GRDC Grains Research Update

Grains Research UPDATE

MULLALEY

Thursday, 21st July 2016

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GRDC Grains Research Update Mullaley

Thursday 21st July, Mullaley Hall

8:30am registration for a 9:00am start, finish 3:35 pm

Agenda

Time	Topic	Speaker (s)
9:00 AM	Welcome	GRDC
9:10 AM	**Practical applications for UAV's and digital imaging.**	*Ben Boughton (Nuffield Scholar & CEO Satamap)*
9:40 AM	**Russian Wheat Aphid - identification, detection, management and implications.**	*Melina Miles (DAF Qld)*
10:05 AM	**Managing patches of glyphosate resistant weeds** – what have we learnt from grower experience? Costs, advantages and practicalities of key IWM tactics.	*Tony Cook (NSW DPI)*
10:35 AM	Morning tea	
11:05 AM	**Harvest weed seed capture systems in the northern region.** Experience with the Harrington Seed Destructor and the Chaff Deck system for weed tramlining.	*Michael Walsh (University of Sydney)*
11:35 AM	**Yield drivers and agronomy for high yielding sorghum** - closing the yield gap!	*Guy McMullen (NSW DPI)*
12:05 PM	**Minimising nitrogen losses to improve use efficiency in cropping systems.** • Understanding loss pathways - how much is lost and factors influencing • The impacts of N source - fertiliser type, organic N and N from pulse crops • Urease and denitrification inhibitors.	*Graeme Schwenke (NSW DPI)*
12:35 PM	Lunch	
1:35 AM	**Nematodes**: Summer cropping options and soil health solutions to manage root-lesion nematodes.	*Kirsty Owen (USQ) & Nikki Seymour (DAF Qld)*
2:15 PM	**Sorghum after canola on the Liverpool Plains** - is there an issue with mycorrhizae?	*Richard Daniel (NGA)*
2:35 PM	**Managing the major mungbean diseases**; halo blight, fusarium wilt, tan spot and powdery mildew.	*Lisa Kelly (DAF Qld) & Sue Thompson (USQ)*
3:05 PM	**A new strain of wheat leaf rust.** Potential impacts, which varieties and what to look for. **Adult plant resistance** - its role and use in rust management.	*Robert Park (University of Sydney PBI, Cobbitty)*
3:35 PM	Close	

Contents

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NDVI is only part of the story – Imagery offers so much more…

Ben Boughton, Satamap Pty Ltd, Gilroy Farms, 2014 Nuffield Scholar (UAVs)

Key words

Remote sensing, management, satellite imagery, variable rate

Take home message

It is important to understand that when imagery is collected there is a broad range of ways it can be used.

Remotely sensed imagery such as satellite imagery (or UAV but varies) is usually first delivered in individual spectral bands such as blue, green, red, near infrared, short wave infrared etc. Using these bands you can then construct all sorts of visualisations and do further calculations. All these examples came from one image capture from the Sentinel 2 satellite on 13 Feb 2016. Location is north of Goondiwindi. It is most likely cotton – but this is just assumed. These are few products that can be generated from a single satellite image acquisition.

1. True colour (natural colour)

Combining blue, green and to create a colour image that recreates the world as our eyes see it. The red square is the paddock we will focus on.

Figure 1. True colour image

2. False colour

Use the above principles but put the 'wrong' bands in the expected colour space. In this example we still combine a version of blue, green and red but the difference is red displays near infrared, green displays red and blue displays green. It sounds confusing but the addition of the near infrared band in the red colour space responds better to chlorophyll highlighting crop variability.

Figure 2. False colour image

3. Individual bands

We can take an individual band and stretch the reflectance values over a defined colour ramp. If we consider the following colour ramp:

Figure 3. Colour ramp

This is a 'haxby' colour chart that has been reversed: low reflectance in white-orange, through to high up in the blue.

If this is printed in black and white – light is low, and dark is high.

