecessarily.

Multiple resistances

As detailed in Table 3 and Table 5; multiple resistance is common with only 6% of ARG samples and 5% of BO samples demonstrating resistance to only a single herbicide group or subgroup. The clear majority of the samples submitted from both species demonstrated multiple resistances.

Similar to the findings in the 2013 survey, multiple resistances are more common than just single product resistance, or put another way- samples with no resistance or single product resistance were rare.

The reader may choose to read into the levels and types of cross resistances but as discussed below each population can be unique in its resistance makeup. The reader should exercise caution to make assumptions as what is demonstrated in this data will not necessarily be applicable to all populations. Further to this the complexity of relationships between the large numbers of herbicides tested can be overwhelming.

Knowing your resistance status

The results sections above have detailed the frequencies of individual resistances as well as a number of generalisations about levels of cross resistances between some herbicides. However, it should be noted these apply to only this set of samples and may not apply beyond the fields in which they were collected. There is no unique and distinct characterisation of a "resistant" ARG or BO plant- each one can be different. For Group A in annual ryegrass there are at least nine known different target site resistance mutations, each of which confers a slightly different resistance profile within and between the group A subgroups. Added to this are multiple nontarget site mechanisms. To add to complexity, the type of resistance found in one patch may differ from the resistance in another patch of weeds. This is particularly likely to be the case for wild oats which is largely self pollinating.

At a paddock level it is foreseeable that some populations may have some herbicide susceptibilities or resistances that cannot be predicted or expected. To best manage these populations formal identification of the resistance status of weeds will ensure that money and efforts are not wasted in applying a herbicide that will not work and that alternative chemistries (perhaps even from the same group) are not overlooked that are mistakenly thought to have resistance issues.

To highlight this point for example

- 86% of BO samples demonstrated resistance to Topik, but only 48% demonstrated resistance to Verdict with both herbicides in the same herbicide group
- 90% of ARG samples demonstrated resistance to Logran and 86% demonstrated resistance to Hussar yet only 59% to Intervix- all herbicides are Group B herbicides

This highlights the value in herbicide resistance testing, particularly to identify which products may still work into the future.

Options are running out!

As discussed the identification of resistance to a number of key products such as the Fop herbicides and Group B herbicides has come as no surprise. Alarmingly, the testing has highlighted some cases of resistance to a few “less used” products thought to be largely still effective and which were forming a key backstop in controlling ARG and BO now and into the future.

Atrazine and trifluralin have had much less use in the region compared to many other products for the control of these weeds. Experience from other regions indicates that resistance to these products can take much longer to develop than resistance to Group A or B herbicides.

However, 19 populations (37%) of ARG samples demonstrated resistance to atrazine. Atrazine is often thought as of underutilised in the region and with little resistance. These results challenge this belief.

Similar to the finding in the 2013 survey, resistance to trifluralin was found to be low with only one population of ARG showing resistance in the 2014 survey. Although the incidence of resistance is low, the presence of trifluralin resistance in the region cannot be denied.

Similarly, Intervix as a product mainly used in Clearfield canola and hence on only a small proportion of our annual cropping area, demonstrated resistance in 59% of the ARG samples.

Resistance to Select in the region is not a total surprise, but for many farmers it is the only reliable in-crop selective herbicide available and is therefore a key tool for managing ARG. However 61% of ARG samples demonstrated resistance at the lower application rate of 350 mL/ha. It is very concerning that every one of these populations were also resistant to Verdict, Axial, Logran, and Hussar. Increasing the application rate of Select to 500mL/ha did decrease the survival to 26% but this still sees ~ 1 in 4 samples with demonstrated resistance.

Flamprop-m-methyl has been talked of as an alternate herbicide product for the control of BO, however has had very little use in recent times (Data collected from 2013 herbicide resistance survey). Despite this, 69% of the BO populations demonstrated resistance to it, all of which also had resistance to Topik. Again a similar finding was found in the 2013 survey with high levels of resistance identified. There are questions over the future manufacture and supply of flamprop-m-methyl but with this frequency of populations resistant, it usefulness may certainly compromised in many situations.

Finally, herbicides play a pivotal role in our current minimum-till or zero till farming systems. Possibly the most important product in the northern farming region is glyphosate and this survey showed significant levels of resistance, with 57% of populations showing resistance at 1 L/ha, 18% at 1.5 L/la and 8% at 2 L/ha applied under laboratory conditions. Generally lower levels of resistance were detected in populations that had received fewer (6-8) applications, while higher levels were recorded where more than 100 applications were reported. This herbicide is invaluable in the control of weeds in our fallow systems which are essential to conserve out of season rainfall to achieve profitable crop yields. It is also important for managing pre-planting flushes of weeds, potentially the largest germination of winter weeds. Loss of the effectiveness of this herbicide will seriously challenge the sustainability of profitable farming systems.

Conclusion

As intended, the survey sampled weed seeds from a healthy cross section of the GOA region of the central West of NSW, with 51 ARG and 42 BO samples tested. This complimented the populations tested in 2013, bringing the total to 130 ARG and 84 BO populations tested across the GOA region over the two seasons.

Testing revealed that herbicide resistance was common place and that in the vast majority of the samples submitted, resistance to multiple herbicides was almost universal. In a number of cases the incidence of multiple resistances was such that there would be only a few potentially effective herbicide options left that might control those weeds.

Testing also revealed the complexity of multiple resistances and the lack of clear patterns make it difficult to assume that a weed population is either resistant or susceptible to a particular chemistry based on its resistance to another or herbicide history. In other words, if you are going to test for resistance, test for products that may work going forward rather than testing simply confirm the ones that you suspect do not.

Herbicide resistance is not an issue confined to Western Australia or other regions only- this survey has identified many populations in the Central West of NSW that could make a Western Australian farmer blush. “Herbicide resistance is here and it is bad”. It should no longer be considered as “someone else’s issues” or that “it’s not that bad”.

The survey was also invaluable in identifying what are some of the most challenged herbicide groups in terms of effectiveness. But the survey also served as a warning to growers, particularly for what many have thought to be “safe” and “effective” herbicide options such as Select®, atrazine, trifluralin and glyphosate. There are clear signs that resistance to these products is here.

The results of this survey are damming and its strength may be the force that is needed to change attitudes and to acknowledge the issue which of course is the first step to better manage the issue of herbicide resistance.

Acknowledgements

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Phosphorus and potassium nutrition

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Key words

Deep placement, wheat, barley, chickpea, sorghum, fertiliser, zinc

GRDC code

UQ00063

Take home message

Positive grain yield increases with deep phosphorus (P) have been inconsistent across the northern region, with crop type (cereal or legume) and seasonal growing conditions affecting the outcome. Cereal crops (wheat, barley and sorghum) are responding (mainly) due to growing both a larger plant biomass and producing more yield. Chickpeas have not been as consistent, with some very good biomass results not always converting to higher yields, or in some cases no effects on either biomass or yield. Negative yield responses are rare in any species, provided soil is allowed to settle after deep tillage.

Potassium (K) responses have generally been additive to phosphorus, meaning we have to overcome the P limit before K can have an effect, but we have also seen evidence of P by K interactions where the application of P helps overcome a low K situation. Potassium responses are most widespread in Central Queensland, while in Southern Queensland and Northern New South Wales they have tended to be restricted to the upland slopes (predominantly) and some grey box soils where lower soil K supply levels have been measured. Soil testing is a good indicator of response (suggested 10-30 cm profile critical values of <0.2 cmol/kg), while chemical analyses of plant biomass have suggested chickpeas are a good indicator of low K soil supply.

Introduction

Cropping in the northern grains region revolves around the capture, storage and use of predominantly summer rainfall on relatively heavy soils to produce both winter (wheat, barley, chickpea, etc.) and summer (sorghum, maize, mungbean, etc.) crops. Native soil fertility was high for some soil types (primarily the Vertosols) but this has declined over time (Dalal and Probert 1997). As stored moisture is the principal plant water source, subsoil supplies of the largely immobile potassium (K) and phosphorus (P) are exploited and this may (will) not be obvious in surface soil nutrient monitoring. With little P or K fertiliser being used, the consequence is that exports of P and K are significant and primarily related to the grain yield of the crop. The removal of crop nutrients depends on the grain concentration and yield, with average rates of P removal being around 2.9-3.2 kg P/t of grain for wheat, sorghum and chickpea. K removal in chickpea (11.0 kg K/t) has been at least twice that for wheat (4.1 kg K/t) and sorghum (3.1 kg K/t). On average, cropped soils across all these northern regions contained 55% (±5%) of the exchangeable K reserves of the uncropped reference sites. This depletion is resulting in increasingly complex nutrient management decisions for growers, with results clearly confirming the impacts of fertility decline and nutrient removal (Bell et al. 2010, 2012).

The wetting and drying pattern of the soil in the northern region means that some of the subsoils have become largely depleted of nutrients, as the moist soil deeper in the profile is exploited by plant roots especially in winter crops where in-crop rainfall is lower. The topsoil is relatively enriched with K in particular, and so the soil testing protocols require adjustment to take account of stratification of nutrients as well as the supply of exchangeable K. Research has identified some strategies such as deep placement of K along with modified soil testing strategies to identify responsive sites. Subsoil testing for these immobile nutrients (P and cations) does not need to be done frequently as the rate of change is very slow.

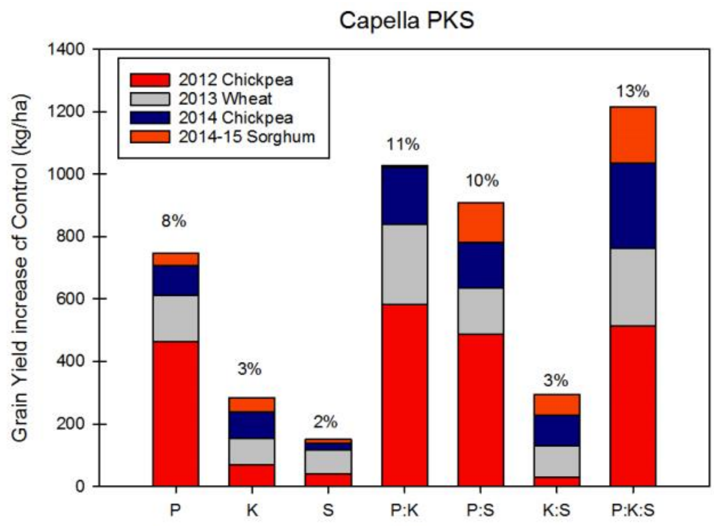
In response to these challenges, the hypothesis was developed that relatively high rates of nutrients could be place in the subsoil (10-30 cm) to provide for several crop phases. The initial application would see some disturbance, with the duration of the responses uncertain. The experiments reported here aim to assess the long-term responses to P and K (and S), alone and in combination, when placed in the soil in bands at between 15 and 20 cm depth.

Results

Central Queensland

Our longest running experiments were set up with sponsorship from the International Plant Nutrition Institute (IPNI). Two nutrient addition experiments were established in which deep banding (~20 cm deep) was used to apply P (40 kg P/ha), K (200 kg K/ha) and S (30 kg S/ha) alone and in combination. The two sites – one at Capella and the other at Gindie – allowed multiple sequential crops to be monitored so medium term effects could be explored. The experiments were established to compare nutrient responses to a deep ripped treatment with no additional nutrients (control). Deep banding occurred in the winter fallow in 2011 and the bands were 50 cm apart.

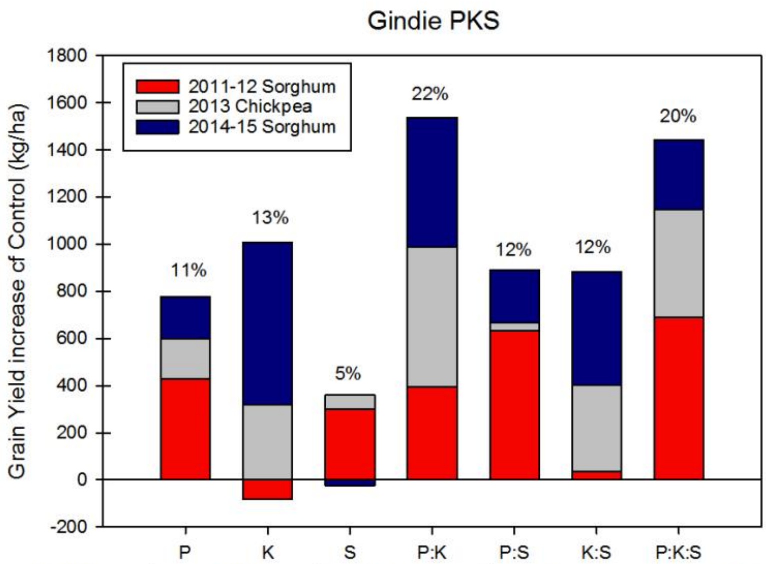
The Capella site had four crops from 2012 until 2014-15 and demonstrated that P (at this site) was the principle limit, with K and occasionally S having additive effects after P was applied (Fig. 1). Applying P alone increased yield by 8% (or a cumulative 750 kg) but responses varied with crop and season. The initial crop grown after application of the treatments was chickpea and all P treatments (P, PK, PS, PKS) increased yield by at least 450 kg/ha. The following wheat crop in 2013 and chickpeas again in 2014 had some increases but where more influenced by P and K together than P on its own.



Depth	Col P	BSES P	Ex K	ECEC
0-10 cm	10	14	0.46	74
10-30 cm	<5	9	0.16	75

Figure 1. Increase in grain yield for four crops to nutrient application at Capella

The Gindie site was particularly interesting, as while the only nutrient limit at that site in the initial sorghum crop was P, the 2013 chickpea crop data suggested K availability was a greater limitation than P (14% response to P but 27% response to K), while the additive effects of (residual) P and K were substantial (51% grain yield increase). That trend continued into the 2014/15 sorghum crop.



Depth	Col P	BSES P	Ex K	ECEC
0-10 cm	13	10	0.17	35
10-30 cm	<5	5	0.07	38

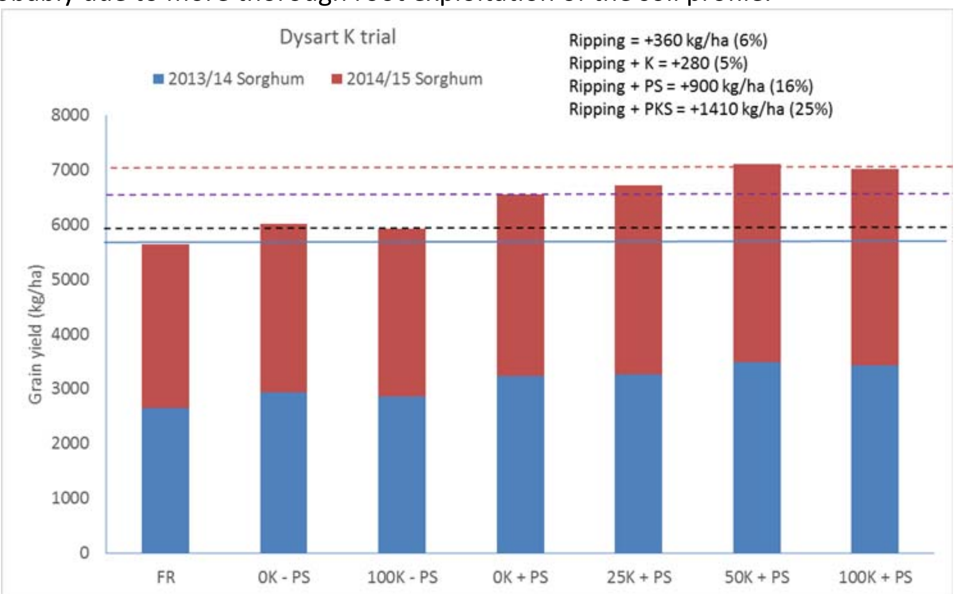
Figure 2. Increase in grain yield for four crops to nutrient application at Gindie

The biomass response to P and K was substantial with chickpea at the Gindie site in 2013 (Fig. 3). The dry matter increase at maturity with PK or PKS treatments was 68% over control (1600 kg/ha). This increase did translate to a yield increase of 530 kg/ha averaged on the same treatments (Fig. 2), but has not always been recorded in crops in Southern Queensland.

Figure 3. Gindie chickpea showing growth in the control treatment (foreground) and with deep PK (background) at 30 August 2013

These two initial PKS sites established that P and K appeared most limiting, and encouraged further investigation with seven rate response sites in CQ (as part of UQ00063) for the nutrients to evaluate increasing rates of addition. Five of these have had their first season of data and two (including the site at Dysart in Fig. 4) are approaching their third crop.

The sorghum responses at Dysart have been consistent between years, and confirm the hierarchy of P (first) and K (second) limitations. The addition of Farmer Reference treatments (FR - existing local management) in these studies has allowed the deep ripping and basal nutrient (N, Zn) effects (mainly in the initial crop) to be quantified. Relative to current practice, the deep ripping and application of P (the S had no significant impact) increased yields by 16% (900 kg/ha) while the further addition of at least 50 kg K/ha raised that response to 25% (>1400 kg/ha) over the two sorghum crop years. Interestingly, the deep ripped treatments have typically accumulated more P and K – probably due to more thorough root exploitation of the soil profile.



Depth	Col P	BSES P	Exch K	ECEC
0-10cm	5	8	0.25	35.6
10-30cm	1	3	0.12	28.8
30-60m	1	4	0.09	31.4

Figure 4. Grain yield response in a potassium rate trial with/without a background PS application in successive sorghum crops grown near Dysart

Similar responses have been recorded at other sites. For example, the initial crop year at Moura in 2015 (chickpeas), with the addition of P (and basal S, Zn) increasing yields by 20% (an additional 350 kg/ha) relative to the FR, while the addition of a further 100 kg K/ha increased the yield advantage to 30% (. an additional 530 kg/ha).

Results for the remaining trials are currently being collated and chemical analysis of the dry matter samples undertaken to assess nutrient recovery.

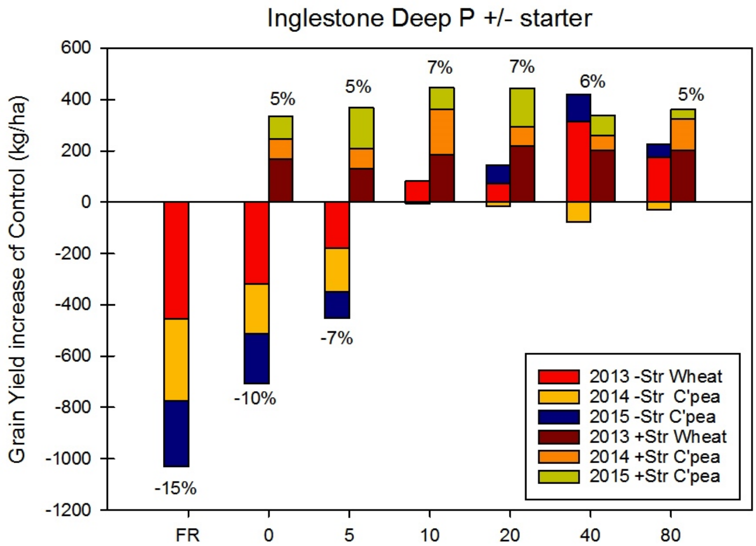
While still in the early stages of experimentation, the results from Central Queensland are encouraging with cumulative increases in grain yield of around 1000 kg/ha over three or four crops. Single year increases of nearly 500 kg have been measured in chickpea, with combinations of P and K together at a number of sites.

Southern Queensland

The P and K work in Southern Queensland has consisted of a cluster of 6 sites on a line roughly from Goondiwindi to Condamine, a site just east of Goondiwindi, 4 sites east of Warra and one north-west of Wondai in the South Burnett.

Cumulative responses to deep fertiliser application on the western downs sites (exclusively deep P, as K status has been adequate), have been poor, but starter P applications at relatively low rates have proven to be very effective. As an example, a site at Inglestone has grown three crops (Wheat - Chickpea – Chickpea) from 2013 to 2015 (Fig. 5). With no starter application, cumulative grain yield was reduced by nearly 1000 kg/ha, representing a 15% reduction in grain produced. None of the deep P treatments have demonstrated any effect above that of the basal N, S and Zn application and deep tillage (the 0 P treatments). Whilst unexpected given the low soil P status, this result has been consistent with crop P uptake data showing as much or more P uptake from the low rate of starter P as that from the deep P bands. Over the 3 crop seasons only an additional 5.3 kg P/ha was taken up in crop biomass from the highest deep P rates, and almost all of this was removed in grain.

The poor acquisition of deep P and the relatively strong response to low rates of starter (especially in chickpeas) raises questions around the most effective P application strategy in these drier western environments.

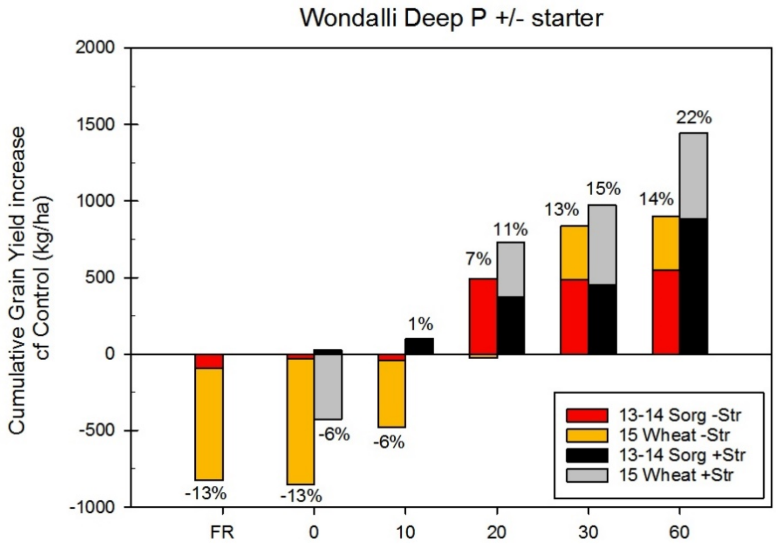


Depth	Col P	BSES P	Ex K	ECEC
0-10 cm	9	22	0.76	36
10-30 cm	4	13	0.44	40
30-60 cm	4	18	0.37	42

Figure 5. Cumulative difference in grain yield versus district practice with deep placed P with three winter crops grown at Inglestone, Qld from 2013 to 2015

Contrasting the results from Inglestone are those from Wondalli, east of Goondiwindi (Fig. 6). The negative effects of having no starter application were similar to Inglestone (13% or 750 kg/ha yield reduction) with the wheat crop accounting for basically all the loss. However, in the presence of starter there was a nearly linear response to increasing rates of deep P, with 10, 20, 30 and 60 kg P/ha delivering 200, 760, 900 and 1500 kg/ha extra grain in the 2 crop seasons, respectively. This site was characterised by higher yields and average crop P uptake, but the greater P demand only resulted in slightly higher deep P uptake (~7.5 kg P/ha) but with slightly more than half that uptake removed in grain.

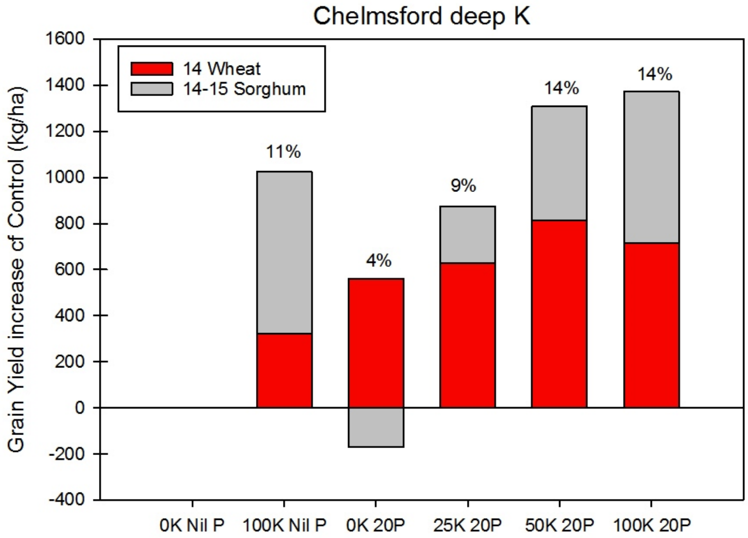
The differences in yield responses and crop P acquisition from deep bands between these contrasting sites may have been influenced by factors such as the timeliness of in-crop rainfall and resulting root activity relative to key physiological processes, general water use by crops and (in winter crops) the rate of temperature increase during reproductive development.