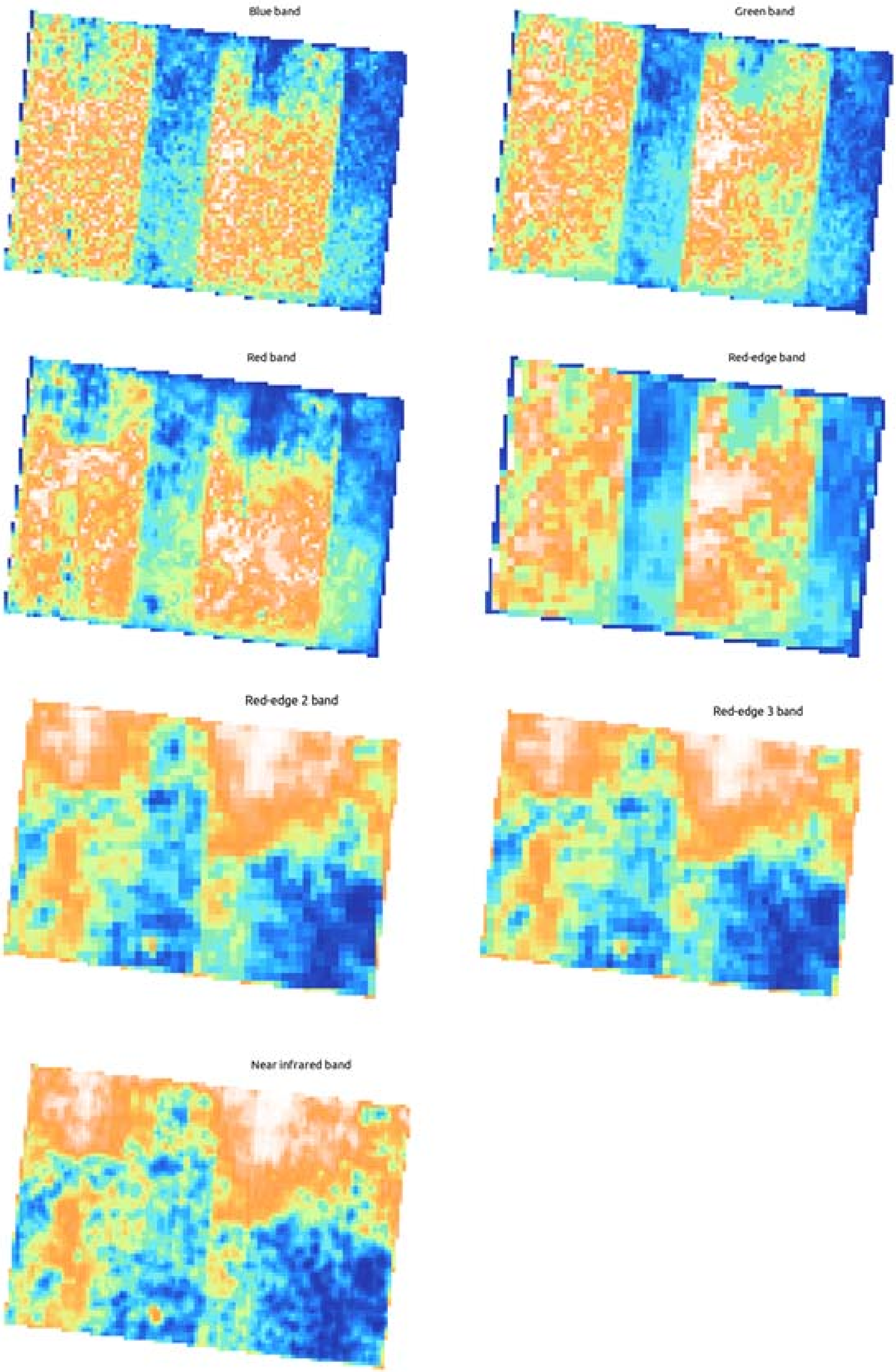

Figure 4. Different colour bands

Notice how each band gives us difference information about the crop, particularly near infrared and red-edge.

*Note imagery has not been atmospherically corrected which is probably why the blue band looks messy. The blue band is the hardest to capture well because our atmosphere does a good job at scattering blue light.

4. Vegetation indices

We can take the imagery one step further and start to apply vegetation indices which involve taking the some individual bands into a known formula to expose more information and/or try correlate with a certain physical attribute.

Most vegetation indices exploit the almost reverse spectral response between red and near infrared.

The most famous of these is Normalised Difference Vegetation Index (NDVI) which is given by the formula:

(near infrared – red) / (near infrared + red)

This generates a map with each pixel given a value between -1 and 1. As we did with the individual bands above we will apply the reverse haxby colour ramp:

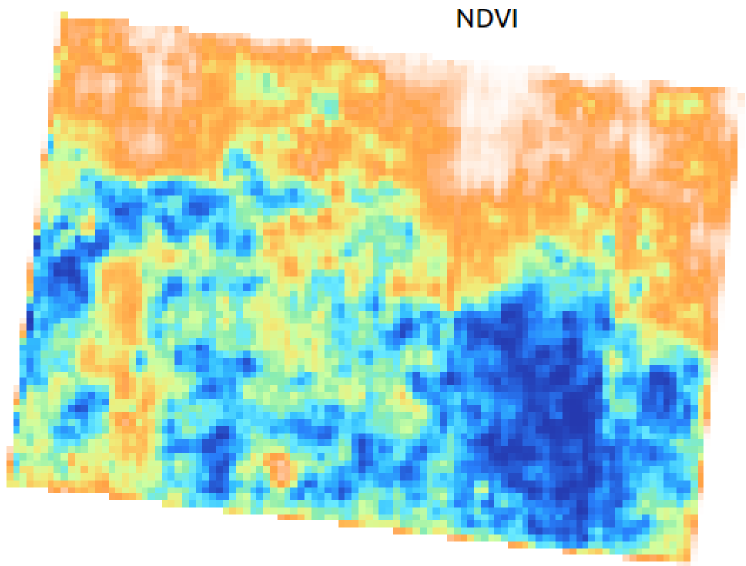

Figure 5. Image created using the NDVI

Of course NDVI is not the only vegetation index. Here are a few others including two band Enhanced Vegetation Index (EVI2) and Modified Triangular Difference Vegetation Index 2 (MTVI2).

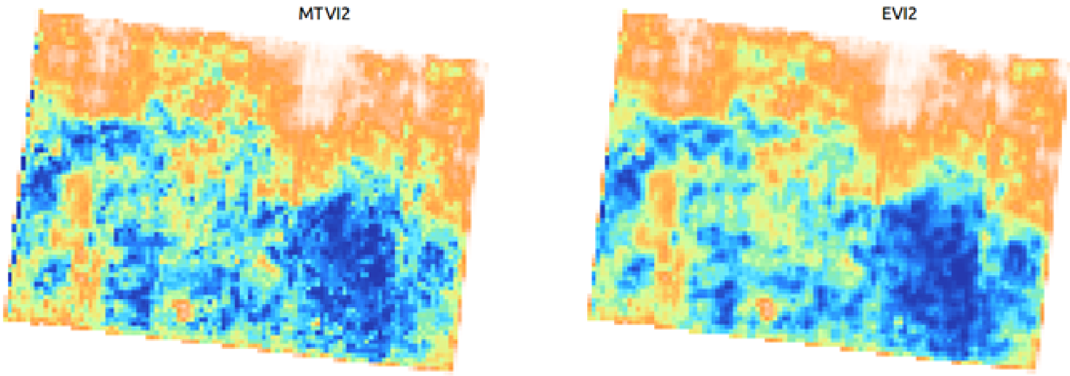

Figure 6. Images created using the EVI2 and the MTVI2

They all appear quite similar when viewed side by side with only small differences as they all work off the same principle as NDVI.

Discussion and conclusion

You should now understand the building blocks of remotely sensed imagery.

If you were to just look at the NDVI map you would get a good understanding of high and low biomass areas and it would give you indication of which areas need your attention. In this particular example, when you look at any of the colour bands in isolation it is evident that there is a management driven function contributing due to the obvious sections. Without a ground truth we would never really know what is going on.