Depth	Col P	BSES P	Ex K	ECEC
0-10 cm	11	96	1.30	28
10-30 cm	<2	13	1.09	30
30-60 cm	<2	13	0.97	30

Figure 6. Cumulative difference in grain yield versus district practice with deep placed P with one summer and one winter crop at Wondalli, Qld from 2013-14 and 2015

Upland slope soils in the eastern areas of southern Queensland have been responding well to potassium application (Fig. 7), even the cereal crops which typically have a lower potassium demand than pulse species. In this instance the '0K Nil P' treatment is the benchmark against which responses are assessed. Both crops showed improvements from the addition of both P and K (an additional 1350 kg/ha grain produced), although the initial sorghum crop response (second crop grown as double crop from wheat) suggested that the primary limitation at the site was K.

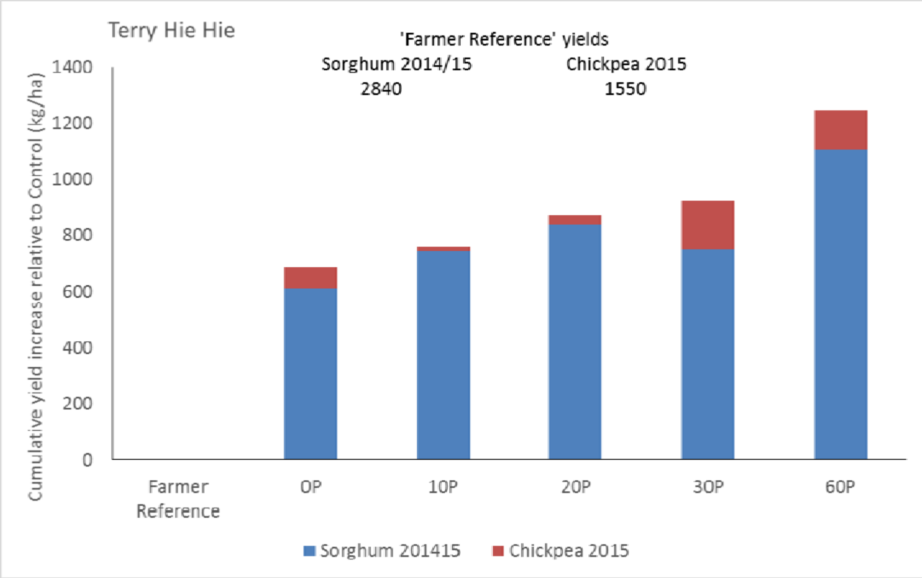


Depth	Col P	BSES P	Ex K	ECEC
0-10 cm	16	12	0.21	41
10-30 cm	2	4	0.14	43
30-60 cm	<2	3	0.12	45

Figure 7. Cumulative grain yield responses in a potassium rate trial with/without a background P application from sorghum in 2014-15 and wheat in 2015 at Chelmsford, Qld

Northern New South Wales

NSW deep placed nutrition sites cover the North West plains, North West slopes, Liverpool Plains and more recently the Central West, although many of these sites haven't had the longevity of the equivalent sites in Queensland. An exception to this however, is the site on the NW slopes at Terry Hie Hie, which was established prior to the 2013 winter season and has now grown 3 crops (wheat, long fallow to sorghum, double crop to chickpeas). Soil test P and K profiles were similar to many other locations. While harvest of the initial wheat crop was lost to an eager contract harvester the subsequent data show some similarity to that from the site at Wondalli (Fig. 6) there was a near linear response to increasing rates of deep P – particularly in the presence of starter P. This response was dominated by the long fallow sorghum crop, and this was particularly interesting given that grain protein contents indicated low available N (7.9% in the FR and 0P treatments, decreasing to only 7.0% with high P). The response to deep P may have been even greater if more N was available. Double cropping the chickpea into the sorghum would have meant that AMF levels should have been very good and helped in the recovery of P from the soil.



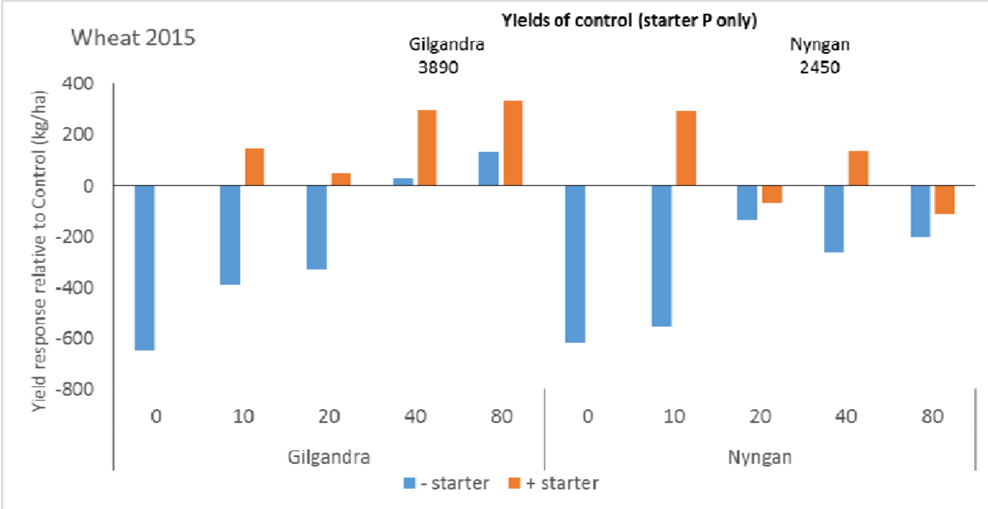
	Col P	BSES P	Exch K	ECEC
0-10cm	20	44	0.37	26.3
10-30cm	5	15	0.22	28.9

Figure 8. Cumulative grain yield responses to deep P rates applied near Terry Hie Hie in Jan 2013. Yields from the initial wheat crop were unfortunately not recorded but data is shown for the subsequent 2014/15 sorghum and 2015 chickpea crops. No starter P was used in the summer sorghum, while starter effects were not significant in chickpea, averages of with and without starter treatments are presented

Most other P sites have only a single year of crop data so far, and results from these sites have been mixed. For example, a site at Garah (Barley in 2015) showed no yield response to either starter P or a range in rates of additional P applied either shallow (5cm) or deep (20cm), despite some obvious biomass differences at anthesis. However the P status of that site was such that starter P responses would not have been expected (Colwell P in the 0-10cm layer was 42 mg/kg) and the P status of the 10-30cm was in the grey area where responses are uncertain (i.e. Colwell P was 6 mg/kg and BSES P was 61 mg/kg). Analysis of biomass to determine crop P uptake has not yet been completed.

The sites in the Central West were contrasting soil types to most other locations (a red Chromosol at Nyngan and a brown Chromosol at Gilgandra) and had deep (20cm) or shallow (5cm) P bands applied just prior to planting. Luckily, post sowing rainfall allowed reasonable establishment at both sites, however the late deep tillage did have some negative impacts at both sites. This was most evident at Nyngan, where treatments without deep tillage recorded 16% better crop establishment and produced 17% more biomass and 18% more yield, regardless of P rate. The negative impacts of late deep tillage were not as evident in crop establishment at Gilgandra, but shallow tilled treatments still produced >10% more grain than deep tilled treatments, irrespective of P rate – possibly due to impacts on profile moisture reserves. The inclusion of an untilled ‘Farmer Reference’ treatment would have allowed a better estimate of the negative impacts of tillage on crop yield potential in this initial season, but the disturbance effects on starting soil moisture should not feature in subsequent seasons.

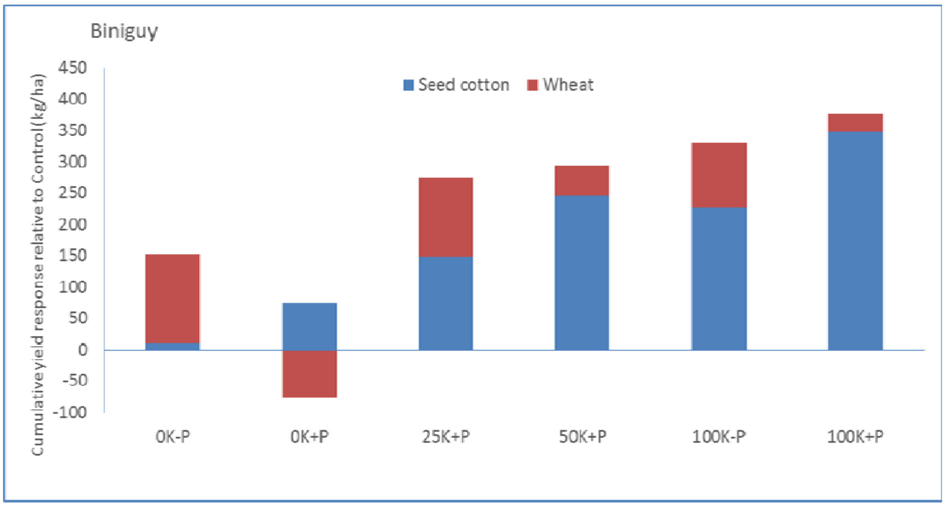
Yields of the Control treatment (starter P with no additional P application) were higher at Gilgandra (3850 kg/ha) than Nyngan (2450), and these higher yield potentials coincided with a greater P demand and more consistent response to additional P application. Both sites showed similar yield losses without starter P application (~600 kg/ha, or 16% to 25% of the Control yields for Gilgandra and Nyngan, respectively), with this reliance on starter P reducing as P rates (shallow or deep) increased. However in the presence of starter P it was only at the higher yielding Gilgandra site that additional P applications produced consistent yield increases, with a maximum of 10% (~400 kg/ha) extra grain produced from the 80 kg/ha P applied. The residual benefits of these additional P applications at different placement depths will be followed in subsequent crops – without the confounding effects of the soil disturbance from the deep P placement.



Gilgandra				
	Colwell P	BSES P	Exch K	ECEC
0-10cm	21	61	1.01	8.4
10-30cm	7	16	0.58	8.4
Nyngan				
	Colwell P	BSES P	Exch K	ECEC
0-10cm	19	50	1.47	6.9
10-30cm	5	12	0.9	7.2

Figure 9. Grain yields from 2015 wheat crops at Nyngan and Gilgandra in response to both starter P and additional P at various rates placed either shallow (5cm) or deep (20cm). Data are shown for the average of the 2 application depths

There has been limited exploration of K responsive sites in NSW at this stage, with the exception of another site on the NW slopes near Biniguy where K responses were followed in successive dryland cotton and wheat crops. There were significant responses in seed cotton yield in an extremely dry year in 2013/14, where the reference yields were only 460 kg/ha of seed cotton (fractionally more than 1 bale/ha). Application of 50 or 100 kg K/ha increased yields by >50%, and there was a suggestion of an additive effect of deep P with K. However there was no evidence of any effects of P or K in the following 2015 wheat crop, where the Reference yields were 4050 kg/ha. The relative importance of subsoil K supplies in the very dry (2013/14 summer) compared to the quite favourable (2015) season would have been marked, in addition to the reported higher critical soil K requirements in cotton than cereal grains. This site also had higher exchangeable K than the Chelmsford site (Fig 7) where significant K responses were recorded in both wheat and sorghum, with the largest differences in the 0-10cm layer, which would have been relatively accessible in the wet 2015 season.



	Col P	BSES P	Exch K	ECEC
0-10cm	15	50.5	0.37	23.4
10-30cm	3.5	10.5	0.19	27.2
30-60cm	<2	6.5	0.20	29.4

Figure 10. Seed cotton (2013/14) and wheat (2015) yield responses to banded applications of K, in the presence or absence of deep P bands, in a site at Biniguy. Data is presented as the yield response relative to the Farmer Reference treatment (no disturbance or deep nutrient placement)

Results from other 2015 winter sites on the NW plains confirm benefits of starter application, but under some excellent growing conditions have not shown any additional yield response to deep placed P.

General discussion

Current deep placement research is demonstrating mixed outcomes, from consistently good responses in some districts e.g. Central Queensland, to more mixed results in southern Queensland and Northern New South Wales. Part of this divergence in responses is related to the widespread low P and K at most sites in Central Queensland, compared to the more variable but generally slightly higher background fertility in other regions. However other factors affecting the utilization of deep fertilizer bands are also at play. We clearly require a better understanding of how plant roots acquire P (and K) from bands in drier environments (where lower soil moisture contents restrict diffusive supply), as well as how improved nutrient supply interacts with crop physiological processes determining harvestable yields under a range of seasonal growing conditions. This information will allow a clearer understanding of where deep placement will produce the most reliable yield responses.

Where evaluated, responses to starter fertiliser are demonstrable in most of our research sites where Colwell P in the top 10cm is low. Growers are encouraged to continue using starter P fertilisers at rates appropriate for the crop row spacing and soil moisture conditions at sowing. Applying small amounts of P in the seed row at sowing is offering excellent utilisation of the nutrient by the emerging crop.

Yield increases with deep P application are predicated on a crops' ability to access and utilise the nutrient in the band, and the structure of different crop root systems is clearly important in this regard. Winter and summer grass crops with fibrous root systems appear to make better use of the bands currently applied on 50 cm row distances, with more consistent increases in dry matter, grain yield and P uptake being measured at responsive sites. The more coarsely rooted chickpea crop has not been able to consistently demonstrate the same ability to utilise nutrient applied on this row spacing – although when responses are recorded they can provide good financial returns. The limited ability of chickpeas to proliferate roots in and around a P band shown by Guppy et al. (GRDC

Updates 2014) is likely to be contributing to this, so proximity of crop rows and fertilizer bands may be more important in chickpeas than the grain crops. Further work is required to confirm this.

Soil testing for K is proving a reasonable indictor of soil supply, but we do not as yet have reliable links between soil K test results and likely yield responses. However reasonable individual and cumulative yield increases in response to applications of K at rates of 50 or 100 kg K/ha at depth, generally in combination with a P source, are being measured on some low soil test K sites.

References

Dalal RC, Probert ME (1997). Soil nutrient depletion. In 'Sustainable crop production in the subtropics: an Australian perspective'. (Eds AL Clarke and PB Wylie). (Queensland Department of Primary Industries: Brisbane, QLD.)

Bell MJ, Moody PW, Klepper K, Lawrence DN (2010). The challenge to sustainability of broadacre grain cropping systems on clay soils in northern Australia. In 'Proceedings of the 19th World Congress of Soil Science; Soil Solutions for a Changing World. '(Eds. RJ Gilkes and N Prakongkep) pp. 302-305. (IUSS: Brisbane, Australia)

Bell MJ, Lester DW (2012). Multiple nutrient deficiencies in northern grains cropping – latest results and management responses for system profitability. In 'Grains Research Updates.' (GRDC: Goondiwindi)

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Day degrees – accessing and using day degrees in field crops as a tool to assist crop management

Jeremy Whish, CSIRO Agriculture

Key words

Crop development, day degrees, thermal time, crop growth stages, modelling

GRDC code

CSP00187

Take home message

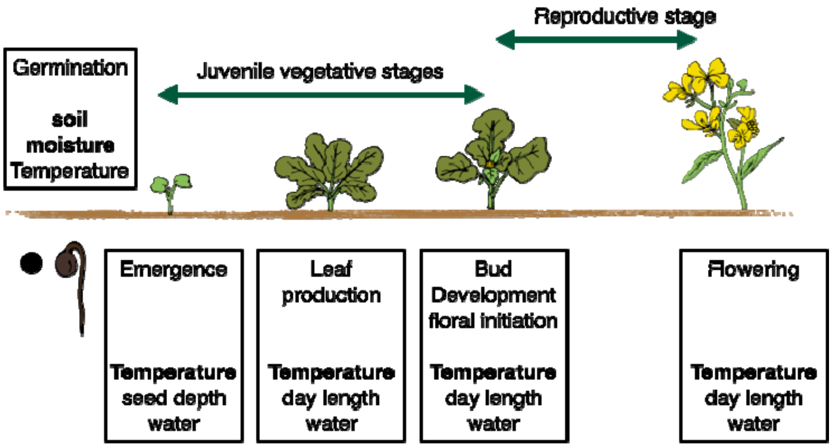
- Day degrees are a “temperature clock” that are a valuable tool in crop management.
- Crops that are only temperature responsive are easier to work with.
- Crop growth can be described by accumulating day degrees to a know target.
- Day length can modify the day degree targets in some crop varieties
- Tools such as Yield Prophet® are a simple way to get accurate day degree information.

Background

Plant physiology and the stages of plant growth

Plants don’t work by calendar days – but by “day degrees”. Simply described, this means that if the average temperature in a day is 20^{o}C then a plant accumulates 20 day degrees in one calendar day. On a course scale this temperature clock is how trees know to drop their leaves in winter and why herbs bolt to seed in spring. Day degrees are a way of measuring the physiological development of a plant. All plants receive signals from the environment that influence their rate of development. When studying the physiology of plants, distinct stages of growth have been identified and these have been formalised into keys that are often used in both plant physiology and agronomy (Figure 1). The description of crop growth stages is called the phenology of the plant.

The most well know key is the Zadocks key for wheat. Similar keys exist for canola, cotton and the pulses and describe each plant development stage. The most common and easily recognised stages are emergence, flowering, grain fill and maturity. Temperature, day length and available water are the key environmental triggers that influence plant development (Figure 1). This paper will not describe the chemical reactions that occur within the plant as a result of changes to temperature and day length. However, as these reactions occur, different hormones are released to trigger the plant to progress through its developmental stages.



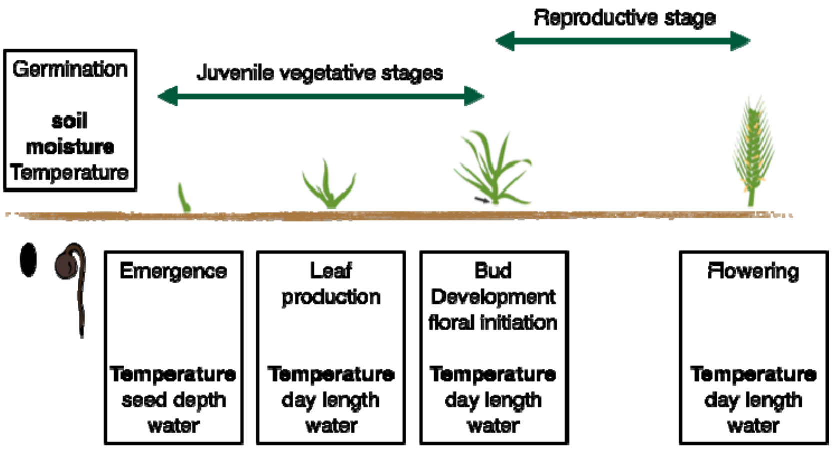


Figure 1. Growth stages for monocot and dicot crops, highlighting the different growth stages and the dominant environmental signels that influence growth in that stage.

What are day degrees and thermal time targets?

Day degrees (also known as thermal time) is a way of combining time and temperature into a single number. In its simplest form it is the average temperature recorded during a day (Figure 2). To calculate the thermal time for a plant's development stage you accumulate the day degrees until a specific target is reached, e.g. variety X accumulates 500 degree days between emergence and flowering.

Simple degree day calculation

$$\frac{\text{Max daily temperature} + \text{Min daily temperature}}{2}$$

date	maxt	mint	dd	cumulative
17/05/2013	19.6	6.3	16.1	16
18/05/2013	18.6	2.7	12	28
19/05/2013	18.2	4.6	13.7	41.7
20/05/2013	18.6	3.2	12.5	54.2
21/05/2013	18.2	3.9	13	67.2
22/05/2013	12.3	10.9	17.05	84.25

Figure 2. Calculation for simple day degrees (average daily temperature) and how the day degrees can be accumulated over time to calculate a thermal time target to move from one plant growth stage to another.

This example is the simplest form and assumes that the plant has a base temperature of 0°C, and that no growth occurs below this temperature. This is generally the case for winter crops. Summer crops like cotton and maize have not developed to grow at cold temperature. Therefore, they have a base temperature well above 0. Cotton for example, has a base temperature of 12°C so when the average temperature is below 12 no growth occurs. The use of a base temperature increases the complexity of our simple day degree calculation to:

$$DD = \frac{(\text{Max Temp} - \text{base}) + (\text{Min Temp} - \text{base})}{2}$$

Figure 3. A simple day degree calculation using a base temperature.

Another way of thinking about this is as a switch when you are above the base temperature in this case 12 you can accumulate Day degrees (Figure 4). This diagram also shows a maximum, that is a temperature when day degrees won't be accumulated because it is too hot and the plant stops growing. In Figure 4, the maximum is 36 degrees.

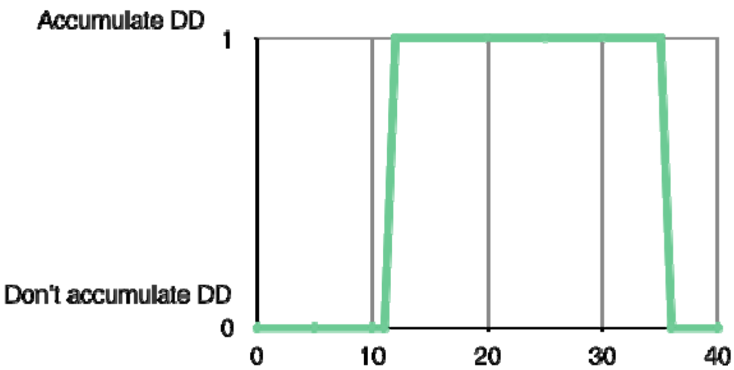


Figure 4. A representation of the cardinal temperatures (temperatures describing the upper and lower limits for plant growth) for growth of a plant that will accumulate day degrees when the temperature is above 12°C and below 36°C.

The inclusion of the maximum temperature has moved our simple average daily temperature calculation into a more complex calculation. We now have cardinal temperatures for plant growth - when we are inside these temperatures (between 12°C and 36°C for the example above) day degrees are accumulated and plant growth occurs. At this point calculating day degrees becomes more than a simple calculation and computers are needed. Crop models like APSIM use day degrees in this way to calculate the growth stages of plants. To improve the accuracy of the calculation and because computers are good at doing lots of calculations very quickly more information is included. We know that temperatures fluctuate during the day so different lengths of time will be spent within the cardinal temperature range so the day is divided into segments, APSIM uses 8, but some models that run on hourly temperature data use 24.

Why would we want to know this?

Understanding how the environment affects the growth of a plant can assist in crop management. Many management decisions are time critical, that is, for optimum results the intervention (spray application, defoliation, cease grazing or fertilisation) needs to occur before a plant reaches a particular growth stage. Identifying these stages can be difficult, for example, floral initiation can occur well before any visible sign appears in the plant. If the crops are grazed, or stressed during this floral initiation period by frost or high temperatures then a yield penalty can occur. Knowing what stage a plant is at can often help prevent yield loss or ensure untimely management does not occur.

In many environments it is important that a crop flowers within a particular window to avoid frost on one hand, and high temperature heat stress on the other hand. If you farm in a region that generally has sowing rain within a particular month you can match your varieties' maturity to ensure you flower inside the optimum window every year. However, a sowing rain in many areas is unpredictable and may occur too early or too late. An understanding of phenology for different varieties allows for specific variety selection to ensure flowering occurs at the optimum time, and the risk of crop loss is reduced. An example of this was presented by Richards et al. 2014 and has been reproduced here with its original caption to highlight the value of understanding the mechanisms of plant development.

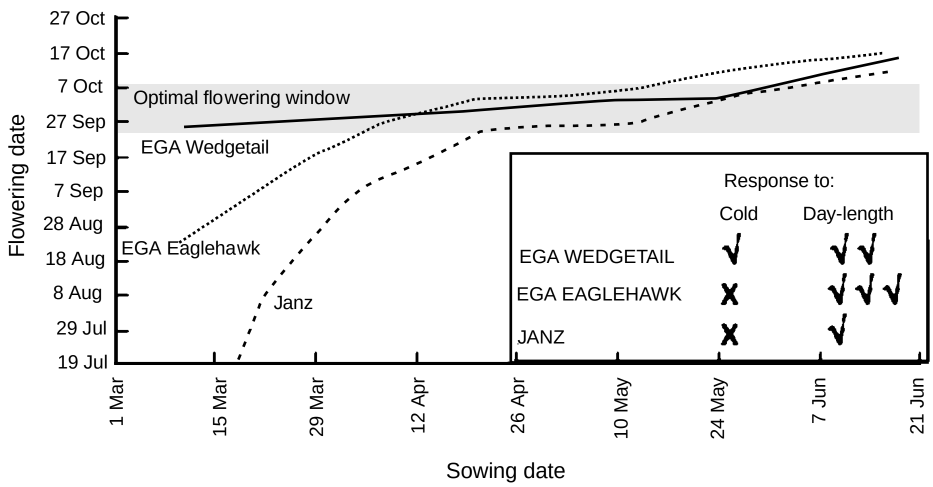


Fig. 9. Flowering date of three wheat cultivars from sowings between March and June at Wagga Wagga in 2006. EGA Wedgetail (—) is a winter wheat with a moderate photoperiod requirement, EGA Eaglehawk (. . .) is a spring wheat with a strong photoperiod requirement and Janz (- - -) is a spring wheat with a minor photoperiod requirement (adapted from GRDC 2011).