Often we see this sort of effect if half a paddock is sprayed with a selective herbicide. This can change the leaf angle on the target species (i.e. spraying Tordon 242 in a wheat crop temporarily changes leaf angle visible in colour bands but not vegetation index such as NDVI).

The red-edge band sits in between red and near-infrared and offers valuable insights into plant physiology such as chlorophyll content. Sentinel 2A offers 3 different red edge bands that could offer valuable information. If you look at the individual bands above you will see the first red edge band is most similar to red and the 3rd is most similar to near infra-red which reflects where these bands sit in the spectrum. This seems to show up variability not seen in the other bands. Just by looking at the data we do not know what is causing this variability but it is an area ripe for investigation. RapidEye is a different satellite constellation from our example but this paper offers further explanation into red edge: http://www.blackbridge.com/rapideye/upload/Red_Edge_White_Paper.pdf .

There are other uses for this imagery. For example, if you take two separate dates, it is possible to generate a change map to see which areas of paddock have gained (or loss) relative biomass.

Understanding the building blocks is one thing, but to make this effort worthwhile consider some of the practical uses for imagery. The accuracy and effectiveness of these can vary but overall the list seems to be getting longer all the time. The more it is in the hands of agronomists and farmers, the more uses are discovered.

Practical uses for imagery include:

- Tracking crop growth within seasons and compare crop growth between seasons.
- Yield forecasting
- Readily identifies areas of average, better than average and below average growth so that inspections and solutions are more targeted.
- Identifying resistant weeds
- Creating variable rate maps

- Irrigation scheduling.
- Identifying inaccurate irrigation in areas/zones
- Emergence and or gappiness maps particularly for replanting
- Identifying better field layouts and areas that are not profitable to farm
- Benchmarking across localities and regions
- Tracking previous crop performance when purchasing properties
- Targeted insecticide applications
- Targeted fertiliser applications
- Harvest timing
- Overall tracking of crops and yield forecasts over farms spread across regions or across Australia
- Picking trends and successful strategies across clients
- Understand crop areas and crop status to help with input forecasting
- Understanding crop dynamics and tracking hail/storm/drift events
- Tracking pasture growth and utilisation
- Crop forecasting and resource management
- Crop growth and yield forecasting on a regional basis and an Australia wide basis
- Using historical data to assess trends
- Tracking fertility especially different fertiliser regimes and the effect of previous crops and the waterlogging et cetera
- Formulating top dressing strategies
- Mapping out areas of high growth for fungicide and growth regulator application.
- Tracking herbicide damage and off target drift
- Assessing trials
- Assessing potential paddock yields for marketing strategies and insurance purposes

It is important to understand that when imagery is collected there is a broad range of ways it can be used. We have only scratched the surface here.

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Russian Wheat Aphid - identification, detection, management and implications

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Managing patches of glyphosate resistant weeds

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Harvest weed seed control systems for the northern region

Michael Walsh, Director Weed Research, University of Sydney

Key words

IHSD, Chaff tramlining, HWSC

GRDC code

UWA00171

Take home message

Chaff tramlining is a simple, effective approach to harvest weed seed control (HWSC) that removes the need for residue burning for HWSC. This system is particularly suited to high residue situations with dedicated tramlines. The newly commercialised iHSD is a more sophisticated approach to HWSC where two hydraulically driven chaff processing mills are neatly fitted to the rear of the harvester. This highly effective system also reduces the need for residue burning but has the added advantage of retaining and redistributing all residues back across the paddock.

Background

There are now several commercially available HWSC methods that effectively target the weed seed bearing chaff fraction during crop harvest. Studies on the efficacy of these practices: narrow windrow burning, chaff carts, bale direct (BDS) and Harrington Seed destructor (HSD) have clearly demonstrated their efficacy in preventing inputs of viable inputs of seed into the seed bank (Walsh et al., 2014; Walsh et al., 2012; Walsh and Newman, 2007; Walsh et al., 2013). However, single system is suited for use across all of Australia's crop production regions and situations. Therefore, there remains a need for the availability of multiple systems and the ongoing development and refinement of current HWSC options. Two relatively new systems, chaff tramlining and the iHSD have recently been introduced and expectations are that their adoption will be high in the northern cropping region.

Chaff tramlining

The practice of concentrating chaff material on dedicated tramlines is termed chaff tramlining where weed seeds are placed in a hostile environment from which it is difficult for germination and emergence. As with all other HWSC systems chaff tramlining focuses on the weed seed bearing chaff fraction and therefore, depending on seed survival has the potential to be similarly effective. In a trial at North Parkes, NSW, comparing narrow windrow burning and chaff lining with conventional harvest both HWSC systems resulted in a 60% reduction in annual ryegrass emergence.

A study evaluating over summer annual ryegrass seed survival at Esperance, WA highlighted the hostile nature of the chaff tramline environment. There was very low seed survival for annual ryegrass seed placed under canola and barley (Table 1). Interestingly though survival was considerably greater for seed placed under wheat chaff. This is despite similar levels of chaff biomass for wheat and barley in particular. At the second time of assessment only annual ryegrass seed beneath the wheat chaff was surviving. At this stage it is not known why there are large differences in seed survival between the different chaff types but obviously this will have a significant effect on the efficacy of chaff tramlining.

Table 1. Survival of annual ryegrass seed at seeding and crop anthesis following placement under a chaff tramline during the previous harvest.

Chaff type	Chaff (t/ha)	Survival (%)	
		At seeding	Anthesis
Canola	31	2	0
Wheat	19	74	10
Barley	18	3	0

Integrated Harrington Seed Destructor (iHSD)

The iHSD is now commercially available as a retrofit system for harvesters in Australia. Testing of the weed seed destruction efficacy of this mill system over the last two seasons has determined that there was similarly high efficacy as the cagemill used in the trail behind HSD system (Table 2). Very high level s of seed destruction were recorded for the four dominant species of Australian cropping, annual ryegrass, wild radish, wild oats and brome grass.

Table 2. Effect of iHSD mill processing of wheat chaff on the seed mortality of four weed species.

Weed species	Seed kill (%)	SE
Annual ryegrass	93	0.7
Wild radish	99	0.2
Wild oats	99	0.1
Brome grass	99	0.2

High weed seed destruction levels were recorded when the iHSD mill system was evaluated under commercial harvest conditions. During the harvest of canola and barley crops known numbers of annual ryegrass, wild radish, wild oat and brome grass seed were introduced to an iHSD mill fitted to a class 9 harvester. Processed chaff was collected and sieved and sorted to recover viable weed seeds. In all instances there was 99% kill of the introduced weed seed.

Summary

The number of HWSC options continues to grow as producers look to utilise this approach to weed control in cropping systems. The iHSD is now commercially available following several years of field stationary mill testing that have proven its efficacy and commercial capacity. Chaff tramlining is becoming widely adopted as growers move to tramline systems and look to reduce residue burning in their production systems. Both approaches are highly effective weed control tools and can provide considerable support for herbicide based weed management programs.

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High yielding sorghum – closing the yield gap

Loretta Serafin and Guy McMullen, NSW DPI, Tamworth

Key words

Sorghum, yield, grain, nutrition, nitrogen, phosphorus, time of sowing, hybrid

GRDC code

DAN00181

Take home message

- Time of sowing can have large impacts on final crop yield, however being able to identify when to plant depending on the season is not possible.
- Nitrogen nutrition had the largest impact on crop yield across the three seasons.
- Hybrid performance varied between seasons and sowing times, however there was no consistent pattern of which hybrid yielded the best.

Introduction

The Liverpool Plains is one of the highest yielding environments for the production of grain sorghum in Australia, making it an extremely important crop in the rotation due to the profit margins which result. The high yields result from in the environmental conditions which the crop is exposed to, in combination with the soils and agronomic management.

While, average yields are high compared to other sorghum production zones, there is a question over whether current yields are fully meeting their potential. There is also a need to determine the contributions that each of the agronomic decisions have on sorghum yields so that their relative impact on the gross margin can be attributed.

In this research six key agronomic practices have been investigated; row spacing, plant population, hybrid selection, nitrogen (N) and phosphorus (P) nutrition and time of sowing at two locations on the Liverpool Plains during the growing seasons of 2013-14, 2014-15 and 2015-16.