Figure 5. Flowering date of three wheat cultivars from sowings between March and June at Wagga Wagga in 2006. Reproduced from Richards et al. 2014

What crops are day degrees commonly used in?

Day Degrees are used for many specialty crops particularly in horticulture. In broad-acre cropping they are most commonly used for the management of cotton crops and Day Degree calculators are available (COTTASSIST) for growers to monitor their crops and be aware of issues, cold shock and heat shock, that can affect the crop development.

Why are they not commonly used in all crops?

Cotton is predominantly temperature sensitive, that is, its growth and development can be described using only day degrees. However, many winter crops are more complex and have additional factors that influence their development.

Phototropism is the effect of day length. As the days lengthen, the crop requires fewer day degrees to move between growth stages like flowering. For example, if we think about a canola crop with no day length sensitivity, it would not matter when you planted it. If you planted it in April it would take the same number of day degrees to flower as if you planted it in June (Figure 6). However, if the plant was sensitive to day length then as the days became longer the plant's thermal target would be reduced requiring fewer day degrees to be accumulated and reducing the time to flowering. This complicates growth calculations because day length is not only seasonal, it is also dependent on your position on the earth surface. For example, in winter, Narrabri has a minimum day length of about 11 hours while Melbourne has about 10.5 hours. If you grew a day length sensitive crop somewhere near Melbourne that had exactly the same growth temperatures as Narrabri, it would flower earlier in Narrabri due to day length effects.

This is why recommending a time to flowering for a variety in calendar days after sowing is meaningless, unless the date of sowing and location are presented. The data presented in Table 1 show this with a real canola variety grown at Gatton in 2015. There were 5 different sowing dates and at the final sowing date, a sixth treatment was included that increased the day length to 16 hours with the use of lights. The increase in day length significantly shortened the time to flowering.

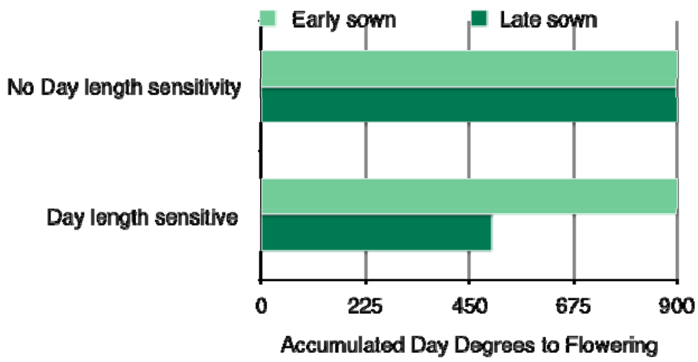


Figure 6. How daylength can reduce the flowering thermal time target, that is, the number of accumulated degree days required to reach flowering.

Table 1. Observed phenological date recroded from a canola cultivar in Gatton Qld. As the day length increased the thermal time required to reach flowering reduced.

Sowing Date	Flowering Date	Thermal Time to flowering	Day length at Flowering
7-4-2015	7-8-2015	2304	11
21-4-2015	28-8-2015	2118	12
20-5-2015	4-9-2015	1812	12
25-5-2015	11-9-2015	1812	12
2-7-2015	30-9-2015	1423	13
2-7-2015 Lights	24-9-2015	1543	16

To complicate things further, different varieties within a crop type will have different degrees of day length sensitivity. Some will be minor and the variety is basically temperature sensitive, others are like the data presented above and very sensitive to day length. The inclusion of day length sensitivity has complicated the prediction of growth stages from the simple day degree calculation. However, a third plant sensitivity can occur in some winter crops and specific varieties.

Vernalisation

Vernalisation is the need for a plant to accumulate cold days before the day degree calculation can begin. In APSIM we treat vernalisation in a similar way to day degrees, but instead of accumulating temperatures above a threshold we accumulate temperatures below a threshold.

One way of thinking about this is that once a plant has emerged it is vegetative and grows leaves and if there is no vernalisation requirement, the vegetative stage immediately transfers to the juvenile stage and starts accumulating day degrees until it reaches its flowering thermal target. If the vernalisation requirement is not achieved the plant remains vegetative and continues to produce leaves. Winter type crops are the best example of this, especially when planted in warmer areas like Queensland. In these environments they don't satisfy their vernal requirement or take time for the vernal requirement to be achieved. Once it is achieved they break out of the vegetative stage and then progress through the juvenile stage until their flowering thermal target is achieved. This delay can cause them to flower late when heat stress is an issue.

Winter wheats and winter canola are extreme examples of this, but many spring wheats and canola varieties have some vernalisation requirement. Varieties grown in Victoria can be short season, but when moved to Queensland become long season as vernalisation is not satisfied. It is not uncommon for varying degrees of vernalisation, thermal time and day length sensitivity to occur within different varieties of a crop so every variety is different and needs to be measured.

The complexity of winter crops is one of the reasons that the use of day degree calculations is not standard practice. However, the development of crop simulation models has shown that we can understand the complexity, and predict it. The use of tools such as Yield Prophet® provides a platform to accurately assess crop phenology (the measurement of plant growth incorporating vernalisation, degree days and day length) and allow specific growth stage management to be improved. However, many management decisions do not require the degree of accuracy available when using a cropping systems model. The simple day degree calculation presented in figure 1 will provide some insight as to why a crop planted at the same time as last year flowered earlier this year. A rule of thumb for wheat varieties like Gregory grown in Coonabarabran is that it will take between 1400 and 1500 degree days to flower from a May sowing. A long term climate file is all that is required to calculate day degrees. These can be purchased from the BOM web site.

Future work

There are a number of projects that are currently being funded by GRDC to improve our understanding of plant phenology and the components to describe them. Systems are being set up to accurately assess new varieties and genetic approaches are being examined to describe a variety by its DNA. Over time this information combined with tools such as Yield Prophet® will enable the type of specific management seen within the cotton industry to be practiced in grains.

Reference

Richards, R.A., Hunt, J.R., Kirkegaard, J.A., 2014. Yield improvement and adaptation of wheat to water-limited environments in Australia—a case study. Crop Pasture Sci. 65, 676-689 doi:10.1071/CP13426

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Reviewed by John Kirkegaard

Managing dual-purpose crops to optimise profit from grazing and grain yield

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Key words

Lock-up times, whole-farm profit, mixed farming, canola, wheat, feed gaps

GRDC codes

CSP00160, CSP00132

Take home message

- A range of winter and spring cereal and canola varieties can be used for dual-purpose. Early sowing with a suitable maturity type for the site and sowing date will maximise forage and yield potential.
- The higher profits on offer rely on attention to detail with both crop and livestock management - other benefits include management flexibility and risk management.
- Timing of lock-up is the critical grazing management decision.
- Lock-up times based on growth stage AND on residual biomass will maximise overall profit and reduce risk.
- A new tool to examine the economics of lock-up decisions has been developed and tested.

Introduction

Dual-purpose crops hold great potential to utilise early-season sowing opportunities to provide extra grazing for livestock and maintain grain yield. With good management, the period of grazing can increase net crop returns by up to $600/ha (i.e. 2000 sheep grazing days at 28c/day) and have a range of system benefits including widening sowing windows, reducing crop height, filling critical feed gaps and spelling pastures. Over ten years of experiments, simulation studies and collaborative on-farm validation across Australia has demonstrated that a wide range of cereal and canola varieties can be successfully grazed and recover to produce combined livestock and crop gross margins that exceed grain-only crops, and increase whole-farm profitability (Table 1).

Table 1. Typical examples of forage, grain yield and gross margins achieved from well-managed dual-purpose crops by collaborating growers in southern NSW

Crop type	Grazing achieved (DSE.days/ha)	Grain yield (t/ha)	Paddock $GM increase above grain only
Winter wheat	1600 - 2700	4.5 – 6.5	+$600 - $1000
Spring wheat	400 - 800	3.0 - 5.0	+$300 - $500
Winter canola	750 - 2500	2.0 – 4.0	+$600 - $1000
Spring canola	300 - 700	1.5 – 2.5	+$300 - $500

Here we provide brief explanations of how grazed crops are able to recover, some best-bet tips on increasing the success and profitability with dual-purpose crops, and give some case studies of what we have achieved experimentally and with collaborating growers.

How can I graze crops and still get the same yield?

The yield potential of any grain crop is related to the biomass at anthesis to support grain-filling.

The yield achieved then depends on conditions during flowering and grain fill to realise the potential.

In Australia, because crops grow the biomass from autumn to early spring, but flower and fill grain as things are getting hot and dry, they almost always grow more biomass than will be needed for the grain yield that can be achieved. A rule of thumb is that each 1 t/ha of wheat grain yield needs 1.8 t/ha of biomass at flowering (i.e. 3 t/ha crop needs 5.4 t/ha of biomass at flowering etc.). Well-managed, early-sown crops in medium and high rainfall areas often produce significantly more biomass at flowering than is needed for the likely grain yield. This explains why we can use some of this excess biomass with careful and timely grazing, and still achieve the target yield.

The "safe" grazing period for cereal and canola crops is from the time the crop is well anchored, until the reproductive parts start to elongate above the ground and can be damaged or removed by the livestock (DC30 for cereals and bud elongation for canola). Any crop can be grazed in this window and grazing will usually delay flowering from a few days to 2 weeks depending on grazing duration.

Early-sown, slower-maturing crops have the longest vegetative period and provide the most grazing potential, but typical grain-only spring crop varieties can also be sown early, and provide useful grazing without significant yield loss following the same principles – but the potential grazing is much reduced (Figure 1), and closer management of lock-up timing is required. ****Each week delay in sowing wheat after early March reduces grazing potential by 200-250 DSE days/ha and yield by 0.45 t/ha.**

Though different strategies and crop types are better suited to different regions due to the rainfall and season length, a mix of the different approaches shown in Figure 1 can be used on the same farm to take advantage of early sowing opportunities in specific seasons to increase and widen the overall operational and crop grazing window.

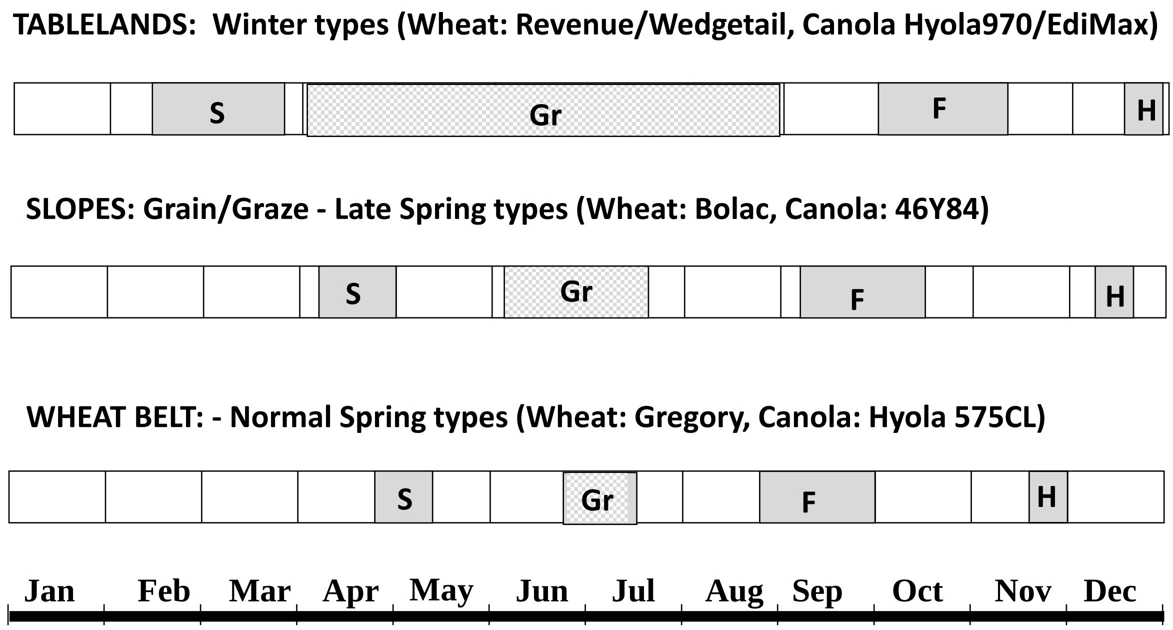


Figure 1. Increased grazing window of early-sown, longer-season winter varieties in longer-season Tablelands areas compared to spring types in the cropping zones. (Typical windows shown are S=Sow, Gr=graze, F=flowering, H=harvest).
(Varieties Revenue⦶, Wedgetail⦶, Bolac⦶ and Gregory⦶ are protected under Plant Breeders Rights Act 1994)
(® Hyola is a registered trademark)

Crop recovery - safe lock-up and grazing rules

The ultimate goal for managing dual-purpose crops is to maximise the profit from the combined income from the grazed forage and the grain. This requires an understanding of how grain yield is affected by heavier or delayed grazing.

Our studies have demonstrated that the time of lock-up and the residual biomass are the critical issues. We can define the overall grazing window into **"safe"**, **"sensitive"** and **"unsafe"** periods related to the impact on grain yield (Figure 2). The early and **"safe"** grazing period is once the crop is well anchored and there is still plenty of time for recovery after a period of grazing, even if the crop is grazed quite heavily. The late and **"unsafe"** period is when the reproductive parts of the crop (spikes in wheat, or buds in canola) are elongating above the ground, and can be removed by stock, and there is also too little time for the crop to recover enough biomass by anthesis to set a reasonable yield potential. Most growers can easily identify these two periods by testing crop anchorage to start grazing, and checking crop development stage to stop grazing. The **"sensitive"** period is the period in which the crop has not yet begun to elongate, but where yield recovery can be very sensitive to the amount of residual biomass left. This is the period where some idea of how much residual biomass is needed to reach a specified target grain yield can assist growers with lock-up decisions to avoid yield loss while maximising grazing potential.

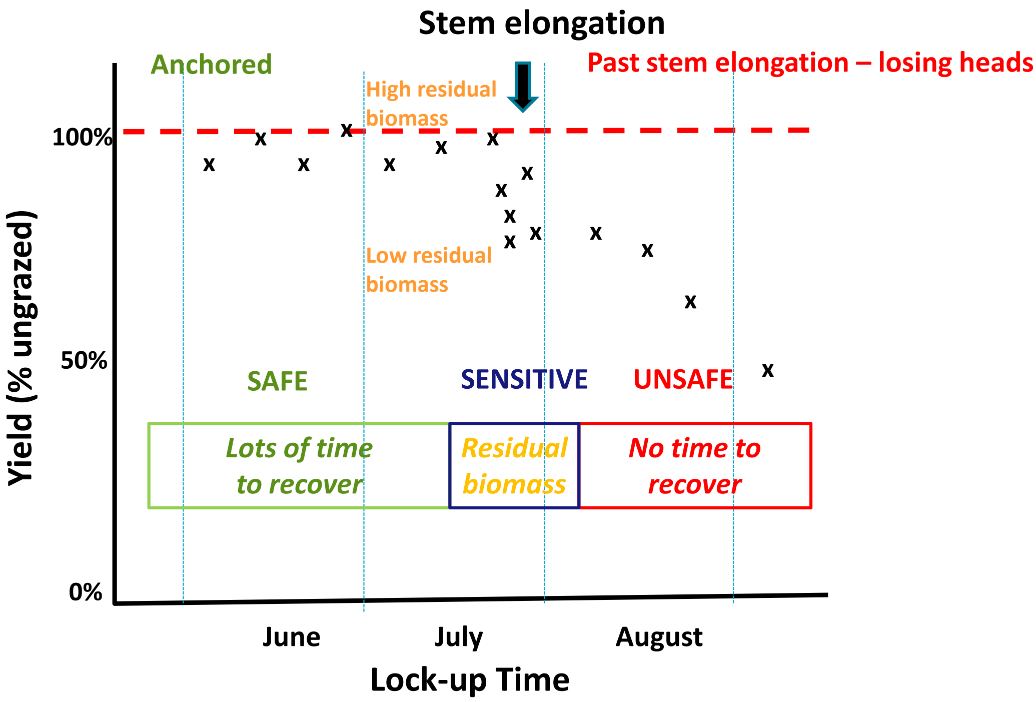


Figure 2. Yield recovery (% of un-grazed crop) of grazed dual-purpose crops highlighting the safe, sensitive and unsafe periods of grazing. Yield recovery from grazing during the sensitive period for a given target yield is affected by the residual biomass at lock-up. Late grazing reduces the time for recovery, so more residual biomass is needed.

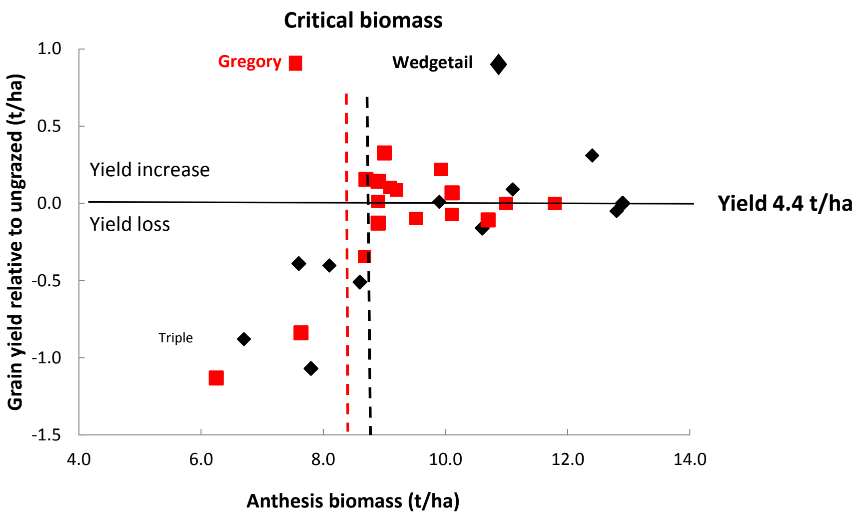
At our main experimental site near Greenethorpe, we have been using experiments with different times and intensity of grazing to investigate the relationship between:

Residual Biomass (lock-up) ⇔ Critical Biomass (anthesis) ⇔ Target Yield

We have used a range of different winter and spring wheat and canola crops in the studies.

An example is that a typical grazing EGA Wedgetail⑴ wheat crop sown on 25 March with a target yield of 4.5 t/ha would require a critical anthesis biomass of around 8 to 9 t/ha (Figure 3A). This critical biomass would require at least 0.5 t/ha of residual biomass to be left in late July (Figure 3B), when the crop becomes unsafe to graze without removing elongating heads (i.e. heads removed if past Z30). Grazing past this point would require close attention to grazing height to ensure heads were not being removed, and more residual biomass (1.0 -1.5 t/ha) would be needed to be left at lock-up in mid-August to still achieve the same critical anthesis biomass, because there is less time left to reach the biomass for the target yield. Note that the spring wheat EGA Gregory⑴ sown on 8 May generally had similar critical and residual biomass levels to attain similar yields.

a)



b)

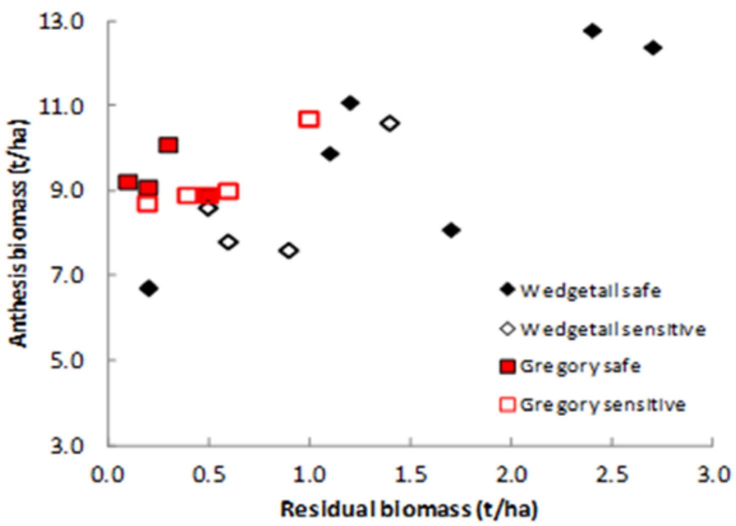


Figure 3. (a) shows that for a 4.4 t/ha target yield in wheat, around 8.0 to 9.0 t/ha was required at anthesis, and treatments with less than this had reduced yield. (b) shows that residual biomass after grazing of >0.5 t/had in late July was sufficient to reach the critical anthesis biomass for 4.4 t/ha yield.

For canola the residual biomass requirement left after grazing is higher than wheat, due to the inherently heavy and thick stem bases and slower regrowth after grazing. Spring canola requires about 1.5 t/ha of residual biomass left when locked up at the end of July (when the stems begin to elongate) to ensure 2.5 to 3.0 t/ha yield potential. Earlier-sown winter canola has even thicker stem bases, and requires around 2.5 t/ha of residual biomass for recovery.

Trade-offs and economics

Ultimately economics (feed value *vs* grain value) in the farm enterprise dictates the acceptable level of grain yield loss (if any) for dual-purpose crops. In many cases, especially where the feed is being used to fatten or finish lambs or cattle, it is possible that accepting a grain yield penalty makes the most economic sense, as shown for the moderately grazed crop shaded in Table 2.

Table 2. Amount of grazing achieved and grain yield from different grazing treatments in a EGA Wedgetail⒫ crop at Greenethorpe in 2013. Income was highest with a small grain yield penalty as the extra grazing was more profitable than yield lost.

Lock-up time	Grazing intensity	Sheep grazing d/ha	Grain Yield	Paddock $GM increase above Un-grazed
Un-grazed	None	0	4.35	0
DC30 (safe)	Hard	1730	4.36	$653
DC32 (sensitive)	Moderate	2530	3.96	$853
DC32 (sensitive)	Hard	2730	3.28	$758

(Economics calculated at $250/t grain and grazing at $0.38/sheep grazing day (i.e. $1.7/kg LW for a sheep growing at 225g/day and eating 1.5 kg biomass/day)

Spring wheats such as EGA Gregory⒫ can also be grazed with success, but due to the later optimum sowing dates and smaller safe grazing window (Figure 1), the amount of grazing achieved is much less (Table 3). The effect of grazing too late and/or leaving too little residual biomass (<0.5 t/ha) can be seen to impact on the economic outcome. In this case with spring wheat, yield was only maintained with later grazing if a large amount of residual remained, and this did not match the economics of grazing hard earlier to provide time for recovery. In general a much greater level of attention is needed to manage the timing of lock-up in spring crops as development is rapid and the plants less robust. But grazed spring wheat and canola crops can widen the crop-grazing window at the farm-scale.

Table 3. Amount of grazing achieved, grain yield and additional income from different grazing treatments in a EGA Gregory⒫ wheat crop at Greenethorpe in 2014. The best outcome was to graze safely with economic penalties for later or harder grazing.

Lock-up time	Grazing intensity (and residual t/ha)	Sheep grazing d/ha	Grain Yield	Paddock $GM increase above Un-grazed
Un-grazed	None	0	4.78	0
DC30 (safe)	Hard (0.5)	1070	4.68	$382
DC32 (sensitive)	Moderate (1.5)	800	4.85	$321
DC32 (sensitive)	Hard (0.6)	1390	3.94	$316
DC32 (unsafe)	Hard (0.4)	1520	3.65	$291

In a review of 134 different grazing wheat experiments we found <10% returned less than grain only, the median increase in net returns from grazing was 25% and in one third of cases, net returns increased by 75% or more. In the 87 canola grazing experiments returns were somewhat less (median 17%) due to less grazing, and higher grain-value and so increased economic risks from yield reductions.

New grazing tool to assist decision making at lock-up

To date, advice on grazing and lock-up management has mostly revolved around crop phenology rules, or calendar dates that come from trial and error over many years. The significant impacts on yield from the removal of reproductive parts by late-grazing are well known, so to maximise grain yield growers are advised to remove stock before DC30 for cereals and bud elongation in canola.

Our work has demonstrated that the risk of a yield "penalty" associated with grazing is likely to increase as the yield potential increases, because a 5 t/ha crop requires a higher level of biomass at anthesis than a 3 t/ha crop, and as a result either an earlier lock-up, or more residual biomass at lock-up is required to reach the higher target. As a result, decisions to continue grazing at the possible expense of grain yield are dependent on the level of yield that has been targeted (**Table 4**).

Table 4. Indicative biomass requirements on different lock-up dates to reach different yield targets in wheat. As the target yield increases from 3 to 5 t/ha, it is necessary to either lock-up earlier or leave more residual biomass to achieve the critical anthesis biomass required.