In each season, trials were conducted at two locations, the NSW DPI Research Station at Breeza and in commercial sorghum paddocks at Pine Ridge (2013-14), Willow Tree (2014-15) or Premer (2015-16) in the respective seasons.

In this paper, results from the three years of trials from the Breeza site will be discussed as this provides a data set over three consecutive years at the same location. The 24 treatment combinations used in these trials were partially factorial (Table 1). The data from a subset of ten of these treatments is presented here (Table 2) as final analysis is ongoing.

The trial treatments were designed around a stepped approach of segmenting the key factors starting with a high input or “Rolls Royce” treatment option (shaded in Table 2; treatment 24) which used the top rates of nitrogen (200 kg /ha) and phosphorus (20 kg/ha) in combination with a recent released hybrid; MR Scorpio. This was then compared to a range of contrasting treatments where only one factor was changed each time; for example less nitrogen, down to a “basic” version (Table 2; treatment 3) which used an old hybrid, MR Buster, with no additional crop nutrition.

The data generated from this complex set of interactions is invaluable in partitioning yield and ultimately economic return from crop inputs.

Table 1. Treatment combinations

Agronomic Factor	Options included in trial		
		TOS 1	TOS 2
Time of sowing (TOS)	2013-14 2014-15 2015-16	31st October 12th November 14th October	10th December 20th December 3rd December
Row spacing	Normal row: 90 cm (2013-14 only) then 100 cm (2014-15 and 2015-16) or Twin rows (two rows 7.5cm apart)		
Plant population	50, 75 and 100,000 plants/ha		
Hybrid	MR Buster, MR Scorpio and 85G33		
Nitrogen	0, 100 and 200 kg N/ha or a 100:100 split at 6-8 leaf stage applied as Urea, side banded at sowing or spread on the surface for the split application.		
Phosphorus	0, 10 and 20 kg P/ha with seed at planting applied as Triple Superphosphate		

Breeza 2013-14 Results

In the 2013-14 season, two trials were run at Breeza on 1.8 m wide raised beds. Both trials were pre-irrigated to ensure a full profile at the start of the season and then one trial was treated as dryland and the second trial was irrigated; receiving two in crop irrigations.

In this season, across all treatments there were only small differences as a result of varying the time of sowing in both the irrigated and the dryland trial, with TOS1 yielding between 0.24 (dryland) and 0.35 (irrigated) t/ha more than TOS2. Differences for the individual treatment combinations varied more.

The largest impact on crop yield was from reducing the nutrition inputs (Table 2), when comparing the high input treatment number 24, using MR Scorpio at a plant population of 50,000 plants/ha in combination with 200 kg of N/ha and 20 kg P/ha with treatment 1 which had MR Scorpio at the same population but no applied nitrogen or phosphorus. The reduction in yield was 2.62 and 2.73 t/ha for TOS 1 and 2 respectively in the irrigated trial and 1.62 and 1.11 t/ha for TOS 1 and 2 respectively in the dryland trial.

If we compare these results to treatment 2 with zero nitrogen and 10 kg P/ha we can see that the majority of the yield is coming from the application of the N as opposed to the P. This is reinforced by comparing treatment 23 with 24, where only the P has been omitted and the N rate has remained at 200 kg N/ha. In both trials and sowing times we see a much smaller variation in the yield of less than 0.4 t/ha, further reinforcing the benefit of the nitrogen and the minimal impact of phosphorus at this site.

The value of utilising new hybrids has been compared in these trials through the use of MR Buster as an old hybrid, and MR Scorpio and 85G33 as new hybrids. If we compare similar treatments, with the exception of changing the hybrid such as treatments 10, 5 and 8 we find small differences of up to 0.5 t/ha between hybrids but no consistent pattern.

The comparison of the “Rolls Royce” treatment 24 with the “basic” treatment 1 showed a 0.98 – 2.89 t/ha difference in yield, validating the major improvements in yield which can be obtained from getting all of the crop agronomics right.