Target Grain yield (t/ha)	Critical anthesis biomass (t/ha on 1 October)	Residual lock-up biomass required (t/ha) on:			
		14 July	1 August	14 August	28 August
3.0 t/ha	5.4	<0.2	<0.2	<0.2	1.3
4.0 t/ha	7.2	<0.2	<0.2	1.2	3.5
5.0 t/ha	9.0	0.8	1.8	3.0	5.3

The capacity for re-growth to achieve different biomass targets varies with the soils and climate of different areas and will vary from season to season. Decisions about lock-up times and trade-offs between grazing and grain will be specific to seasonal prices and grazing enterprises. Our grazing tool is designed to allow the user to set the yield target, and investigate the consequences of different lock-up decisions based on relative prices achieved for grain and livestock.

Whole-farm flexibility and risk management

A well-chosen dual-purpose crop should flower in a suitable window – even if not grazed. This maximises yield potential for the crops whether they are grazed or not, and provides peace-of-mind if circumstances change making grazing impossible or unwise. Likewise, where seasonal conditions deteriorate and crop recovery after grazing is poor, the crops can be cut for hay, silage or grazed out as sacrifice crops. In this way, dual-purpose crops provide an excellent risk-management tool on mixed farms with several "exit points" as seasonal conditions, relative prices change.

On a typical 1500ha cropping program, the inclusions of around 500ha of dual-purpose crops might create an extra 2-3 DSE/ha of winter stocking that can be considered as available. Growers can utilise this as feed by increasing the stocking rate, or maintain livestock at the same farm level, but take the opportunity to winter-clean areas of pastures. Dual-purpose crops can also be introduced onto graze-only farms to assist in rejuvenating areas of perennial pastures, and to generate income to control difficult weeds, with an excellent opportunity to re-establish clean pastures after a period of cropping.

The opportunities are significant, but the crop and livestock management requirements to capitalise on dual-purpose crops are considerable. Successful early establishment, weed control and withholding requirements, stock planning, management and logistics are not trivial to optimise the whole-farm benefits of the extra winter forage.

A few tips for success with grazing crops

- **First time? Get good agronomic advice and plan well ahead.**
  - What is your livestock plan to make money from the extra winter feed?
- **Select a suitable paddock and be prepared to sow early**
  - Weed control, withholding periods, stubble management, stored water for early-sown crops
- **Sow early with the right crop and variety – several options available**
  - Winter wheats in March, long-season springs wheats in mid-April, spring wheat late-April
  - Winter canola types in March, spring hybrid types from mid-April
  - Select vigorous canola varieties (hybrids) with good blackleg resistance (>R-MB)
- **Protect early-sown crops from establishment pests and aphids that transmit virus**
  - Seed dressing are affordable and effective, but follow-up aphid sprays in warm autumns may be required if aphids persist due to Barley Yellow Dwarf virus.
- **Aim for a good plant population for good early biomass production for grazing**
  - 150 plants/m^2 for wheat; 40 plants/m^2 for canola
- **Ensure sufficient N up-front for good early biomass production**
  - 100-150 kg/N for winter wheats and canola; 50-100 kg/ha for spring wheats and canola
- **Don't graze too early as crops are building root mass and can be checked**
  - Twist and pull test – usually need at least 1.5 t/ha biomass (6-8 leaf stage in canola)
  - Recovery and winter growth of canola slower than cereals
  - Graze canola once for longer as animals take some time to adjust (at least 2 weeks grazing)
- **Animal health issues**
  - Take usual precautions for bloat and nitrate poisoning as usual for palatable feed
  - Don't fertilise with N close to grazing, apply upfront and post-grazing
  - ***Na/Mg supplements required for grazing wheat to maximise live-weight gain**
  - For canola take usual Brassica precautions, cattle are more sensitive than sheep
- **Grazing management**
  - Stocking rates around 1000 kg/ha live-weight work well, but adjust to feed on offer
  - Animals take time to adjust to feed and do best if grazed for longer – avoid frequent change
- **<u>Lock-up time is key!!</u>**
  - Remove stock before DC30 in wheat and bud elongation in canola
  - If grazing later, ensure grazing does not remove reproductive parts
- **Top-dress N after grazing to assist yield recovery**

- Assume wheat needs to see 40 kg N/ha for every 1 t/ha of yield and canola 80 kg N/ha - and adjust topdressing according to existing N and target yield.

Further reading

https://www.grdc.com.au/uploads/documents/GRDC_Dual-PurposeCrops.pdf

http://www.ausgrain.com.au/Back%20Issues/241mjgrn14/Match%20flowering.pdf

http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0011/272945/winter-crop-variety-sowing-guide-2015.pdf

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Dual purpose crops

Keith Harris

Key words

Dual purpose crops, grazing, profitability

Take home message

- Advantages of dual purpose crops are to minimise risks, capitalise on early rainfall events, flexibility in enterprise mix and improved cash-flow
- Dual purpose crops require a high standard of management
- Ideal grazing facilities would allow for an excellent water supply, shelter belts, rotational grazing and drafting cattle into similar weight ranges before being placed onto grazing crops. Try to minimise handling and ensure that all animal health issues are addressed.

Many farmers would be aware that I have been promoting the benefits of growing **'Dual Purpose Crops'** for several decades and in particular over the last 12 years; whilst managing the Romani Pastoral Company owned Northern properties; including Windy Station.

Windy Station a 20,000 Ha property located on the Liverpool Plains; which is better known as a major cropping property with very fertile cracking clay soils. Unfortunately these rich black Vertosol soils are the result of hundreds of years of extensive flooding, from the neighbouring hills and the Murrurundi Range located to South of the Property. It is not uncommon to see up to 2,000 Ha of some of Windy's most fertile country affected by flood-waters.

On my arrival at Windy an analysis of paddock cropping performance identified that the same paddocks consistently appeared in the bottom 20%, due mainly to flooding, waterlogging, poor drainage, planting issues, etc and therefore these paddocks were consequently re-allocated to forage crops or pastures.

Figure 1. Floods on Windy Station - at least 3 years in 5.

Figure 2. Windy Steers grazing 'Naparoo Wheat'

Windy management decided the best way to protect their topsoil from increased erosion was to slow the water flow through the property, particularly on the low lying flood prone areas; even if it required the re-establishment of improved pastures or favouring Winter Forage or Dual Purpose Crops.

Many farmers believe that by running livestock on these quality self-mulching black soils of the Liverpool Plains was only asking for trouble and that particularly cattle would cause irreversible damage through increased soil compaction.

Windy Management have found that most of our self-mulching black soils have the ability to self-repair after a normal wetting and drying period. These soils rapidly crack open when dried through lack of rain; which enables water infiltration next time it rain. Our experience suggests that there is only minor losses; **if any**, in subsequent crops after grazing and we believe the opportunity to grow dual purpose crops on these types of soils has not being fully utilised.

Soil compaction limits root development and slows water infiltration; which may potentially increase soil erosion; however several GRDC funded or partly funded projects have supported Windy's observations.

Windy Management decided that they needed to re-classify some of the cash-cropping areas in an attempt to reduce the risk of substantial crop failure; due to potentially untimely flooding. Over the years the flooding intensity had increased through Windy; particularly after many farmers on the neighbouring slopes had constructed soil conservation works; including new contour banks, drainage channels and waterways.

Benefits of growing dual purpose or winter forage crops

1) Minimise risks

- Floods close to grain harvest have caused or can cause severe damage to ripening crops
- Floods during the growing period of grazing crops can provide irrigation type benefits
- Floods in November / December on grazing crops not so critical as benefits already banked
- Minimise the risks associated with dry periods late Winter / Spring such as 2013 / 2014 / 2015

2) Capitalise on early rainfall events

- Grazing or Dual Purpose Crops can be planted late February (Oats) & late March (Wheat)
- thus capitalising on late Summer rainfall events. **Also spread workloads!**
- Early sown crops will provide quality feed from mid-May most seasons

3) Flexibility in Enterprise Mix.

- Not reliant totally on grain prices / export markets / grain quality issues / downgrading weather damage; etc.
- Buying & selling trading cattle - Budget profit from weight gains
- Opportunity to back-ground cattle for feedlots ?? Potential to lock in sale price at purchase!
- In most cases cattle prices at feedlots are higher when grain prices are down! Obviously grain is a major input cost for feedlots and therefore it has a major impact on feedlot margins.
- The decision to lock up dual purpose crops does not need to be made until late July. During a normal average season when late winter / early spring feed reserves (pastures) are looking good dual purpose crops can be locked up / top dressed / weed controlled if necessary / and kept for grain production. Unfortunately current northern area dual purpose varieties do not yield as well as the southern or central NSW 'EGA Wedgetail⑭' wheat variety.
- Obviously growers could also elect to continue to graze their crop; taking into account cattle & grain prices / stored soil moisture levels / seasonal outlook; etc.

4) Improved cash-flow

- **Dual purpose crops offer the benefit to generate early income** from the start of the grazing period. **Cattle often sold after 70 days grazing in late July** and after achieving a weight gain of between 90-120 kg /head (Budget 70 days x average 1.6kg/head/day - good crop).
- Remember you don't need to finish the cattle; best returns often obtained from backgrounding cattle for local feedlots, A good idea is to speak with feedlot before you buy the cattle or there maybe an opportunity to background cattle on their behalf; being paid for weight gain only!
- A well managed forage crop can provide sufficient early season feed for up to 5 weaners/ha. **Therefore early income potential paid August should realise well over $1,000/Ha.**
- No need to wait until December or January (6-8 months) to realise cash-flow
- Dual purpose crops grain recovery in northern areas should Budget 50% of ungrazed crops.

Dual purpose crops demand high standard management

We should stress that for a dual purpose crop to be as or more profitable than grain only crops in this prime Australian grain growing area the standard of management needs to be just as high for it as it is for grain only crops.

Whilst this sounds logical, detractors against the logic of high value dual purpose crops all too often compare results from far less, poorly prepared and poorly managed grazing crops.

Attention to soil fertility needs to be at least as good, especially with dual purpose crops being demanding of **high soil nitrogen if high production is to be achieved**. Weed control needs to be of a high standard and the dual purpose wheat crops place in the overall property rotation also needs to abide by the same rules as those which apply to grain only crops to reduce risk of disease, weed and nematode issues.

We believe that grazing winter forage crops on Windy Station in recent years has been one of the highest returning 'gross margins' and that the advantages of growing dual purpose winter cereals is highly underrated particularly in Northern NSW.

Windy Station has achieved average weight gains in weaner steers of between 1.2 kg/head/day up to a staggering 2.44 kg/head/day over grazing periods between 70 to 130 days plus on forage oats or wheat.

Obviously not all farm layouts are suitable for effectively growing forage or dual purpose crops; however where possible growers should re-consider this option around early planting dual purpose winter forage crops which can provide quality early winter feed and which can be locked up for grain recovery.

Ideal grazing facilities would allow for an excellent water supply, shelter belts, rotational grazing and drafting cattle into similar weight ranges before being placed onto grazing crops. Try to minimise handling and ensure that all animal health issues are addressed.

No doubt having an ideal environment for grazing cattle had the ability to lower stress within the animals and this is without doubt one of the prime considerations in maximising weight gains. A trial with a mineral supplement "Causmag" (magnesium cobalt) demonstrated a 20% weight gain over similar steers grazing wheat without "Causmag".

However cattle being grazed in our specifically established ideal grazing environment achieved an additional 20% without "Causmag" supplement. We believe the "Causmag" lowered stress levels in cattle; however by following protocols the ideal environment will achieve weight gains similar to that achieved in feedlots.

Table 1. Gross margin summary comparison between wheat only, grazing only and dual purpose crops.

Gross Margin Summaries:-		**Wheat Only**			**Dual Purpose**		**Grazing Only**	
Income - Wheat $280/t	5.0 t/Ha	$ 1,400.00		2.5 t/Ha	$700.00		nil	
- Grazing 70 days x 1.6 x $2.80/kg x 4 head					$ 1,254.40			
- Grazing 100 days x 1.6 x $2.80/kg x 4 head							1,792.00	
Total Income/Ha		**$ 1,400.00**	**/Ha**		**$ 1,954.40**	**/Ha**	**$ 1,792.00**	**/Ha**
Expenses								
Seed		$44.00			$44.00		$ 44.00	
Fertilizers & top dressing		$149.20			$209.20		$209.20	
Chemicals - Weed Control		$ 58.80			$ 58.80		$ 58.80	
Harvesting		$68.00			$ 58.00			
Freight to sale		$ 110.00			$ 55.00			
Workings - Spraying, Slashing, Planting, etc		$144.00			$160.00		$ 160.00	
Cattle ownership - interest, animal health, etc					$ 58.40		$ 83.43	
Total cost/Ha		**$ 574.00**	**/Ha**		**$ 643.40**	**/Ha**	**$ 555.43**	**/Ha**
Gross Margin		**$ 826.00**	**/Ha**		**$ 1,311.00**	**/Ha**	**$ 1,236.57**	**/Ha**

Should note that cattle prices have risen by 30% in last 12 months which make these figures very conservative.

Acknowledgements

Please note for additional information we suggest you read associated GRDC funded results on the GRDC website, including papers

- Grazing effects did not drive yield loss in black Vertosol Soils by Dr Chris Guppy et al.
- Feed mineral supplements when grazing cereals by Dr Lindsay Bell & Dr Hugh Dove

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Profitable dual purpose cereals in the north/central west
A Purlewaugh case study

Robert Freebairn, Agricultural consultant, Coonabarabran

Key words

Dual purpose winter crops. Timely sowing critical. High standard of agronomy fundamental for timely sowing high production and high profitability.

Take home message

Dual purpose crops can be a vital part of a mixed business farming operation. Reliable dual purpose crops require a high standard of agronomy including timely sowing, careful choice of variety, good sub soil moisture, and high soil fertility.

Role of dual purpose cereals on our property

Dual purpose winter crops, or grazing only ones, can regularly gross $1000 -$1500/ha with costs typically $300 - $350/ha. Plus they take a lot of pressure off the remaining grazing base (pastures) commonly giving them a chance to get away and be in an improved position to provide good feed when dual purpose crops are locked up for grain.

Dual purpose crops supply quality feed in good quantities when other pastures are growing at a slow rate, especially in years with dry autumns (five of the last six years).

For our property, 30 km east of Coonabarabran , 20 percent of the farm is sown to dual purpose crops each late summer early autumn, 30 percent is tropical grass based (aim for 50 percent) and 50 percent is improved native grass based. In both native and tropical grass pastures winter legumes are an important part of the pasture.

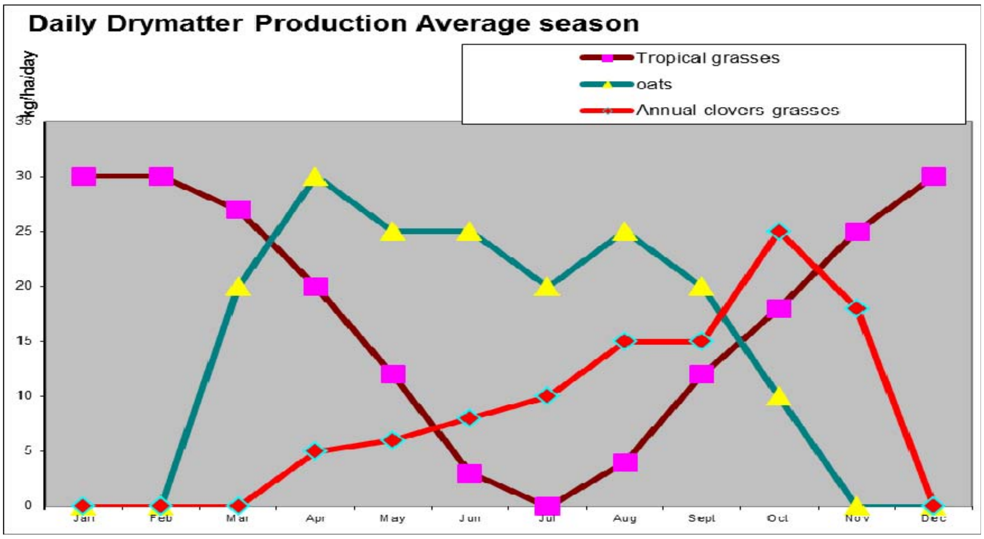

Figure 1. Daily drymatter production in an average season

Profitability

On a light acid soil farm in a 625mm rainfall area, projected GM for 2015/16 is $409/ha (based on 200 steers turn-off with margin gain of $800/beast). Stocking rate 7 DSE/ha.

Pasture fertiliser cost/ha for the pasture area is $40. Winter forage cropping cost (60/ha) $300 - $350/ha. Costs Include seed, DAP, Urea, sowing, seed, weed (including fallow) and insect control.

Winter forage crops can return over $1350/ha (100 -150 days grazing x 1.2 kg/beast/day x $3kg plus grain recovery in seasons with good springs, averaging 2.0 t/ha) and most years gross $1000/ha or better.

Other than dry-lick no supplementary feeding is practised. Drought strategy is stock down and quickly rebuilds when good conditions occur.

Sow early critical

Often the difference between early sowing and missing that opportunity is the difference between good winter feed and poor winter feed. Early sown crops onto subsoil moisture can generally survive for months if no follow up rain occurs and then provide almost instant feed when rain does eventually fall.

Being able to sow early and reliably (high probability of successful establishment) is critical for almost guaranteeing a high quality reliable winter feed supply.

For us that can mean sowing as early as 20th February, as we did in 2014, but in other years that will be too hot for a reliable establishment. To maximise the probability of sowing early sowing with minimal soil disturbance, press wheels and if available a lighter soil paddock all improve probability of early sowing success. Good sub soil moisture plus stubble cover also helps with reliable early establishment.

That's a challenge as late summer and autumn rains are so unreliable. Probabilities of achieving this outcome improve dramatically if one can realistically establish crops on a very minimal rainfall event.

One pitfall of sowing early is that summer weeds like annual summer grasses can also germinate with the crop. Where winter crops are being sown as part of a strategy to clean up paddocks for future pasture sowing, that can be a problem, especially after a drought as little opportunity occurs to control fallow weeds that can keep germinating until mid autumn.

Temperature and temperature forecast important

We use the guide that if mean daily temperature (average of maximum and minimum) is 23^{o}C or less and not likely to rise it is a reasonable bet to sow if soil moisture is ok (little hard data to support this claim). This is a better guide than choosing a date (such as early March for our area). Sometimes we sow as early as 20th February and in other years as late as mid-April.

Sowing rainfall probability. CliMate best guide

Being able to sow and achieve germination on a minimal rainfall event is critical. For example according to the App "CliMate" the odds of receiving 10mm or more within a three day period in our sowing window of late February to the end of April is 96 percent. "CliMate" can provide such estimates for most areas.

But if we needed 30mm for a successful establishment (heavy soil, little subsoil moisture) the odds of being able to sow in this slot drops to 61 percent. In other words we miss out on the chance of good winter feed from forage crops in more than one third of years.

Sub soil moisture important

Stored soil water is not only important for keeping crops growing during dry periods over autumn winter and spring but also maximises the probability of being able to establish them on time, a key consideration for reliable winter feed. If there is a good level of stored soil water at the required sowing time the probability of being able to sow on time increases dramatically.

Evidence from GRDC funded research notes that for every mm of stored soil moisture crop yields can increase by 15 -25 kg/ha. For grazing crops the gains are at least similar.

It is neither logical nor supported by research to sow crops directly into pastures without storing any soil moisture if reliable yields, grain or grazing, are aimed for. Even in lighter soils that can't conserve great amounts of water that extra 40 -100mm is commonly vital for early sowing as well as consistent good winter growth.

Direct drilling crops into active summer pastures, even poor ones where weeds generally replace pastures for water use, in addition to confronting little if any stored soil water, commonly face greater nitrogen deficiency. NSW DPI research notes differences of 40 kg/ha or more in available soil nitrogen where fallow weeds were not controlled in a timely manner.

Maximising stored soil moisture, as well as having moisture close to the surface as possible is dependent on efficient fallow capture and storage of rainfall. Early control of weeds over the fallow is critical, even if it means additional fallow sprays. It is not uncommon for example for us to spray our fallows five times over the fallow period.

Zero till and stubble retention part of the story

Reasonable levels of stubble cover (old pasture if coming from a pasture phase or crop residues in a cropping sequence) helps with fallow moisture capture as well as moisture storage closer to the surface. Zero till with stubble is generally more than helpful.

Narrow points and press wheels

Disc or narrow point plus press wheel seeders generally improves reliability of successful germination on a small rainfall event, while the ability to moisture seek with narrow points and press wheels greatly enhances the length of sowing window after larger rainfall events.

Variety choice critical

"Spring habit" winter cereal varieties (oats, wheat, barley triticale cereal rye) sown in February or March commonly came to head in May, June or July, with time dependent on sowing time variety and environment. These crops commonly recovered slowly and often poorly after grazing.

In contrast varieties with "winter habit" recovered far better after grazing, are less likely to be adversely affected by frost and retain high quality longer.

"Winter habit" is a characteristic where the growing point remains at ground level until a sufficient amount of cold weather triggers plants to change to "spring habit", which means the head begins rising up the stem. Spring habit varieties have no such delay with heads growing up the stem as soon as tillering occurs.

When animals graze below the growing point, which can be quite early for spring habit types, the tiller dies and new tillers need to reform. Reforming of tillers can be slow, especially in the middle of winter and if soil water supply is low.

Varieties vary in their levels of "winter habit". This means varieties with only low "winter habit" level will transfer to "spring habit" with heads growing up the stem after a shorter period of cold winter weather than varieties with high levels of "winter habit". High levels of "winter habit" means heads remain at ground level for a much longer period in a given environment.

Desirable "winter habit" level is largely relates to climate and purpose. For example if the purpose is mainly for early sowing and for long grazing time over winter and spring a variety with a high level of "winter habit" may suit best.

A dual purpose role is more likely to best suit a variety with moderate to lower levels of "winter habit". This allows early sowing with no running to head too early, nor loss of tillers, and a period of 30 to 100 days grazing prior to locking up for grain recovery. Desirable length of grazing is variable and is not only related to variety type but sowing time (more if early) and seasonal conditions.

Climate also has a big role in choosing how much “winter habit” a variety should have. Colder areas have “winter habit” satisfied faster, therefore varieties with greater “winter habit” are needed. In contrast in warmer environments varieties with less “winter habit” are needed, unless used only for grazing.

Varieties with “winter habit” tend to grow slower at first than “spring habit” types. This slower growth is more than often of little consequence if sowing earlier as the crop tends to make it up with better recovery post grazing in winter early spring.

Soil fertility

Nitrogen deficiency remains a more than common yield limiting factor in dual purpose crops.

A typical dual purpose cereal crop may provide 4.0 t/ha of drymatter for grazing and yield 4.0 t/ha of grain. The amount of nitrogen utilised in this example is typically 150 kg/ha for grazing and a further 84 kg/ha for grain, a total of 234 kg/ha.

While not a lot of the nitrogen needed for grazing is removed from the paddock in animal product, it takes time to be re-released to the soil via urine and faeces and the rotting back of trampled material. Nitrogen recycling is often also not distributed evenly across a paddock.

Figure 2. Urea at 100 kg/ha applied to oats mid-winter. In foreground no urea applied.

Treat sowing seed for rust and aphids

A major risk with early sowing of some cereal crops is barley yellow dwarf virus (BYDV), a sometimes major disease threat to most varieties of oats, barley and wheat.

BYDV risk can be minimised by treating sowing seed with a registered insecticide to reduce risk of aphid attacks. Be aware that many insecticides have a grazing withholding period, commonly around nine weeks post sowing.

Rust can also be a greater risk in early sown crops, especially if autumns are humid. There are few resistant oat and barley varieties and popular winter habit wheats are commonly not that resistant to some rusts. Again seed treatment with an appropriate fungicide, or fungicide treated fertiliser applied with seed, can help reduce risk of early rust outbreaks.

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Soil water workshop concurrent session (Day 2)

Better profits from good soil water decisions

Dr Peter Wylie and Simon Fritsch, AgriPath

Key words

Soil water, Water Use Efficiency, Yield gap, Rotations, Opportunity Cropping

Take home message

Profit on the average farm can be doubled by good planning of farming systems, operations, crop choice and attention to detail on crop agronomy. Crop margins can be improved by optimising soil water storage and making decisions based on soil moisture, seasonal outlook and time of planting.

Water Use Efficiency benchmarks can be used to estimate attainable yield for various amounts of soil water or the total water available, if looking back in hindsight. WUE has a wide variation and the accuracy of estimating attainable yield is improved if benchmarks are used for low, medium and high yields. For wheat and sorghum these WUE benchmarks in the Northern Region are 9, 12 and 15 kg/ha/mm for low, medium and high yields respectively.

Introduction

Average farm profit on grain farms in New South Wales, according to ABARE surveys, is around 2-3% Return on Assets Managed (ROAM). From here there a large gap, to move up to the profits achieved by the Top 20% of benchmarked farmers, of 8 to 10% ROAM. Top performing farms produce an additional $500,000 profit each year compared to their peers.

Part of this profit gap is the difference between average farm yields and the attainable yields which result from good farming practices. Across the Northern Grain Region this yield gap is some 50 to 90%. Farm profitability would more than double with a 50% increase in yield.

Closing the yield gap requires getting a lot of things right, which requires time to be spent on management, seeking advice and planning for good crop margins and farming operations.

Good yields are about more than weeds and fertilisers. Farming systems are the key to good profits. Well-planned rotations which manage disease, nematodes and weeds can provide extra gains in crop yields, by improving timeliness and reducing grain losses from weather risks.

Yields are a product of soil water, in-crop rainfall and water use efficiency. Good farm profits depend upon making good decisions based on soil water and profit margins which might be achieved from various planting opportunities.

1. What is an extra 20mm of soil water worth

Good practices for storing rainfall during fallow may result in an extra 20mm of soil water, which on the average can result in an extra 400 kg/ha of wheat and around 50% more profit. Extra soil water, not only produces more grain, it improves the water use efficiency on the total amount of water used by the crop.

The results of wheat yields at Gunnedah, modelled using APSIM, show an extra 24mm of soil water increased WUE from 11 to 12 kg/ha/mm and yield by 537 kg/ha. At Coonamble an extra 16 mm increased yield by 381kg/ha.

Table 1. Effect of soil water capacity on water storage and crop yield
APSIM modelling by G. Mclean, DAFF Qld. 2014

Soil PAWC mm	Wheat May 30 Plant	Planting soil water	In-crop Jun - mid-Oct	Harvest soil water	WUE kg/ha/mm	Yield average kg/ha
150	Gunnedah	136	236	28	11.1	3814
180	Gunnedah	158	236	30	12.0	4351
	Increase	22			24.1	537
150	Coonamble	126	201	16	8.7	2716
180	Coonamble	142	201	17	9.5	3097
	Increase	16			23.4	381

Profit would increase from $280/ha to $408/ha with an extra 20mm at Gunnedah, a rise of 46% and for a yield increase of 0.47 t/ha from an extra 20mm at Coonamble, profit would rise 75% from $123 to $216/ha.

2. Optimising soil moisture

Building a healthy soil is the key to good infiltration of rainfall. In most seasons there is some heavy rainfall which causes runoff during a summer fallow. Soil cover is maximised by zero-tillage and a well-planned rotation. With minimal compaction as a result of controlled traffic the soil will have an improved infiltration rate. With high levels of organic matter input, soil structure and earthworm numbers improve over the years, rather than decline.

At Gunnedah, rainfall during a summer fallow is 400 mm on average, of which around 25%, or 100 mm is commonly stored for the next crop. Good fallow management may increase storage of fallow rainfall to around 30% and result in average soil water storage of 120 mm.

Good control of weeds during fallow is important for good water storage. Delayed weed control or a few escapes can quickly reduce the water stored by 20 mm or more. A good rotation program is important for managing weeds and herbicide resistance.

Residual herbicides can keep down weed control costs and help in managing glyphosate resistance grass weeds. Residual herbicides can also improve timeliness by taking the pressure off the fallow spraying, when weed control in hot weather is needed in a short space of time. Residual herbicides require planning and sometimes locking in a crop sequence, to avoid problems with plant back periods and effects on the following crops.

Good spray techniques are important for good weed control and soil water storage. Farmers should seek advice on nozzle selection, water rates, adjuvants, speed of spraying and weather.

3. Attainable Yield projections based on WUE

Rather than use a fixed estimate of attainable wheat or sorghum yields for a district, it is more useful to calculate attainable yield using water use efficiency (WUE) benchmarks for a particular soil type or the amount of soil water available.

WUE calculations in summer rainfall areas need to take into account soil moisture at planting and harvest. Evaporation is variable in the Northern Grains region. It should be ignored, because it shows high WUE in a dry season when in fact it can be quite low. WUE is calculated by dividing grain yield by water available, which is soil water at planting, plus in-crop rainfall less an estimate of soil water at harvest.

Data from 200 farm and trial observations on wheat in the Northern Region over the 7 years 2005 to 2013, has shown an average yield of 3.36 t/ha with a WUE of 12.3 kg/ha/mm.

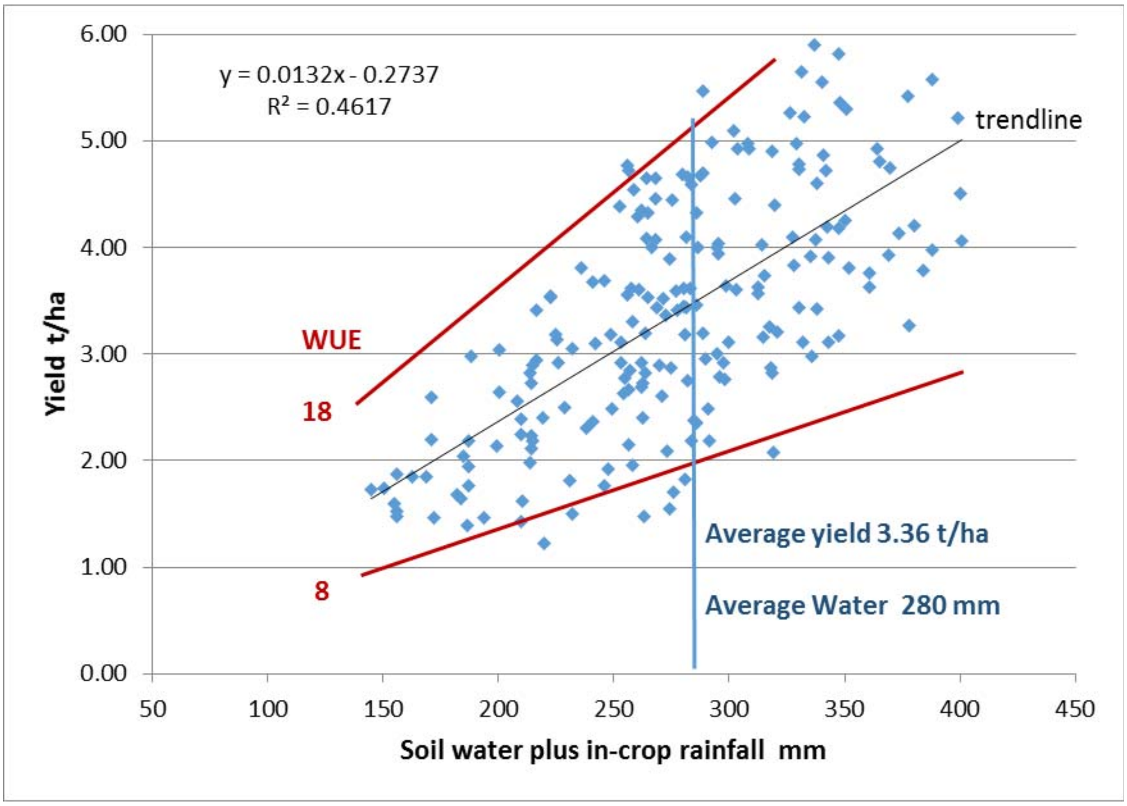

Figure 1. Yield of wheat vs water available in the Northern Grains Region
(Trial data and farm records 2005-2013, collated by Agripath)

WUE is mostly within the range of 8 -18 kg/ha/mm, with the major variation being an increase in WUE as the yield increases. One explanation for WUE improving is the increase in Harvest Index, which is the ratio of grain to total above ground biomass. At low yields the harvest index is low due to fewer heads per plant, each with less grains and lower grain weight. The harvest index of wheat is 0.2 at a yield of 2 t/ha and peaks at 0.4 when yields are above 4 t/ha. (See Figure 2)

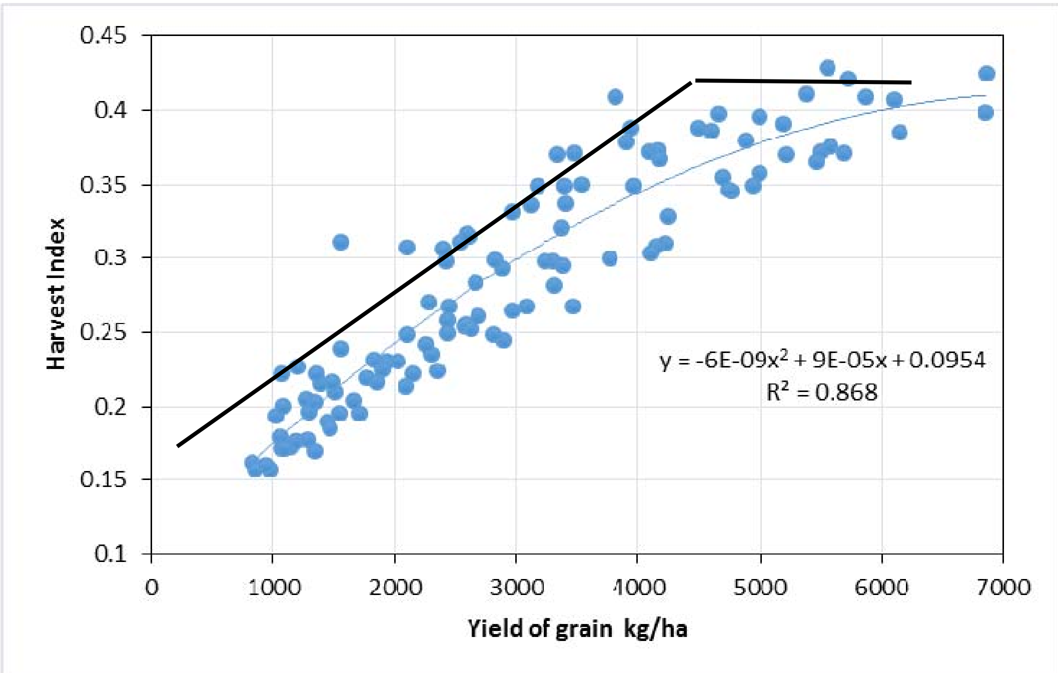

Figure 2. Harvest Index of wheat at Gunnedah (100 years of Apsim simulated yields)

Table 2. WUE data and benchmarks at low, medium and high yield levels
Data is from trials and farm records, across the Northern Grains Region: 2007-2013

	Low yield	Medium	High yield
Wheat yield range	**<2.5 t/ha**	**2.5-4 t/ha**	**>4 t/ha**
Observed WUE	9.01	11.86	15.07
STDEV	1.87	1.92	2.04
Benchmark for WUE	9	12	15
Sorghum yield range	**<3 t/ha**	**3-5 t/ha**	**>5 t/ha**
Observed WUE	8.6	11.4	15.2
STDEV	1.48	2.13	2.60
Benchmark for WUE	9	12	15
Chickpea yield range	**<1.5 t/ha**	**1.5-2.5 t/ha**	
Observed WUE	6.55	8.55	10.46
STDEV	1.02	1.61	1.81
Benchmark for WUE	7	9	11

The wide range in WUE values means that using the average of 12 kg/ha/mm is a crude benchmark. Using more than one number for WUE will improve the accuracy and usefulness of this benchmark, both in predicting yield and reviewing yield in hindsight. Data in Table 2, shows the average WUE for wheat in the Northern Region at low, medium and high yields.

These values for WUE are in accordance with the French and Schultz benchmark of 55 kg/ha of wheat biomass per mm of water transpired. When soil evaporation is included in the equation, 37 kg/ha of biomass is produced per mm of water (French and Schultz 1984). At a low yield level, with a harvest index of 0.2, there would be 7.4 kg/ha of grain per mm, rising to 14.8 kg/ha of grain, with a harvest index of 0.4 at high yields.

Attainable yields in the table below are derived from average rainfall and the WUE benchmarks derived from a mix of trial and farm data. They compare well with APSIM modelled yields which show variation in potential yield for soils of different plant available water capacities (150 to 200 mm).

Average rainfall during summer, between November and May at Gunnedah is close to 400mm, with the potential to store 110 mm of soil water. An extra 28 mm of soil water at the start of the fallow brings this to 138 mm on average at wheat planting. With average winter rainfall from June to September of 198 mm this means 308 mm of water is available to a wheat crop, which at 12.5 kg/ha/mm is an attainable yield of 3.84 t/ha.

Table 3. Attainable yield estimates of wheat and sorghum in Northern NSW

Attainable wheat yield (t/ha) – Northern NSW - May 30 plant								
	Planting soil water	In-crop Jun - mid-Oct	Soil water at harvest[1]	Available water (mm)	WUE kg/ha/mm[2]	Yield average[3]	APSIM yield 150mm[4]	APSIM yield 180mm[5]
Goondiwindi	141	176	25	292	11.5	3.35	3.4	3.92
Gunnedah	138	198	28	308	12.5	3.84	3.81	4.35
Moree	130	173	23	280	12	3.36	2.98	3.47
Coonamble	106	159	16	249	12	2.98	2.72	3.10
Walgett	106	142	20	228	11	2.51	2.53	2.90
Attainable Sorghum Yield – September 30 plant								
Goondiwindi	149	203	28	324	12	3.89	3.61	4.34
Gunnedah	136	274	14	396	13	5.15	3.65	4.29
Moree	121	252	22	351	11	3.85	3.08	3.72
Coonamble	118	137	15	240	11	2.64	2.28	2.54
Walgett	111	148	14	245	11	2.70	2.3	2.59

1. Soil water at harvest time estimated by APSIM – average over 100 years
2. WUE benchmarks from trial and farm data collated by Agripath
3. Yield calculated from average rainfall (Rainman) and WUE
4. APSIM simulated yield over 100 years, for a soil with 150mm PAWC
5. APSIM yield with 180mm PAWC soil, 200mm at Gunnedah

4. Making decisions on double crops

Decisions on which crops to grow and the rotation program are important for good farm profit. Changes to fallow length and planting opportunity crops should be based on potential crop margins, which are influenced by soil water and commodity prices.

Too much opportunity cropping can result in a string of low margin crops and low farm profitability. Including some long fallow in cropping plans can reduce risk and boost profit in dry years. In the example below, for the Liverpool Plains, the combined margin of a double crop of mungbean and the following crop of sorghum is less than a sorghum crop on long fallow. This may not always be so and depends upon the price.

The key is to evaluate the potential margin of the crop based on soil moisture and to decide whether it is good enough to proceed.

Table 4. Margins from crops with different fallow length and price

	Mungbean double crop Average $/t	Sorghum after mungbean	Sorghum on long fallow	Mungbean double crop High $/t
Yield (t/ha)	1	3.5	6	1
Price	680	240	240	1200
Gross $/ha	680	840	1440	1200
Fertiliser:	30	118	178	30
Seed	40	35	35	40
Fallow sprays	40	40	60	40
Weeds, Pests	75	45	45	75
Fuel & Repairs	90	90	105	90
Harvest costs	50	50	55	50
Freight & Misc.	45	92	145	45
Labour and machinery	160	190	215	160
Total costs	530	660	838	530
Gross Margin	150	180	602	670

There are advantages of long fallows, where soil water storage allows, such as reducing the pressure of harvest and allowing more use of residual herbicides – which may in turn help manage herbicide resistance and keep down the cost of fallow weedicides.

Decisions on fallows and other aspects of crop sequencing should be made to favour the most profitable or pillar crop. If sorghum is the pillar crop, then it might be appropriate to grow some or all of it on a long fallow from wheat or barley. If chickpea is the most profitable crop, then it is not given the best opportunity for yield if it is all grown as a double crop after sorghum. If there is not a reasonable amount of soil water to grow as a double crop after sorghum, some chickpea may be grown on a fallow. In western districts, sorghum might well be late planted and harvested in May or June. A fallow over the next summer may store good soil moisture for a high margin chickpea crop.

5. WUE declines with soil water and planting time

One of the most important determinants of wheat yield is the decline in yield which occurs with delays in planting. The WUE of wheat declines around 0.5 kg/ha/mm for each week of delay past the optimum time around mid-May, increasing to 0.8kg/ha/mm after mid-June. Yield loss from late planting is worst in dry years with a hot finish. If WUE is 12 kg/ha/mm for wheat at Gunnedah, planted in mid-May, it will decline to around 8 kg/mm for wheat planted in early July.

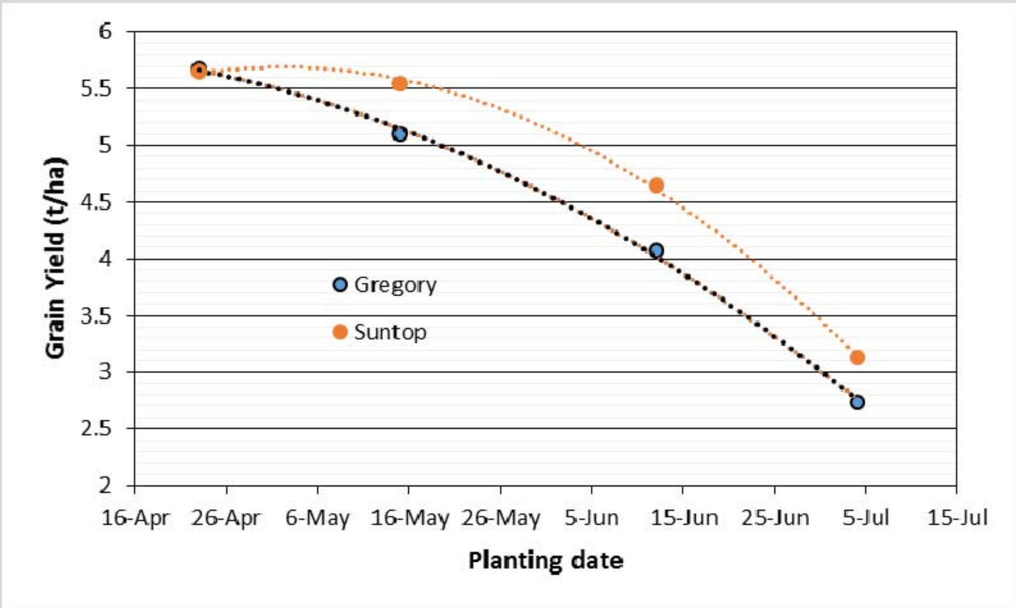

Figure 3. Yield of wheat at four sowing times, Narrabri 2014 (Graham et al 2015)

The loss in yield makes a huge difference to profit potential, with estimates of profit from wheat at the optimum time of more than four times that of wheat planted six weeks late.

Table 5. Effect of planting time on WUE, yield and profit of wheat.
Data from Agripath benchmarking

	Liverpool Plains Good soil water: 150 mm		**Liverpool Plains Low soil water: 90 mm**	
Wheat planted:	mid May	Late June	mid May	late June
Average water (mm)	308	305	248	245
Water use efficiency	13	9	11	7.7
Yield (t/ha)	4.00	2.74	2.72	1.89
Price	250	250	250	250
Gross $/ha	1000	685	680	471
Fertiliser	144	104	100	80
Seed	30	30	30	30
Weeds, Pests	75	75	75	75
Fuel & Repairs	90	90	90	90
Harvest costs	50	50	50	45
Freight & Miscell.	92	75	74	62
Labour & Machinery	181	181	181	181
Total costs	660	605	600	563
Gross Margin	340	80	80	-92

This loss from late planting is much greater than the risk of loss from frost. Even late plantings can be damaged by frost, while it is not much of a proposition to grow wheat with a profit potential which may be less than $50/ha. See Table 5. This effect of planting time on profit highlights the benefits of moisture seeking on wheat margins, if more wheat crops can be planted at the optimum time.

6. Using yield estimates to vary management decisions

Yield estimates using soil water and WUE benchmarks can be useful for making better decisions on fertiliser and other aspects of crop agronomy, such as varietal selection or seeding rate.

An example is that sorghum yield potential in the higher rainfall areas is likely to exceed 10t/ha in 30% of years, but yields in these years are likely to be limited by nitrogen supply. Adjusting N application at planting can be profitable using yield estimates at planting, based on soil moisture and seasonal outlook. Improved soil moisture and seasonal outlook (Table 6) show rising yield estimates. The SOI is more useful for summer crop than winter crop and rainfall for much of the Northern Grains Region is greater on average with a positive SOI, rather than a negative one.

A second way to improve nitrogen supplies to improve sorghum yields in above average rainfall years is to regularly apply feedlot manure or recycled organics. An application of 10 t/ha of feedlot manure will contain around 160 kg N, mostly in an organic form. In a dry summer there will be very little nitrogen released from the manure, but in a wet season when conditions are favourable, 30 to 50 kg of N may be mineralised. If an additional 40 kg N becomes available in a wet season, it could be enough to improve sorghum yields by 2.5 t/ha, assuming grain protein in a high yielding year is likely to be around 8%.

Table 6. Nitrogen required by sorghum according to soil moisture and SOI – Gunnedah

Soil water mm	In-crop rainfall SOI <-5*	Average expected rainfall	In-crop rainfall SOI >+5*	Expected WUE kg/ha/mm	Yield estimate t/ha	Nitrogen required kg/ha**
80	175			10	2.55	43
80		205		11	3.13	53
80			220	12	3.60	61
160	175			14	4.69	80
160		205		15	5.47	93
160			220	16	6.08	103

*SOI is for August and September prior to a Sept 30 sowing, with data from Rainman.

** Nitrogen in grain at 9.5% protein – depending upon soil N, more may needed to grow the crop

A third way to improve the supply of N for a good year is simply to increase the annual N fertiliser rate. If the rate was increased to 22kg N/t., rather than a 17kg/t target, this would result in an extra 30 kg N being applied for a yield estimate of 6 t/ha. The extra N could increase yield by around 1.5 t/ha in a good year. If 4.5 tonnes of extra sorghum was produced in the highest yielding 3 years over a 10 year period, this could be worth $1000 for an outlay of $420/ha. In the drier seasons, some of the extra N would be exported from the farm as higher protein levels in the grain, but overall the extra N might contribute to a small increase in N reserves in soil organic matter.

7. Rotations and resilient farming systems

Good farming systems involve crop selection, rotations, sound practices for zero-tillage and planting, combined with good risk management. Well-planned rotations which manage disease, nematodes and weeds not only improve crop yields, they can improve timeliness, keep down costs and reduce grain losses from weather risks.

It is not possible to make good profits without managing problems such as nematodes and crown rot. In combination these two problems could be dragging down wheat yields by 20% and profit by 40%. Nematodes require a plan to keep soil populations low, using break crops, such as sorghum and canola. New varieties of wheat, such as Suntop⦶, offer potential to suppress nematode populations.

Management of weeds, particularly glyphosate resistant summer grass weeds, is another factor driving decisions on rotations. Rotation plans which include some fixed cropping plans and long fallows can pave the way for increased use of residual herbicides to help reduce costs and to better manage glyphosate resistance.

Timeliness of operations, a poor strike or harvest losses can affect yield and drag down profit. A rotation program which provides diversification of crops can make a big difference to the timeliness of planting and harvesting. For example, a program with barley, wheat and chickpea has a planting and harvest window spread over two or three weeks, rather than one week for wheat alone.

8. Monitoring moisture and analysing data on yield, WUE and profit

In most years, somewhere on the farm, a high yielding area of crop shows what is possible. Yield maps, EM surveys, soil moisture and fertility testing and trials measured by yield maps can help to understand yield differences and the limitations of soils on a farm.

Moisture is the key to grain yields and measuring soil water holding capacity and soil water at planting time can improve decision making. EM measurements allows rapid assessment of soil moisture and soil moisture variability across paddocks.

Benchmarking of crop yields and WUE can indicate where there may have been problems with such things as fallow moisture storage, timeliness or not enough fertiliser.

Acknowledgements

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References

French R. and Schultz J. 1984. Water use efficiency of wheat in a Mediterranean-type environment. 1 The relation between yield, water use and climate. Aust. J. Agric. Res. 35(6) 743-764

Graham R. 2015. Wheat variety response to sowing time. GRDC Grains Research Update Goondiwindi.

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General plenary session day 2

"Big data is lots of small data in a common platform." Managing big data in grain production - new opportunities and challenges. Future collaborative platforms for big data/mapping and where the industry is heading

Mark Pawsey, SST Software Australia

Key words

Data, mapping, grains production, data management

Before we begin talking about Big Data as an industry concept I want to talk a little about our story as a small company with a 20 year journey in agricultural data management. In the mid 90's SST was providing geo-spatial software to farm service providers mainly in the Corn Belt of the USA. Our investment in site specific management was a hit and we quickly gained significant market share including internationally in 23 countries. But we began to see flaws in an open system related to the lack of scalability due to unstructured data and outputs.