Breeza 2014-15 Results

In the 2014-15 season, only a dryland trial was conducted at Breeza, on 2 m raised beds. The beds were pre-irrigated to provide a full profile and then remained dryland. The two times of sowing were planted 12th November for TOS 1 and 20th December for TOS 2 and resulted in a large difference in yield, with TOS 1 on average yielding 6.46 t/ha versus 2.57 t/ha for TOS 2. The late planting suffered under cold conditions during grain fill and high midge pressure. As a result of these combined stresses on the crop in TOS 2 there were very few differences of note between the different treatments.

Large differences in yield between treatments were observed in TOS 1. The largest impact on yield was obtained from reducing the nitrogen nutrition to the crop. The “Rolls Royce” treatment 24 provided the highest yields in TOS1 with 200 kg N/ha and 20 kg P/ha. There was a negligible impact on yield when the P was omitted in treatment 23 but the nitrogen rate was maintained. In contrast, when the N rate was reduced to 0 but 10 kg of P was retained as in treatment 2 the yield was reduced by 1.70 t/ha. Reducing both the P and N to zero (treatment 1) resulted in a larger reduction in yield of 2.72 t/ha.

The yield performance of the different hybrids, comparing treatments, 5, 8 and 10 was much larger in the 2014-15 season, than in the 2013-14 season. Differences of 1.3-1.4 t/ha were found between hybrids when all other factors were kept the same but again the pattern of which hybrid performed the best was not consistent across the sowing times, with MR Buster being the highest yielding in TOS 1 and MR Scorpio in TOS 2.

Comparing the “Rolls Royce” treatment 24 with the “basic” treatment 1 resulted in a 0.84 t/ha yield difference in TOS 1. The differences in TOS 2 were negligible for reasons discussed earlier.

Breeza 2015-16 Results

In the 2015-16 season a dryland trial was conducted at Breeza, on 2 m raised beds. The beds were pre-irrigated to provide a full profile and then remained dryland. The two times of sowing were planted on the 14th October for TOS 1 and 3rd December for TOS 2 and resulted in a large difference in yield, with TOS 1 on average yielding 3.21 t/ha compared to 6.20 t/ha for TOS 2.

Differences between treatments at both times of sowing were much smaller in the 2015-16 season than in previous seasons (Table 2). However, similar to previous seasons the largest impacts were obtained from reducing both the nitrogen and phosphorus nutrition. The “Rolls Royce” treatment (24) yielded 0.44 and 0.69 t/ha more than the base MR Scorpio treatment (1).

Varying the hybrid selection (treatments 5, 8 and 10) resulted in yield differences of 0.30 – 0.65 t/ha however in line with the other seasons, there was no consistent pattern.

Incorporating the use of twin rows, as in treatment 15 compared to treatment 5, had a larger positive impact on yield with the later sowing time, than it did in TOS 1; 0.54 compared to 0.22 t/ha respectively.