In the early 2000's the concept of the SST Information lab emerged. Now service providers could evolve scale and efficiency within an organisation and create consistent outcomes for farmers via internal standards. The gains of this model were however degraded by the challenges of manual data processing, skills mobility and silo's emerging within a single organisation.

The result through collaboration with our customers and a quest for our own productivity gains came in the mid 2000's when an investment was made into a single global synchronised database platform. From that platform blossomed a suite of innovations such as machine automated processing, secure synchronisation, stable tractor interaction, software innovation and other gains now supporting 120 million acres of farm land. Now our attention is starting to turn towards Big Data or as we are calling it Analytics.

One key principle we believe is indisputable is that agriculture is inherently spatial and requires site specific data. We plant a seed at a specific point on the earth and make decisions around it which need to be tied to that location meaning GIS data management is essential. For example try taking data off a tractor without using a GIS software system!

Big Data in agriculture is being promoted as the panacea to global food security and sustainability and it quite possibly could be. The potential value in helping identify relationships and predictive decision making is enormous. But I ask you is Big Data really the end goal for agriculture? Is it in fact a digital economy generating lots of standardised small geo-referenced data that is really the goal?

The first assumption of Big Data is that we have lots of data together in one place and probably in a cloud! Which means its sitting on someone's computer! The path to Big Data in agriculture lies not in the cloud, but the economic, technical and social foundations of a structured digital agriculture economy.

The idea of Big Data in agriculture is suffering from the old sales adage of "Selling the sizzle and not the steak". There is probably no more complex production system than agriculture, and the variety of data decisions and data types that make up the agricultural production system are frightening. Bringing together structured and unstructured data is hard enough, let alone when the industry is rife with proprietary file formats. Most of the discussion about Big Data in agriculture is theoretical and idealistic with little thought given to the realities of collecting data from disparate systems and creating economic and technical pathways to aggregate it. Hence most current Big Data initiatives involve weather data and models which can be useful for risk management and other decisions but will never deliver the hard core metrics and understanding we need for true practice change on farm.

So to break that down, two paths exist to Big Data in agriculture which can be defined as a Top Down or Bottom up approach. Top Down is the aggregation of remote data such as weather data, satellite imagery and potentially sensor data from emerging networks. This is the most scalable approach and is the domain of modelling and inferred outcomes which allow for decision making prior to the event. The problem with this data is that it lacks a feedback loop of what did occur to fine tune the model and asking farmers to enter that actual data is unlikely to be successful!

The bottom up approach of aggregated farm data is more traditionally defined as benchmarking. But as geo spatial data from the farm itself becomes more available the ability to query and identify relationships becomes a reality. This is the domain of data collected from farm software, tractors and machinery sensors. This data opens up the ability to understand and predict outcomes using more intensive field level data combined with the remote weather and other data. This "small data" analysis and the relationships found within a farm are just as valuable as those found in a regional data set its just they only benefit the one farmer. Attempts are underway to integrate the two camps which will be essential as neither tell the whole story alone. The point of integration however is where the breakdown exists.

So if what we really need is the field level geo-spatial data, how do we collect it and in a way that's useful. A term born in the late 90's among my colleagues for data collected other than for running the day to day farming operation was "recreational data keeping". Data needs to be collected first for business use then made available for other applications so we need to make sure it has business value first. Secondly farmers need to be willing to invest in machine generated data such as from tractors and other equipment. And it's not just the financial decision but the decision to use the data. In many cases the yield monitor comes factory fitted but the value proposition to use it has not been well defined. Without clearly defined value propositions the field level data we need for Big Data will never exist.

Ultimately it leads us back to the farmer and the farm service providers who walk side by side with the farmer every day. Many farmers can embrace technology and practice change independently, however many more benefit from services support. If Big Data is the panacea in agriculture to global security then we need to focus on value driven farm level services to encourage adoption and implement practice change. Offering a "pot of data gold" at the end of a rainbow as the reward for collecting data or worse cash for contributing that data is not the answer. The only sustainable model for farm services and extension is in commercial agronomic service providers who live in our regional communities.

So maybe what we really need when we break it down is an investment in a digital agriculture exchange framework starting with digital agronomy and extending through to digital value exchanges and data co-ops. Data collected for agronomic and business practice on farm is the starting point which is where our farm services model becomes so important. Once data exists a structured digital supply chain can offer value for farmers sharing that data.

Three models for digital agriculture

Digital agriculture is emerging as a high profile market. As the opportunity for innovation and disruption attracts more attention, three potential models have emerged. The first model is the one company does it all approach. This is the domain of large multi-nationals who want to be a one stop shop for the farmer. The chance of one company being the best at every aspect of agriculture is low, even through aggressive acquisition of other companies. Even if one company was able to provide quality expertise and service across the board, concerns of privacy and constrained competition would hamper progress.

The second model, and the one that is the most popular today is the interconnected API approach. In this model, companies stand up data transfer connections pipes between themselves. The problem is the data inside the pipe is not standardised. While this approach is manageable for a few relationships, it will never stand up to the emerging multiples of required connections which need to maintain currency of data and data edits.

The third model is the centralised data repository approach. In this model, all data synchronisation seamlessly occurs due to common database schemas that all compliant applications have adopted. This industry specific cloud can be thought of as a centrally secure “cloud data vault.” This data vault is able to access, receive, and create data from many different sources, such as software and machinery loggers. Data can be seamlessly and securely shared securely between users while administration rights protect against unauthorised abuse.

This model is currently executed on platform known as agX®, and is a service model (PaaS) available to all players in the agri-business industry. agX is emerging in numerous tractor controllers, farm software applications, farm apps, data services and on demand data providers such as aerial and satellite imagery providers. As agX continues to gain adoption, a market place of third-party, best-of-breed products is evolving.

agX® is the result of tens of millions of dollars, a decade of development, and deep domain knowledge. As new innovations arise, companies can develop new products cheaper and bring them to market faster by utilizing the agX Platform. Furthermore, being agX compliant is extremely valuable because it integrates products into a larger pool of users and markets that are commonly aligned.

This allows a farmer the option of using software and apps from many different vendors and migrating data seamlessly between apps. A service provider can differentiate their offerings to farmers by investing in customised solutions that add value. Software vendors can be nimble and aggressive in developing solutions to market opportunities without having to reinvent the wheel each time. The supply chain can develop value exchanges whereby the farmer can willingly share valuable farm data with those who can provide security of supply, access to markets and improved risk management solutions. Corporate ERP systems can become integrated solutions all the way down to the farm gate thanks to structured database schemas existing that conform to corporate requirements. Irrespective of Big Data what is emerging is a marketplace and ecosystem of interconnected and interoperable systems driven by proprietary IP and commercial market forces. In other words two mates can get together and write an app that can focus on one feature that will talk to the data a farmer already has in the cloud data vault. They don’t have to compete to be the farmers “one” software system as now it’s an “ecosystem”.

Big Data is now a reality and the opportunity to share data via trusted entities where regional geo-spatial data sets can be created that identify relationships and trends exists. Allowing farmers to compare results for common management practices and soil types to fast track agronomic and business practice change becomes a real prospect. Ag Retailers now have access to Business Intelligence tools and Researchers can engage with farm level outcomes on a regional scale to compare to R & D outcomes and run models. The ideal “Trust entity” to represent farmer’s data in aggregate needs to be identified but the agX system in itself does most of the work managing security, privacy and engagement pathways.

If we can collaborate around an industry framework without creating an artificial construct that needs ongoing public funding or disrupting a commercial digital agriculture marketplace we can start creating farm level value that will drive a digital supply chain. Public policy, public R & D, industry bodies, the farm services sector, farm input supply sector, private investment in technology and the farmer themselves can all achieve their individual competitive goals when focused around a common framework. If we focus on the small data value on farm and upstream into the supply chain the rest will take care of itself.

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Using remote data sources to improve agronomic management

Ben Boughton, Satamap Pty Ltd, Gilroy Farms, 2014 Nuffield Scholar (UAVs)

Key words

remote sensing, management, satellite imagery, variable rate

Take home message

- Remote sensing is a tool that is gaining in popularity with forward thinking agronomists to add value to their clients.
- It enables us to ‘see’ plant attributes that our eyes cannot with bands such as near infrared.
- Data access is becoming easier and cheaper.

What is remote sensing?

Remote sensing is the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to on site observation

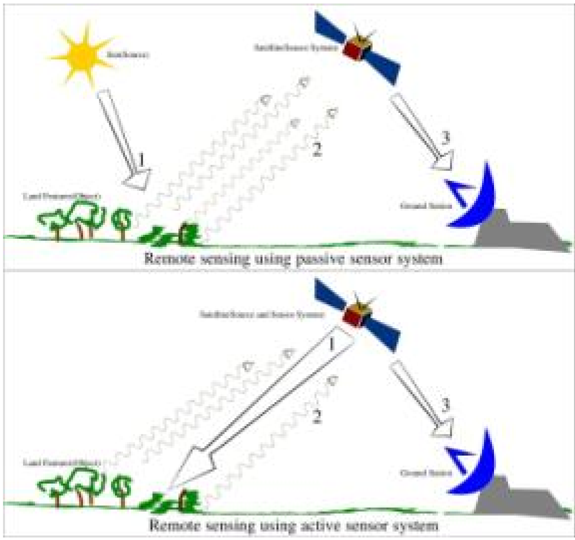

Figure 1. "Remote Sensing Illustration" by Arkarjun - Own work.
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Why does it matter?

- It adds value to your business - Clients will recognise the professionals that utilise all available tools to make decisions that affect their business
- It’s not going away - RS innovation is almost vertical
- The longer you wait to learn about it the harder it becomes

Who collects the data?

- There are 40+ satellites collecting optical imagery
- Some Government run missions make all data open and free such as USGS Landsat program and the new ESA Sentinel mission

- Commercial satellites from companies such as Digital Globe and Blackbridge offer very detailed data, often scheduled

How do we make sense of it?

- Imagery comes back to Earth as digital numbers provided by sensor (DN)
- Taking into account sun angle, atmosphere and sensor specs, DNs are converted to reflectance values
- The reflectance value is used to make images (true and false colour), and generate other information such as vegetation indices

What can it see?

- The sensor 'looks' at different bandwidths
- Blue, Red and Green bands which our eyes can see
- Near infrared, short wave infrared, thermal bands which our eyes cannot see

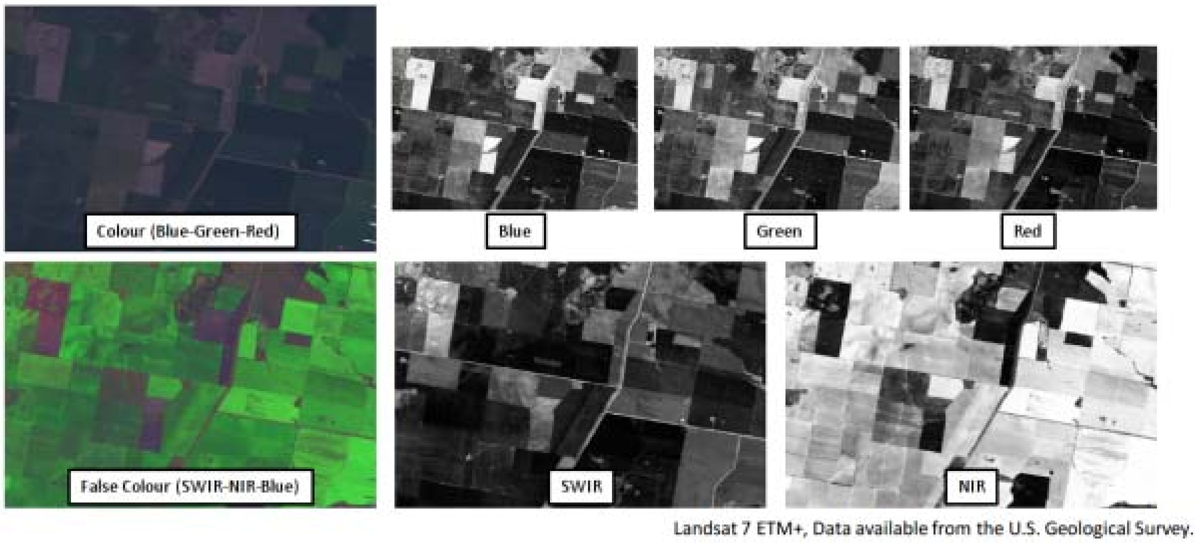

Figure 2. Bandwiths viewed by remote sensing

What do you mean by resolution?

- **Spatial resolution** – pixel size of an image representing the size of the surface area on the ground (i.e. m2)
- **Spectral resolution** – wavelength interval size (discreet segment of the Electromagnetic Spectrum) and number intervals that the sensor is measuring
- **Temporal resolution** – time that passes between imagery collection periods for a given surface location
- **Radiometric resolution** – ability of an sensor to record many levels of brightness (contrast for example)
  and to the effective bit-depth of the sensor (number of grayscale levels) and is typically expressed as 8-bit (0-255), 11-bit (0-2047), 12-bit (0-4095) or 16-bit (0-65,535).

What can we do with it? Example – Chickpeas 2015

This example is of a chickpea paddock grown north of Moree in 2015. The aim here is to display data from different sources to get a better understanding of what happened throughout the growing season.

The crop was planted on a full profile of moisture in May into heavy barley stubble with a single disc no till planter. Establishment was reasonable but there were a few gaps.

Two rainfall events, 51mm in June and 50 in July let to a water-logging event. The next significant rainfall event was 25 mm on 29 October.

The combination of stored moisture, high stubble cover, poor drainage from tramline direction, and a charged fallow catchment area upstream all contributed to this event.

The dry finish enabled the affected areas to recover reasonably well producing an average yield of about 1.9t/ha.

Figure3. Photographs of chickpeas taken August 2015

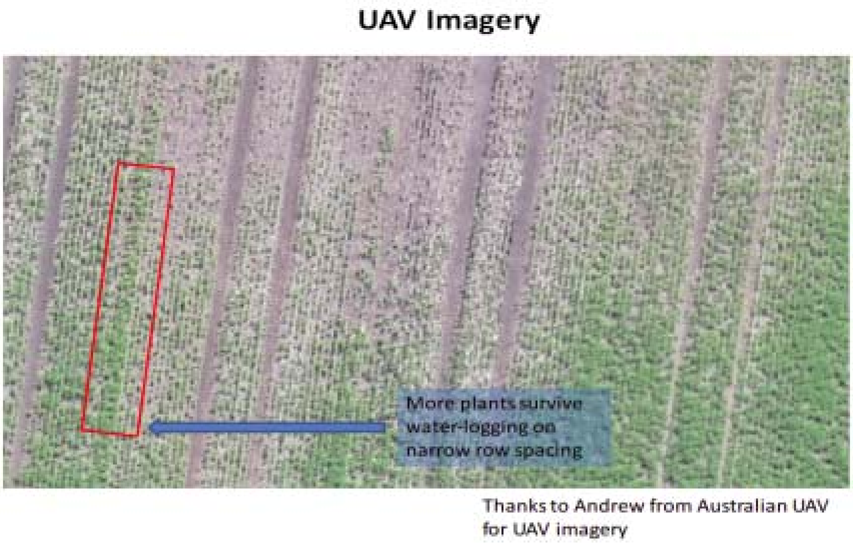

Figure 4. Imagery from UAV take 26-08-2015 enables us to see individual plants

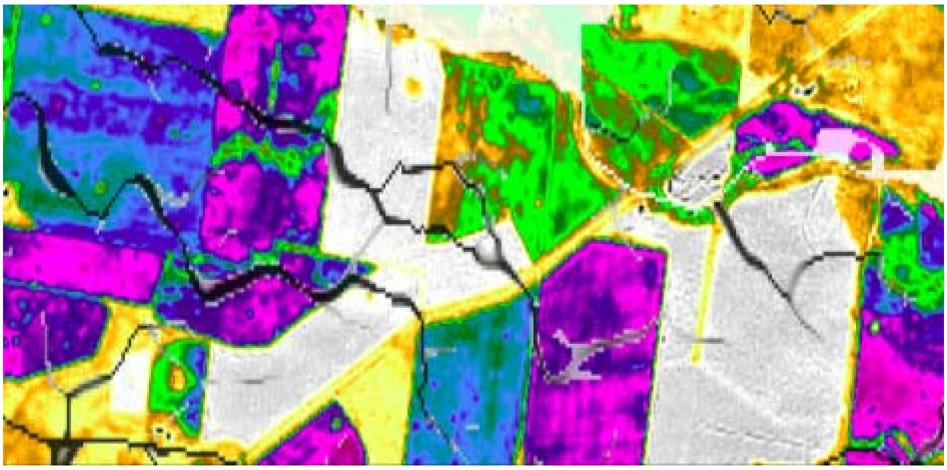

Figure 5. Satamap imagery with flow accumulation layer on top showing where water accumulates when it rains

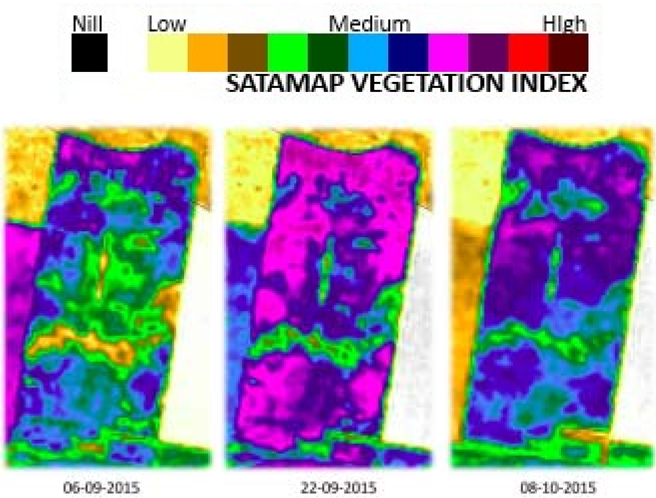

Figure 6. Satamap imagery showing how biomass changes of 16 day period

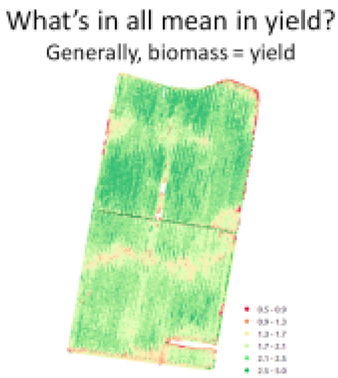

Figure 7. Yield map from harvester shows general trend of high biomass resulting in higher yield. Overall an excellent result.

What can we do with it? Look at it – Moree district view September 2015 vs 2015

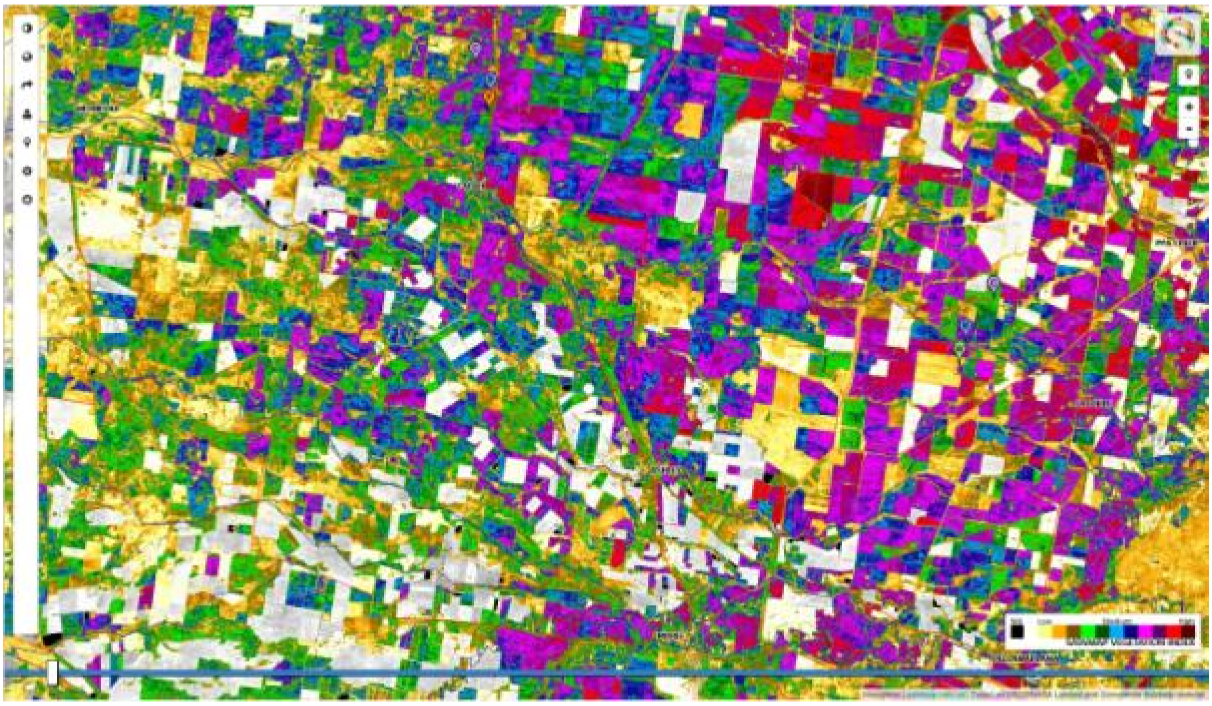

Figure 8. North of Moree, September 2015

Figure 9. North of Moree, September 2014

What can we do with it? Look at it – Some satellite imagery closer up

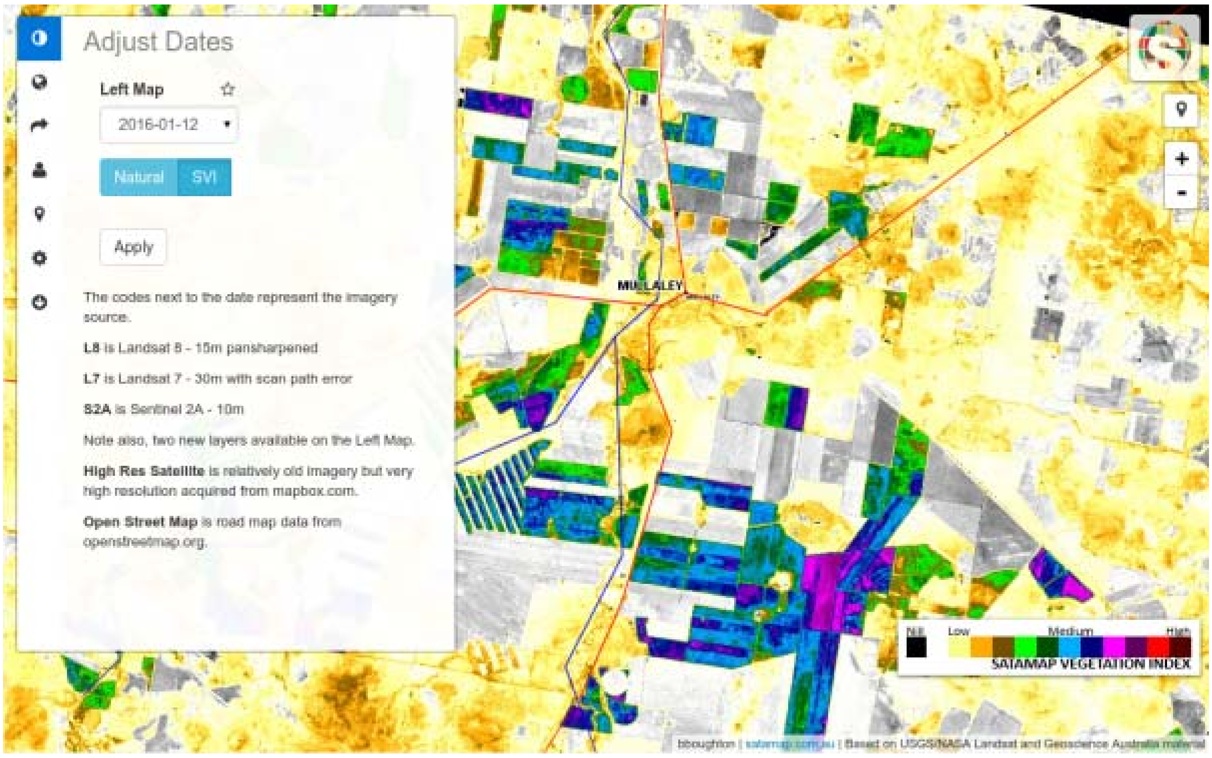

Figure 10. Mullaley area 12 Jan 2015

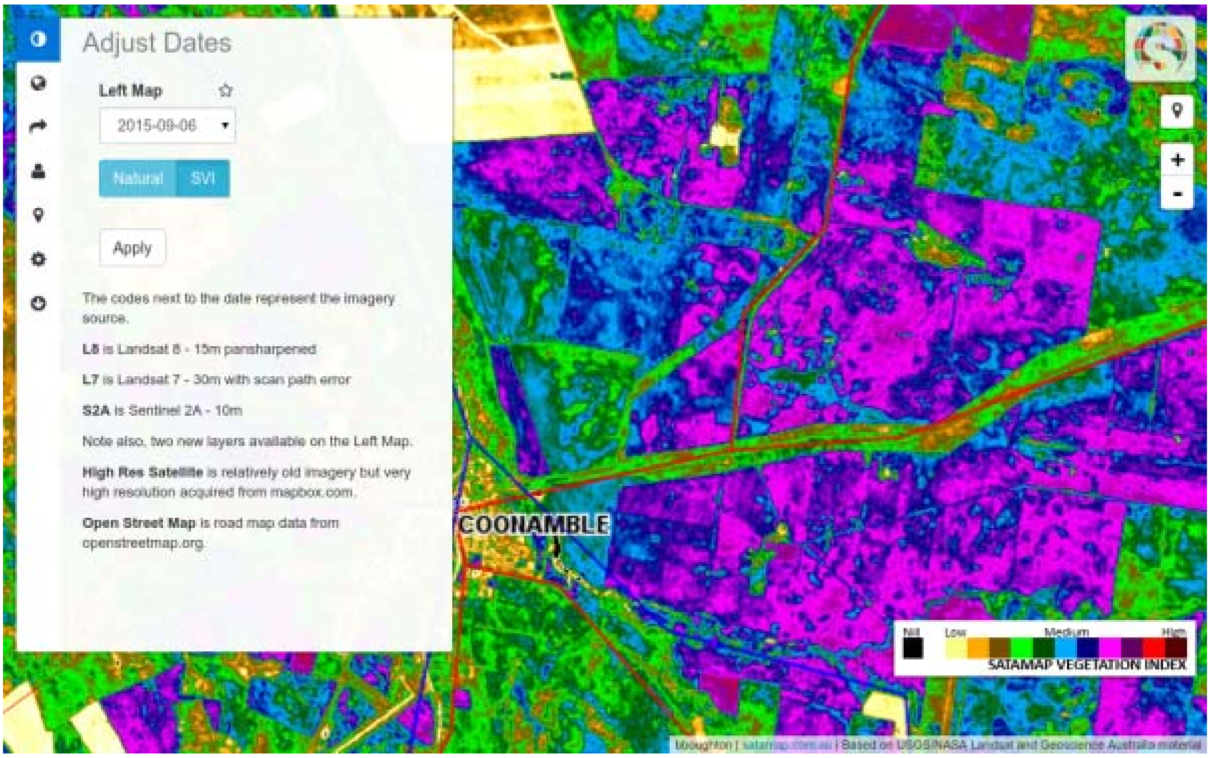

Figure 11. Coonamble 6 September 2015

What can we do with it? - analyse & build information

- Look at trends over time by ‘stacking’ imagery
- Create variable rate prescription maps:

Process:

- Imagery detects patches of barnyard grass in fallow in 2013
- Water map generated to apply higher rate of flame to areas where barnyard grass seedbank is highest
- Spray operator import shape file and controller automatically adjusts rates
- Practically limited to about 20% rate variation

Figure 12. Prescription map for Flame herbicide. Red is low rate, green is high

Where can I get it?

Australian companies offering satellite imagery fully processed and ready to use on farm:

- PrecisionAgriculture.com.au
- PASource.com
- Satamap.com.au

Contact details

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Email: ben@satamap.com.au

Understanding & managing N loss pathways

Mike Bell (QAAFI), Graeme Schwenke (NSW DPI) and David Lester (DAF Qld)

Key words

Nitrate denitrification, ammonia volatilisation, N use efficiency, ^{15}N recovery, summer sorghum

NANORP codes

01202.027; 0102.004

Take home message

- Over the past 3 years, we have had 6 experiments with isotope-labelled (^{15}N) urea fertiliser in northern NSW and a further 11 in southern Qld, all focussed on measuring the fate of applied N fertiliser in summer sorghum. Normal fertiliser contains ^{14}N so the use of ^{15}N allows us to trace the fate of urea-N applied to the soil from sowing through to harvest.
- Between 56 and 100% of the applied N was found in the soil and plant at harvest, with in-season rainfall (both timing and amount) and soil C and N status having a major impact on the seasonal loss potential.
- Avoiding unnecessarily high N rates, delaying or splitting N fertiliser so that peak N availability coincides with peak crop N demand and relying on residual N from legume rotations all significantly reduced gaseous N losses from dryland sorghum, although the effectiveness of any management strategy varied with seasonal conditions.
- Nitrification inhibitor-coated urea significantly reduced nitrous oxide emissions in all studies, but did not improve grain yields enough to justify the additional cost on an agronomic basis.
- Depending on the season, delaying/splitting N applications gave either no yield benefit (dry season) or a significantly greater yield (good in-crop rainfall). Much of the unused N after a dry season remained in the soil and, provided loss events were not experienced during the fallow, significantly benefited the following crop.

Why the focus on N losses?

Fertiliser is a major contributor to crop variable costs, particularly in the northern parts of the region where soil organic matter and associated mineralisable N reserves continue to decline. This will continue to be the case unless the legume frequency in crop rotations increases substantially compared to that typically used (i.e. typically 1 legume crop in every 4-6 crops grown – Edwards *et al*. 2012).

Given the substantial investment in N fertilisers, there needs to be considerable attention to factors that affect the efficiency of use of applied N (NUE), with indices such as crop recovery of applied N (kg fertiliser N accumulated in the crop or in the grain/kg N applied) and the agronomic efficiency of N use (kg additional grain produced/kg N applied) used to benchmark NUE. Any loss of applied N will affect NUE by reducing the pool of N that a crop can use to produce biomass and grain yield. Understanding the loss pathways and how they are influenced by seasonal conditions and management strategies are an important first step in optimising NUE for a given situation.

A recent survey of advisors throughout NSW and Qld (>150 advisors in total) showed the overwhelming majority recognized that N losses exist and can be significant, with a perception of increasing risks of losses in summer compared to winter cropping. There was also a perception of greater potential N losses (as much as 20-40% of applied N) in the northern part of the region, but given the unpredictability of environmental conditions that favour losses, few advisors actually factor those losses into fertiliser recommendations. The results from our projects conducted in the recently completed NANORP initiative, funded by GRDC and the Department of Agriculture) provide some interesting insights into these losses in summer sorghum cropping.

Where do losses occur, how big are they & what are the drivers?

Essentially, nitrogen can be lost from cropping soils via **downwards**, **sidewards** or **upwards** movement. **Downward** movement of nitrate [NO_3^-] via leaching is a greater problem in lighter textured soils than in the medium–heavy clays dominating the northern grains zone, but previous research has demonstrated some N losses, albeit small on an annual scale, can occur via this pathway.

Sideways movement can occur rapidly through erosion of organic matter rich topsoil during intense rainfall events, or more slowly through lateral subsoil movement of nitrate-N in soil water. The main **upwards** N loss pathways consist of gaseous losses through either ammonia volatilisation or denitrification of nitrate.

Ammonia volatilisation losses can occur soon after fertiliser is applied to soil, primarily when that fertiliser is surface applied. In previous research on northern NSW clay soils, we found losses from broadcast urea averaged 11% (5–19%) when applied to the surface of fallow paddocks, 5% (3–8%) when applied in a wheat crop (mostly dry soils), and 27% when applied to pasture. Ammonia N loss from pastures was higher as there was little rain after spreading. Nitrogen losses from ammonium sulfate were less than half the losses from urea at 2 pasture sites and 5 out of 8 fallow paddocks on non-calcareous soils, but were higher than urea (19–34% N loss) from fallowed soils with more than 10% calcium carbonate (Schwenke 2014).

A range of factors influence the actual amount of N lost through ammonia volatilisation. Fillery and Khimashia (2015) recently published a simple model to predict ammonia volatilisation losses from fertiliser applied to moist soils. Their model starts with a maximum potential loss figure which is then discounted according to input factors including clay content, soil pH, fertiliser rate, rainfall in the week after application, presence of a crop canopy, and the placement of the fertiliser. Their model predicted the losses we measured in our fallow studies fairly accurately, but was not used on our studies in wheat paddocks where the potential for loss was deemed minimal due to the dry surface soil. In our field study we found that wind-speed after fertiliser application was also related to the amount of N lost over time.

Nitrate denitrification losses can be large, but require the simultaneous occurrence of low soil oxygen availability (an extreme examples is when soil is waterlogged for an extended period), high soil nitrate concentration (soon after soils have been fertilized) and readily available (labile) carbon to support an active microbial community. Clearly these set of circumstances do not coincide every year, but when they do, denitrification losses can be high, with rates of loss typically higher when soils are warmer in spring and summer rather than late autumn and winter. Interestingly, this is consistent with the survey information that the risk of N losses in the region was perceived to be greater in summer cropping and in the (warmer) northern cropping areas.

Unlike ammonia volatilisation, it is more difficult to quantify total N losses due to denitrification. This is because variable proportions of those losses can occur as N_2 or as N_2O, and direct measurement of denitrification losses in the field has so far only been able to quantify losses as N_2O. There are reports in the literature of the ratio of losses as N_2:N_2O being anything from 1:1 to 70:1, depending on soil and environmental conditions. To put this uncertainty into perspective, this means the NANORP measurements of annual N_2O losses at fertiliser N rates delivering maximum yield of 1-2 kg N_2O-N/ha could be indicative of total denitrification losses ranging from negligible to >100 kg N/ha. The use of nitrogen fertilisers labelled with the ^{15}N isotope allows the fate of applied N to be studied in greater detail, with the difference between fertiliser N applied and that recovered in the plant (tops and roots) or remaining in the soil after harvest representing fertiliser N lost to the environment. In soils where fertiliser N has been banded below the soil surface and leaching losses are minimal (such as in the alkaline Vertosols), most of the unaccounted-for fertiliser N is presumed to have been lost via denitrification. When cumulative N_2O emissions data are available (such as in 12 of the 18 NANORP sites in Qld and NSW where ^{15}N was used), the ratio of total N lost (from ^{15}N results) to that lost as N_2O can be used to estimate the ratio of N_2 to N_2O for these summer cropping systems.

The impact of N source on loss susceptibility

Nitrogen for crop production can come from (a) soil organic matter, (b) crop residues—especially legumes, (c) manures, and (d) fertiliser. To minimise N losses, managers need to match zones and times of N supply with N demand (from crop production). Ideally, the N would be produced or added as the crop needs it, but it must also be available where the plant roots can access it, i.e. in soil with available moisture for active roots.

Mineralisation of organic matter, residues and manures to plant available N forms requires moist soil and warm temperatures, so rates of N produced are greater during summer than winter. How much mineral N much is produced depends on the amount of organic matter in the soil, the amount of crop residues remaining and their N concentration, and the amount and type of manure applied, its N concentration and its method of application. In contrast, fertiliser N is either immediately available for plant use (in ammonium or nitrate forms) or soon available after conversion in soil (e.g. from urea to ammonium and nitrate).

Under non-waterlogging conditions nitrate [NO_3^-] is the N form that is produced in the soil regardless of the original source, and will accumulate over time if no significant N losses occur. So, the principal impact of N source is in the timing and rate of mineral N accumulation in the soil. If a loss event occurs while mineral N is still being produced, only that already present as nitrate will be subject to loss. If a loss event occurs after all mineralisation or urea conversion through to nitrate has taken place, then the original source will have little influence on how much is lost. An advantage of mineralisation-sourced N is that its slower-release may see it progressively distributed throughout the soil profile by fallow rainfall, rather than being present in a concentrated zone if applied all at once from fertiliser.

Managing N losses from any of these sources requires matching the times-of-year the N becomes available with potential for intense rainfall events and the time-of-year that the N will be required by the crop. Since applying N fertiliser at sowing creates a pool of nitrate N in the soil that is largely not accessed by the crop during the first 2 months post-sowing, this nitrate is at risk of denitrification losses. In splitting N application between sowing and booting, we have demonstrated reductions of 58–81% in N_2O emitted (largely from denitrification), compared to urea all-at-sowing. In a dry growing season, the late-applied N may not have sufficient rainfall to enable its uptake for crop production, as we found in 2013-2014 sorghum season. However, in situations where there are no major loss events between one crop season and the next, this unused N may be available to the following crop in the rotation sequence. An example of this is discussed for unused fertiliser N from a split N application in NSW in 2013/14 season.

Use of urease & nitrification inhibitors to limit fertiliser N losses

Urease is a naturally occurring enzyme that increases the rate of conversion [hydrolysis] of urea [$CO(NH_2)_2$] to ammonium [NH_4^+]. Urease inhibitors are applied with urea to delay this conversion and keep the urea in the urea form. When hydrolysis occurs it creates a localised zone of highly alkaline pH which further converts some of the ammonium to the gaseous form ammonia [NH_3], which can be lost from the soil surface by volatilisation. The greatest risk of volatilisation loss occurs when urea is broadcast onto a moist soil surface and is not incorporated into the soil via rainfall or soil covering. While there are many compounds that can inhibit the urease enzyme, the main one available for use in Australian agriculture is NBPT [N-(n-butyl) thiophosphoric triamide], although it is actually the breakdown product of NBPT that is the inhibitor. Urea coated with NBPT has been shown to reduce ammonia volatilisation loss in a range of crop and pasture situations.

Nitrification is the process of conversion of ammonium [NH_4^+] to nitrate [NO_3^-] in the soil, so the use of a nitrification inhibitor with an applied fertiliser aims to delay this process and keep more of the nitrogen in the ammonium form. The reason for applying this inhibitor is to prevent N loss via nitrate leaching or nitrate denitrification, which occurs in anaerobic soil conditions (e.g. waterlogging). Losses from denitrification in dryland cropping are sporadic, but can result in up to 50% of the applied fertiliser N being lost to the atmosphere, mainly as di-nitrogen gas [N_2]. The greenhouse gas nitrous oxide [N_2O] is also emitted from the soil during denitrification. Unlike ammonia volatilisation, which only occurs at the surface, denitrification occurs within the soil wherever nitrate and labile carbon (as an energy source for the microbes which drive this process) are present. Denitrification gases [N_2, N_2O] are not retained by soil adsorption, unlike ammonia [NH_3] which is easily adsorbed by soil surfaces. Some of the chemicals that can be used for nitrification inhibition include 3,4-dimethylpyrazole phosphate (DMPP), dicyandiamide (DCD), and 2-chloro-6-(trichloromethyl) pyridine. Urea coated with DMPP (commercially available as Entec®) has been shown in 4 northern NSW and 4 Qld trials to reduce N_2O emissions by an average of 85% (range: 65–97%) compared to uncoated urea. Despite the reductions in N_2O loss, there have generally been marginal or no benefits to grain production or gross margins from using DMPP that justified its additional cost compared to untreated urea.

Measurement of fertiliser N losses with ^{15}N-isotope-labelling experiments (2012-2015)

During the past 3 years we have used isotope-labelled (^{15}N) urea fertiliser to trace the fate of applied N in 6 season-long mini-plot field experiments with sorghum near Tamworth and Quirindi/Breeza in NSW, and in 11 experiments on the Darling Downs and Inland Burnett regions in Qld (Kingsthorpe, Kingaroy, Kupunn, Bongeen and Irongate). Normal fertiliser contains ^{14}N so the use of ^{15}N allows us to trace the urea-N applied into the harvested grain, the plant residues, large roots, and the soil profile after harvest. The difference between what we applied and the total of what was found after harvest was assumed to be the N lost by denitrification, as the urea was mixed/banded into the soil to minimise ammonia volatilisation, adjacent crop rows and soil were sampled to quantify any lateral movement and/or the mini-plots had raised steel borders to minimise surface runoff. Possible leaching of applied N was accounted for by deep coring of the mini-plots and measurement of mineral N to 150 cm depth.

Trial results

NSW sites (see Figure 1).

In <u>2012-13</u> experiments, total gaseous loss (N_2 + N_2O) ranged from 28–45% of applied N. At the Tamworth (drier) site, there was no effect of N fertiliser rate on the proportion lost (21%), while at the Quirindi (wetter) site, N losses were 43%, 44% and 27% from the 40, 120 and 200 kg N/ha treatments, respectively. It is likely that the proportion lost from the 200 N rate was lower because some of the excess nitrate N moved lower in the soil during the heavy rainfall period rather than being denitrified. Evidence for this was seen in the greater uptake of applied N into the grain protein in this treatment.

In <u>2013-14</u>, a much drier sorghum-growing season, we used ^{15}N either as (a) urea at sowing, (b) as urea applied at 7-leaf stage, or (c) as urea applied at sowing with a nitrification inhibitor. At the Tamworth site, there was no difference in total N lost between treatments (26%), but of the N applied only 10% was found in plant tissue at harvest when applied at the 7-leaf stage, compared to an average of 36% in the plant when N was applied at sowing. This is because there was only one rainfall event after the late-applied N fertiliser, so limited opportunity for plant N uptake after the topdressing. At the Quirindi site, there was only 4% total N loss from the inhibitor treatment, compared to an average N loss of 20% from urea either applied at sowing or at 7-leaf stage. The main difference between the urea and the inhibitor treatment was in the extra 15% of applied N found in the soil at harvest in the treatment where the inhibitor had been used, compared to ordinary urea. Only 13% of the late-applied N was found in the plant tissue (including grain) at harvest, compared to an average of 28% in the other treatments applied at sowing.

In 2014-15, an ideal summer for sorghum growing (after a dry start), our treatments compared (a) urea added at sowing, and (b) urea split between sowing (33%) and 7-leaf stage topdressing (67%). At the Tamworth site, there were also two different N rates applied, depending on whether the previous crop was sorghum (120 kg N/ha) or soybean (40 kg N/ha).

Overall N losses averaged 29%, and were not affected by the previous crop, but were 4% greater when the N was applied all-at-sowing. The difference in N loss was an extra 4% found in the top 0-10 cm of the soil of the split N treatments; there was no difference in N recovery in the crop.

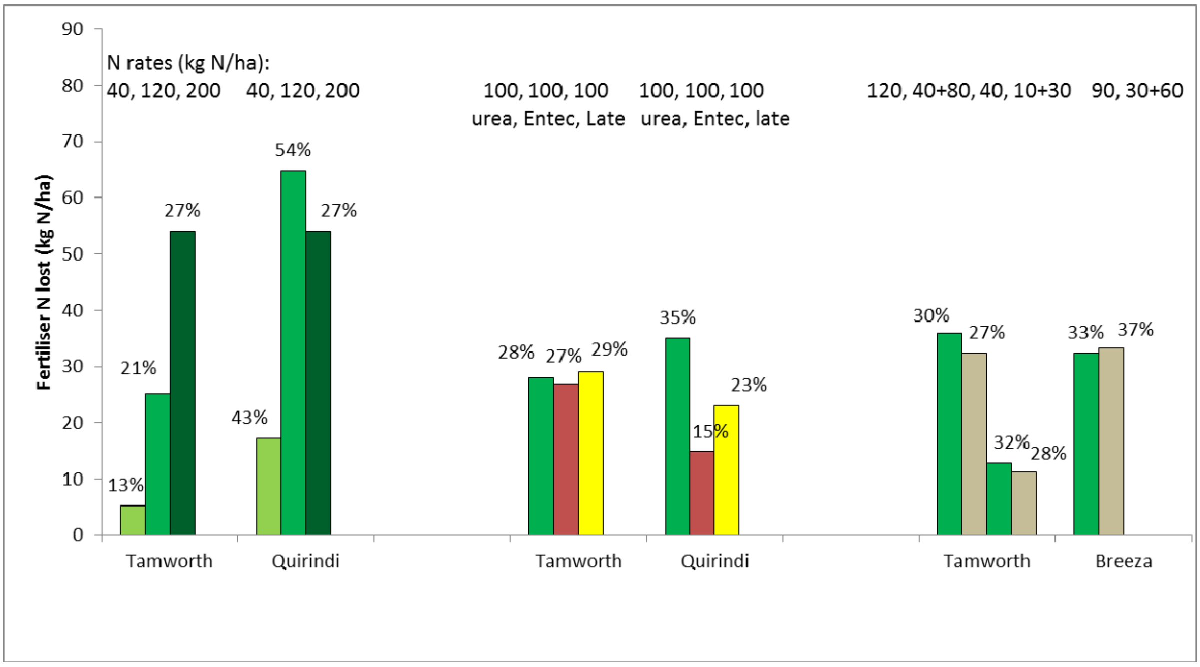

Figure 1. Losses of applied urea-N in field trials on Vertosol soils in northern NSW during the NANORP project. Losses were calculated from recoveries of 15N labelled urea in soil and plant material.

Qld sites (see Figure 2).

In a very wet 2012-13 season, total gaseous loss (N_2 + N_2O) ranged from 23–48% of N applied prior to or at sowing on black and grey Vertosols but was minimal with split applications on a brown Ferrosol near Kingaroy with very low soil N reserves. On the Vertosol sites at Kupunn (sown early October) and Kingsthorpe (sown late November) losses tended to increase with fertiliser N rate, representing 23%, 40% and 47% at Kupunn and 34%, 46% and 48% at Kingsthorpe for the 40, 80 and 120 kg N/ha rates, respectively. The high losses in the 80 and 160 kg N/ha rates at Kupunn emphasised the vulnerability of any excess fertiliser N supply (optimum N rate was 80N at that site) remaining in the soil during a late season wet event (block received 100mm and was flooded near physiological maturity). Conversely, the N_2O-N emissions monitored at Kingsthorpe suggested most losses occurred in response to prolonged wet (not waterlogged) soil in the 6-8 week period following sowing and fertiliser application (i.e. before most crop N uptake occurred). For this site-season combination the optimum N rate was ~170 kg N/ha.

At the Kingaroy site the interaction between rotation history (grass or legume ley pastures) and N rate was explored, with the higher fertiliser N requirement after the grass ley (100 kg N/ha versus 70 kg N/ha after the legume ley) resulting in similar crop yields but emissions intensities (kg N_2O-N/t grain yield) twice as high as in the legume history.

The 2013-14 season was much drier, as in NSW. Experiments again looked at losses in response to urea-N rate (Bongeen), while also comparing responses to urea to those from urea with a nitrification inhibitor (Kingaroy and Kingsthorpe). The impact of the inhibitor was assessed in terms of crop performance (growth, yield and N uptake), but total gaseous N losses determined using ^{15}N were only assessed for the urea treatments. Losses were lower at all the Vertosol sites (13-30% of applied urea-N), but slightly higher in the Kingaroy site (15-25% of applied N), with the latter requiring frequent sprinkler irrigations (totalling 160mm) to provide enough water to grow the crop. The relationship between losses and N rate evident in 2012/13 was not as consistent in 2013/14, and was perhaps most evident at the irrigated Kingaroy site, where 14%, 18% and 28% of applied N was lost in the 40, 80 and 120N rates, respectively (optimum N rate at this site was ~120 kg N/ha). In the Vertosol sites the lower yields and crop demands (and hence lower optimum N rates) did not lead to large N losses during the growing season as there were few (2 at Kingsthorpe and only one, near physiological maturity, at Bongeen) significant rainfall events and most ‘surplus’ fertiliser N could be found as NO_3-N in the soil profile after crop harvest.

Despite 65-70% reduction in annual N_2O emissions in the treatments with the nitrification inhibitor at both sites, there was little agronomic benefit other than a slight (10-15 kg N/ha) reduction in the optimum N rate and a slight increase in yield (the latter at Kingaroy only) with the inhibitor. These responses were not sufficient to cover the price premium charged for the commercial nitrification inhibitor product (i.e. ~20% more/kg N applied).

2014-15 turned out to be a great sorghum growing season after a dry start that caused poor crop establishment and a replant at one early-sown trial site. We ran 5 experiments, with 3 again comparing rates of urea with urea and a nitrification inhibitor. The other sites either simply looked at urea N rate (Irongate early sown) or the interaction between N rates and crop rotation history (Kingaroy). In the later sown Vertosol sites that experienced wet conditions during early growth (Irongate late and Kingsthorpe) losses again increased with N rate, although not always as a proportion of N applied. Losses ranged from 15-45% of applied N, depending on site, with the contrast between the early and late sown Irongate sites particularly interesting. Fertiliser N was applied at the same time at both sites (planting of the successful early sown block), but there was no effective rainfall after that until flowering in the early block (and re-sowing of the late block). The lower losses of fertiliser N in the early sown block were related to the strong sink present (a well grown sorghum crop near flowering) when the fertiliser N was converted to nitrate-N by in-season rainfall, compared to the late sown block where nitrate rapidly became available but there was effectively no crop uptake for a period of 4-6 weeks, during which soils remained wet.

Once again, the reduction in N_2O emissions from use of the nitrification inhibitor was much greater than any effect on crop growth or fertiliser N requirement. The effect of grain legumes in the crop rotation on fertiliser N requirement, N_2O emissions and N losses was also consistent with the ley pasture trial in 2012/13 – fertiliser N requirements were less and N_2O emissions intensity was lower (by 25%) in the legume systems compared to back to back sorghum.

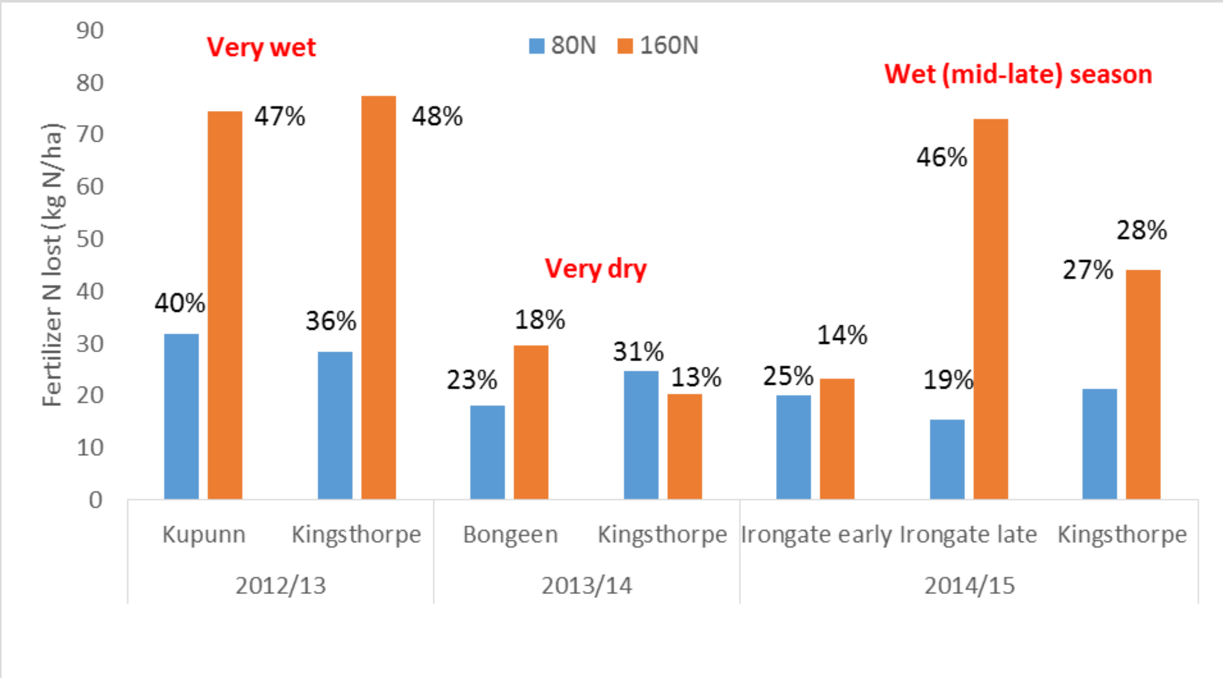

Figure 2. Losses of applied urea-N in field trials on Vertosol soils in Queensland during the NANORP project. Losses were calculated from recoveries of ^{15}N labelled urea in either soil or plant material.

Local case studies illustrating management strategies to reduce N losses

NSW – Impact of timing of N application (Courtesy of Maurie Street and Ben O'Brien, GOA)

In 2015, two central-west wheat trials on nitrogen rate and timing of application showed poor crop N uptake by wheat when urea was pre-applied in late December 2014. At both sites (Narromine, Nyngan), the urea was drilled into sandy clay loam topsoils. The sites had already had 40-50 mm during December and another 30-40 mm followed in the week after N was applied. Another 140-180 mm of rain fell from January until sowing in early May 2015. The aim of these trials was to compare pre-applied N, at-sowing N and in-crop N applications on wheat production and grain protein. While the crop data is not yet available, in-crop sensing results (NDVI) indicated that the pre-applied N treatments were not showing the N-rate responses seen in the at-sowing N treatments.

Pre-sowing soil testing conducted in the pre-applied N plots was unable to account for 2–91% of the N applied in December, with greatest apparent losses in the 200 kg N/ha treatments at both sites. Profile results indicated little or no downward movement of mineral N below 30 cm depth in the soil. Nitrate denitrification was presumed to have caused much of these losses since the urea was incorporated into the soil. However, some ammonia may have volatilised from the soil surface of these light-textured soils. Weed N uptake and N immobilised by microbial breakdown of crop residues may also have accounted for some of the applied N.

Qld – Impact of legume N on fertiliser requirement and N_2O emissions

An experiment was established at Kingaroy to explore the impact of crop rotation (grain or grain legume pre-histories) on fertiliser N requirement and NUE during a subsequent sorghum crop in 2014/15. The pre-histories were sorghum, peanut or soybean in the 2013/14 summer, all harvested for grain. In the second summer crop year (sorghum), the fertiliser N rate required to achieve maximum sorghum grain yield (6.3 t/ha) was reduced by at least 50% after a peanut rotation (i.e. 60 kg N/ha compared to 120 kg N/ha) or eliminated totally after a soybean crop (i.e. no fertiliser N response). Fertiliser N losses determined using ^{15}N recovery were negligible at the optimum N rate in each history (<5 kg N/ha), with 65-70% of the applied N accumulated in crop biomass at this high yielding site. Regardless, cumulative N_2O emissions during the growing season and the emissions intensity (kg N_2O N/t grain produced) were 35% higher in the sorghum history with 120 kg N fertiliser/ha than in legume histories with 60 kg N fertiliser/ha.

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In Qld the project team also included Prof Peter Grace, Dr Clemens Scheer, Dr David Rowlings and Dr Max de Antoni Migliorati (QUT), while the field program was managed by Gary Harch, Peter Want, Lawrie Smith, Peter Aegis, Rod Obel and Trish Balzer. Julie Renwick, Alice Strazzabosco, Rachael Nicholls and John Taylor (QUT) are recognized for their analytical work.

References

Fillery IRP, Khimashia N (2015) Procedure to estimate ammonia loss after N fertiliser application to moist soil. Soil Research (online early) http://dx.doi.org/10.1071/SR14073

Schwenke G (2014) Nitrogen volatilisation: Factors affecting how much is lost and how much is left over time. http://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/07/Factors-affecting-how-much-N-is-lost-and-how-much-is-left-over-time

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Wheat rust in 2015 – where are we heading?

Steven Simpfendorfer, NSW DPI Tamworth

Key words

Stripe rust, management, variety purity, leaf rust, disease standards, Adult Plant Resistance (APR)

GRDC code

DAN00176: Northern NSW integrated disease management

Take home message

- Stripe rust has not gone away!
- Know the difference between a 'hot individual plant' and a 'hot-spot' before creating panic
- If you had stripe rust in your EGA Gregoryᶲ in 2015 it is likely a seed purity issue. Consider freshening up your seed source.
- EGA Gregoryᶲ remains MR to stripe rust and does NOT require fungicide application
- Consider 'up-front' or early season fungicide management of stripe rust in Suntopᶲ in 2016, especially under higher nitrogen status
- Be aware of the development and spread of new wheat leaf rust pathotypes in your region
- The north is on track with rust management, do not slip on minimum disease standards, any perceived short-term gains are likely to result in long-term pain for ALL.

Stripe rust in 2015

Stripe rust first appeared in wheat crops in north NSW/southern Qld (North Star and Goondiwindi) in moderately susceptible (MS) varieties (Sunzellᶲ and Gauntletᶲ) at the start of August in 2015. Cooler autumn/winter temperatures and rainfall during this period were very conducive to the development of stripe rust in 2015. Stripe rust infection occurs as long as there is leaf wetness of between for 5-6 hours (minimum 3 h) with temperatures below 20^oC (optimum 6^oC to 12^oC). During much of the growing season these conditions usually occur overnight. There were numerous reports of stripe rust 'hot-spots' in the MR-MS variety Suntopᶲ across regions in 2015. Samples of stripe rust were submitted to the Australian Cereal Rust Control Program (ACRCP) at the University of Sydney's Plant Breeding Institute throughout the 2015 season, with pathotypes 134 E16 A+ (WA pathotype), 134 E16 A+ 17+ (WA Yr 17+ pathotype) and 134 E16 A+ 17+ 27+ (WA Yr 17+27+ pathotype) confirmed in Queensland and northern NSW.

Three non-fungicide treated GRDC funded NVT trials were conducted in northern NSW (North Star, Spring Ridge and Tamworth) in 2015. Early and very high levels of stripe rust developed in the North Star and Tamworth sites with lower and later development of stripe rust occurring at the Spring Ridge site. All trials allowed good evaluation of the relative resistance of wheat varieties and advanced breeding lines to stripe rust in the absence of fungicide protection.

All sites were exposed to natural infection from stripe rust. That is, they were not artificially inoculated with stripe rust spores. The development of significant levels of stripe rust at all three geographically spread sites highlights that stripe rust inoculum was not a limiting factor in the 2015 season. All rusts (stripe, leaf and stem) are ***biotrophs*** which means they require a living host to survive between seasons. This is primarily volunteer wheat in the case of cereal rusts but wheat stripe rust has been shown to also survive on barley grass in some seasons. Barley grass also gets infected by a barley grass specific stripe rust pathogen that cannot infect wheat but can cause infection on some barley varieties. Barley stripe rust is not currently present in Australia which is fortunate, as overseas screening indicates that around 80% of current barley varieties would be MS or worse if this exotic pathogen was to establish here (William Cuddy, personal communication). Any samples of stripe rust on barley or barley grass should be submitted to the ACRCP for pathotype determination. The higher probability of summer rainfall in northern NSW/Qld is conducive to the survival of volunteer wheat between cropping seasons which is commonly referred to as the ***green bridge***. When combined with a wide spread in sowing times of roughly between March for dual purpose wheat varieties through to June for quicker maturing main season varieties this situation is quite conducive to the survival and development of stripe rust.

Early and severe infection levels developed at the North Star site with the WA Yr17+27+ confirmed as the dominant pathotype in the trial. The WA Yr17+ pathotype developed as a mutation of the original WA pathotype, being first detected in 2006. This pathotype further mutated to develop virulence for the *Yr27* gene with the WA Yr17+27+ pathotype first detected in 2011, which reduced the resistance level of varieties such as LivingstonΦ and MerindaΦ (Figure 1). All three pathotypes are now distributed across the northern region including into Qld.

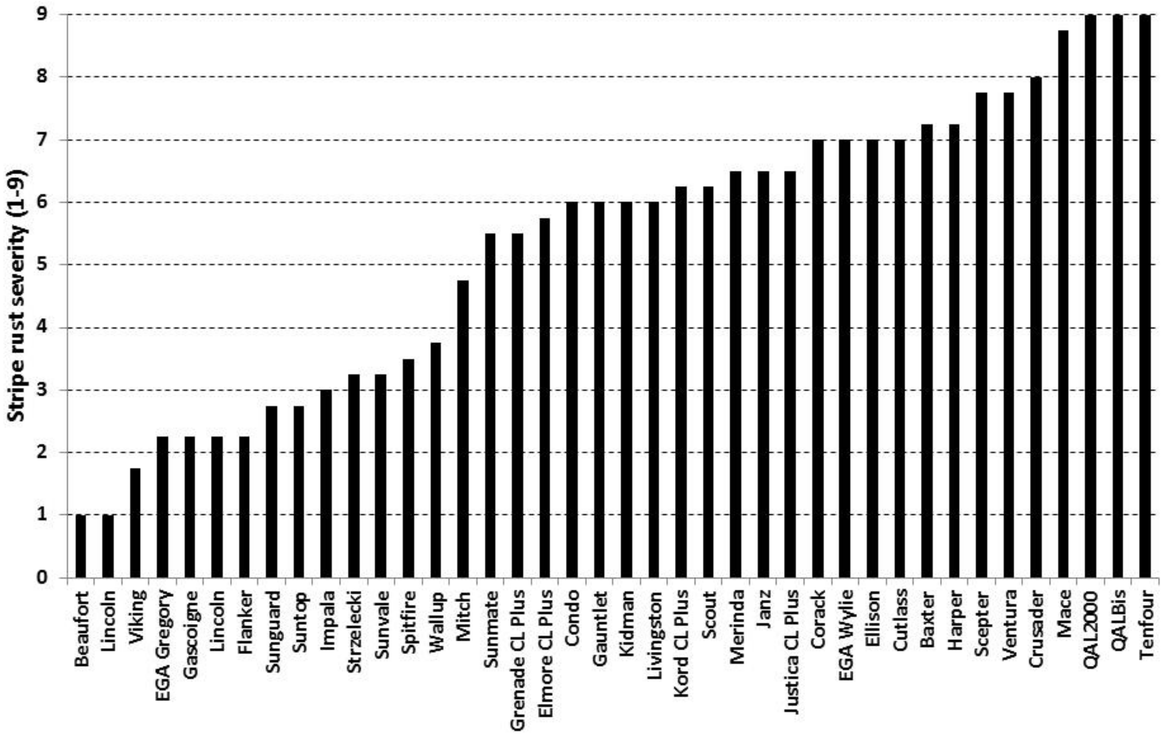

Figure 1. Stripe rust reaction of released wheat varieties in main season NVT - North Star 2015

Stripe rust in EGA GregoryΦ

Two reports of the supposed 'break down' of stripe rust resistance in EGA GregoryΦ occurred around Wongarbon and Warialda in 2015. NSW DPI inspected the EGA GregoryΦ crop at Wongarbon and there were 'hot individual plants' NOT 'hot-spots' evident in the crop. A ‘hot-spot’ is **all** plants in at least a 1 m circle with development of pustules and occurs due to higher humidity during winter causing spores to remain in small clumps that are relatively heavy, which limits spread by wind. Spread is therefore mostly over small distances, which results in the appearance of ‘hot-spots’ of infection usually first appearing in late winter to early spring. All plants along multiple 1 m sections of row affected by stripe rust were pulled from the EGA Gregory⊕ crop at Wongarbon and separated into individual plants. It then became obvious that there were individual plants along the row infected with stripe rust and others with no visible signs of infection. That is, there were infected individual plants ('hot individual plants') but **not** every plant along a 1 m section of row and adjoining rows infected with stripe rust. There were **no** 'hot-spots' evident in the paddock. This process was explained and repeated by the consulting agronomist with the Warialda EGA Gregory⊕ crop who similarly concluded that it was 'hot individual plants' and clearly not 'hot-spots'. To complete the picture, individual heads from visually infected and uninfected plants from Wongarbon were collected and sent to the University of Southern Queensland (USQ) for molecular analysis to determine varietal purity. Grain collected from 6 out of 6 plants without visible stripe rust infection were identified as EGA Gregory⊕. In contrast seed collected from 5 of 8 plants with stripe rust infection were identified as NOT being EGA Gregory⊕ but all had a similar banding pattern indicating they were all the one contaminant. The actual contaminant variety was not determined but clearly it has increased susceptibility to stripe rust. In both situations the concern around stripe rust appears to be related to more susceptible off-types (contaminants) in the EGA Gregory⊕ crops. Pure EGA Gregory⊕ remains MR to stripe rust and does not require fungicide management. MR varieties such as EGA Gregory⊕ can still develop low levels of stripe rust under high pressure as was evident at North Star in 2015 (Figure 1). However, the level of infection, while visible, does not result in the loss of enough green leaf area to cause significant economic yield loss. If growers are concerned about the levels of stripe rust in their EGA Gregory⊕ then they should consider freshening up their seed source to one with a known and higher purity.

Stripe rust 'hot-spots' in Suntop⊕

'Hot-spots' of stripe rust occurred in two crops around Wellington in 2013, several crops across eastern Australia in 2014 and in numerous crops of Suntop⊕ in eastern Australia in 2015. 'Hot-spots' of stripe rust first appeared in Suntop⊕ crops in northern NSW in early-mid August in 2015. 'Hot-spots' in Suntop⊕ across seasons has been generally linked with higher nitrogen status within paddocks with some paddocks only developing 'hot-spots' in the headlands where double the N rate was applied at sowing. Generally, affected Suntop⊕ crops had no up-front fungicide management and did not have a fungicide application around GS30, which commonly occurs commercially in combination with an in-crop herbicide. There is no new pathotype of stripe rust with increased virulence to Suntop⊕ and it has been confirmed from different paddocks that there is currently no underlying issue with seed purity. That is, crops are pure Suntop⊕ and furthermore true 'hot-spots' are evident in affected paddocks and **not** isolated individually infected scattered plants which would be more indicative of an issue with seed purity.

Suntop⊕ is rated MR-MS to stripe rust, which indicates that it requires one fungicide input (up-front or early between GS30-32) to limit disease development. This message can become complicated as it is often tweaked to the likely timing of epidemic development (significant green-bridge over summer likely to favour earlier epidemic), conduciveness of environment (west of Newell Highway generally drier and hotter which reduces disease pressure) and sowing time (earlier sowing likely to be more favourable to stripe rust and early epidemic development). Generally, varieties such as Suntop⊕ (MR-MS), Lancer⊕ (MR) and even EGA Gregory⊕ (MR) rely largely on Adult Plant Resistance (APR) genes that slow down the rate of disease development. In general, the resistance of the plant increases with plant age and as the temperature rises. The APR gene in EGA Gregory⊕ (*Yr18*) generally appears to express earlier than the gene (*Yr31*) in Suntop⊕. APR in Suntop⊕ appears to be more interactive with lower temperatures and higher N levels which both appear to delay the expression of APR within the leaves. The timing of APR expression remains one of the major issues with stripe rust management in the northern grains region which differs with variety, sowing time, temperature and even N status. When 'hot-spots' occurred in many Suntop⊕ crops in 2015 the actual infection became more obvious because APR had expressed and killed off infected cells within the leaf and the surrounding cells. This renders the infection non-viable by denying the stripe rust fungus of living cells to survive in. Yellow flecking of the flag leaf and other leaves on uninfected Suntop⫯ plants adjacent to the 'hot-spots' indicated the active expression of APR killing spores landing and trying to infect these plants. A close inspection of the oldest leaves (seedling leaves) within the 'hot-spots' revealed a mass of old discoloured pustules which highlights that the infection had been present in these patches for a considerable period. Suntop⫯ still has a very useful level of resistance to stripe rust and is by no means a 'sucker' for stripe rust. This fact is often not easily acknowledged at the grower level when Suntop⫯ for example, may be the most susceptible variety they are currently growing. Hence, the appearance of any infection and the estimation of yield loss (loss of green leaf area) can appear exaggerated without a true susceptible variety to compare infection levels with (Figure 1). Personally, the infection levels observed in 'hot-spots' of Suntop⫯ in 2015 were consistent with an MR-MS reaction. Varieties such as Suntop⫯ which rely on APR as their main source of resistance are worthwhile protecting at early growth stages with seed or fertiliser treatments or an in-crop fungicide application around GS30-32. This will provide protection until APR is expressed later in the season.

Stripe rust management in 2016

The key messages remain the same;

- control the green bridge (volunteer wheat) at least four weeks prior to sowing to delay the onset of epidemics
- select varieties with improved levels of resistance (MR-MS minimum)
- ensure variety identification/purity
- tailoring fungicide strategies to varietal resistance level, rainfall zone, growth stage and seasonal conditions
- monitor crops regularly.

With varieties such as Suntop⫯ that rely largely on APR, consider using an in-furrow fungicide to protect early growth. Flutriafol on starter fertiliser has been shown to provide extended protection against stripe rust in the northern region and is a more common component of stripe rust management strategies for susceptible wheat varieties in the southern region. Fluquinconazole seed treatment also protects early growth but tends to not provide the same length of protection as in-furrow treatments in northern trials.

Be 'alert not alarmed' of leaf rust pathotypes

There are two new pathotypes of leaf rust of potential significance to northern NSW and Qld. The first (76-3,5,7,9,10,12,13 +Lr37) was a mutation of an existing pathotype with combined virulence for the genes *Lr13*, *Lr24* and *Lr37*. It was first detected around Warialda on the feed wheat variety Naparoo⫯ in 2013 and has only really caused issues in this variety in subsequent seasons. A newer 'SA pathotype' of leaf rust (104-1,3,4,6,7,8,10,12 +Lr37) is an exotic introduction to Australia and was first detected in South Australia in 2014. The SA pathotype of leaf rust has rapidly spread north being detected at Dunedoo, Tamworth, North Star and Gatton in 2015 but not at levels that warranted fungicide application. However, this is a warning for subsequent years and growers should check the rating of varieties to these new leaf rust pathotypes with a minimum disease standard of MS recommended by the ACRCP for the northern region. Impala⫯, which has a leaf rust rating of S to existing leaf rust pathotypes, has required fungicide management in northern NSW in recent seasons when conditions (humid and temperatures between 15°C to 25°C) have been conducive to disease development.

Avoid growing susceptible varieties – has the message changed?

No!

The northern region did the right thing by moving away from growing very susceptible varieties such as H45⊕. Numerous field trials across the northern region, largely GRDC funded NVT trials where stripe rust development is routinely controlled with a fungicide management program, highlight that there is no yield penalty associated with growing newer varieties with improved levels of stripe rust resistance. There is a big difference in the level of fungicide intervention required across a season with a susceptible variety (likely three fungicide inputs) compared to an MR-MS variety (one fungicide 'up-front' or around GS30-32) to manage stripe rust in the northern region.

Why are minimum disease standards important?

Minimum disease standards of MR-MS for stripe and stem rust and MS for leaf rust are recommended by the Consultative Committee of the ACRCP for wheat varieties in the northern region (Qld and nth NSW). Selecting varieties with these minimum levels of resistance reduce the build-up of rust epidemics within the region (the more susceptible the variety the bigger issue they are as a green bridge), decrease disease pressure from existing rust pathotypes within the season, reduce the probability of mutations within existing pathotypes occurring with increased virulence to existing rust-resistance genes and reduces the reliance on fungicides as a management tool. The continued production of susceptible and very susceptible varieties, while stripe rust can be controlled with fungicides, jeopardises current and future disease resistance genes. The problem is if you choose to go this way and become reliant on the continuous use of fungicides in susceptible varieties then you are potentially making that decision for the whole industry as rust spores can be spread large distances by wind. Mutations that develop on your farm rapidly spread across regions.

Is fungicide resistance an issue?

A mini-review was recently written on the risk of rust fungi developing resistance to fungicides (Oliver 2014). To summarise, the rust fungi are classified as having a low risk of developing fungicide resistance, which appears justified by long fungicide usage patterns mainly overseas with no confirmed cases of agronomically significant fungicide resistance being reported in a rust pathogen species. The general conclusions from the review were 'Rust fungi have a reputation that suggests they are immune to the development of fungicide resistance, and this has led growers to rely heavily on fungicides for the control of diseases such as stripe rust. This reputation is based on a long history, during which many other species have developed often disastrous resistance to fungicides, especially *Botrytis, Zymoseptoria* and powdery mildews, while rusts have remained well controlled". Within Australia, barley powdery mildew in WA and *Septoria tritici* blotch (*Zymoseptoria,* STB) of wheat in the southern region have been reported in recent years to have developed partial resistance to triazoles. In terms of cereal rusts, the strobilurins (Group 11) are 'protected by a serendipitous intron, DMI fungicides (triazoles, Group 3) are protected by relatively low resistance factors and SDHIs (Group 7; medium to high risk of resistance development) have been protected by mixing with other fungicides and their recent introduction". However, the reviewer still urges vigilance when it comes to the rusts.

It is interesting that in the review (Oliver 2014) the argument that rust fungi are regularly exposed to fungicides but have not yet developed any resistance was largely based on more extended use patterns overseas. "In Europe, where fungicide use on wheat is close to universal, rusts have been regularly exposed to fungicides, even though other species, such as *Blumeria graminis* (powdery mildew) and *Zymoseptoria tritici* (STB), are the prime targets'. It is therefore not too hard to imagine that the converse could occur in Australia where reliance on controlling stripe rust in susceptible wheat varieties is the main target for repeat fungicide applications but this practice is potentially selecting for resistance in other fungal species such as powdery mildew and STB that have a medium to high risk for developing fungicide resistance. Fungicide development and the search for new chemistries in Europe are continually driven by the evolution of resistance within STB to existing and recently released fungicides. This is **NOT** a good scenario and as an industry we would be wise to learn from their mistakes!

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References

Oliver RP (2014) A reassessment of the risk of rust fungi developing resistance to fungicides. *Pest Management Science*, 70: 1641-1645.

Further information

http://rustbust.com.au/

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