Breeza Sorghum Yields 2013-2016					Irrigated				Dryland				Dryland				Dryland			
Trt No.	Hybrid	Plant population ('000/ha)	Applied N (kg/ha)	Applied P (kg /ha)	2014 Yield (t/ha)	Yield Gap	2014 Yield (t/ha)	Yield Gap	2014 Yield (t/ha)	Yield Gap	2014 Yield (t/ha)	Yield Gap	2015 Yield (t/ha)	Yield Gap	2015 Yield (t/ha)	Yield Gap	2016 Yield (t/ha)	Yield Gap	2016 Yield (t/ha)	Yield Gap
					TOS 1		TOS 2		TOS 1		TOS 2		TOS 1		TOS 2		TOS 1		TOS 2	
24	MR-Scorpio	50	200	20	6.56		6.69		3.83		3.99		7.42		2.62		3.19		6.22	
23	MR-Scorpio	50	200	0	6.83	0.27	6.30	-0.39	4.02	0.19	3.73	-0.26	7.29	-0.13	2.64	0.03	3.28	0.09	6.07	-0.15
14	MR-Scorpio	50	100	0	4.52	-2.04	5.96	-0.73	2.97	-0.86	3.45	-0.54	6.75	-0.67	2.56	-0.06	3.19	0.00	6.52	0.30
5	MR-Scorpio	50	100	10	5.64	-0.92	5.66	-1.03	3.01	-0.82	3.38	-0.61	6.10	-1.32	2.81	0.19	2.86	-0.33	5.72	-0.50
10	MR-Buster	50	100	10	5.60	-0.96	5.36	-1.33	3.52	-0.31	3.24	-0.75	7.34	-0.08	2.32	-0.30	3.52	0.33	5.74	-0.48
8	85G33	50	100	10	5.06	-1.50	5.35	-1.34	3.37	-0.46	3.57	-0.42	5.93	-1.49	1.54	-1.08	2.88	-0.31	6.01	-0.21
2	MR-Scorpio	50	0	10	4.01	-2.55	3.80	-2.89	2.35	-1.48	2.87	-1.12	5.72	-1.70	2.44	-0.18	2.86	-0.33	5.72	-0.50
1	MR-Scorpio	50	0	0	3.94	-2.62	3.96	-2.73	2.21	-1.62	2.88	-1.11	4.70	-2.72	2.12	-0.50	2.75	-0.44	5.53	-0.69
3	MR-Buster	100	0	0	4.60	-1.96	3.80	-2.89	2.85	-0.98	2.51	-1.48	6.04	-1.38	2.49	-0.13	3.66	0.47	6.01	-0.21
15	MR-Scorpio (Twin rows)	50	100	10	5.70	-0.86	5.29	-1.40	3.37	-0.46	2.91	-1.08	6.58	-0.84	2.56	-0.06	3.08	-0.11	6.26	0.04

Table 2.
Grain sorghum yields **f**rom Breeza 2013-2016

Conclusion

Over the three years of research, the most important agronomic inputs for sorghum yield have been related to time of sowing and nitrogen nutrition. In dryland situations the most difficult aspect of selecting whether to sow early (as in TOS 1) or late (TOS 2) is picking when the seasonal conditions will be most favourable. As seen in this data set yield can vary dramatically between years and by a large or quite small amount depending on seasonal conditions.

Nitrogen nutrition has been consistently shown to be an important driver of final grain yield. Often the combination of nitrogen and phosphorus has proven beneficial even at this site, which is not considered to be P responsive.

While hybrid selection plays an important role around many plant characteristics such as maturity, midge resistance and lodging, in these trials there were variable and inconsistent responses to using newer released hybrids compared to the old genetics of MR Buster. This reinforces that while genetic gain is important, much larger benefits can be obtained from optimising crop agronomy.

The “Rolls Royce” treatment in this trial has demonstrated that further yield gains are likely if additional inputs, particularly in the form of nitrogen and phosphorus nutrition are applied to grain sorghum. The question which needs to be answered is how economic is it to chase these higher potential yields.

While the field trial component of this project has finished, the importance of finalising the interpretation of results from these trials and the economic impacts of these treatments cannot be overlooked. This paper has focused on obtaining the highest yields from grain sorghum; however the comparative gross margins from these trials will ultimately provide the most powerful insight into where investment should be placed for the best outcomes.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC and NSW DPI, the author would like to thank them for their continued support. In particular, Ian Carter “Connamarra” Pine Ridge, James Arnott “Berwicks” Willow Tree and Ed & Fiona Simson “The Plantation” Premer.
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Understanding & managing N loss pathways

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Key words

Nitrate denitrification, ammonia volatilisation, N use efficiency, ^{15}N recovery, summer sorghum

NANORP codes

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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. 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. 1 legume crop in every 4-6 crops grown).

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 containing 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 example 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 our 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, farm 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 machinery. 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 are present (the carbon is an energy source for the microbes which drive this process). Denitrification gases [N_2, N_2O] are not retained by soil adsorption, whereas ammonia [NH_3] is easily adsorbed by soil surfaces. Some of the chemicals that can be used to inhibit nitrification 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. As ^{15}N fertiliser is extremely expensive, all measurements were confined to small mini-plots (1 m2) within larger field trials.

Trial results

NSW sites (see Figure 1).

In **2012-13** 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 down 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 **2013-14**, 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 (DMPP). 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.

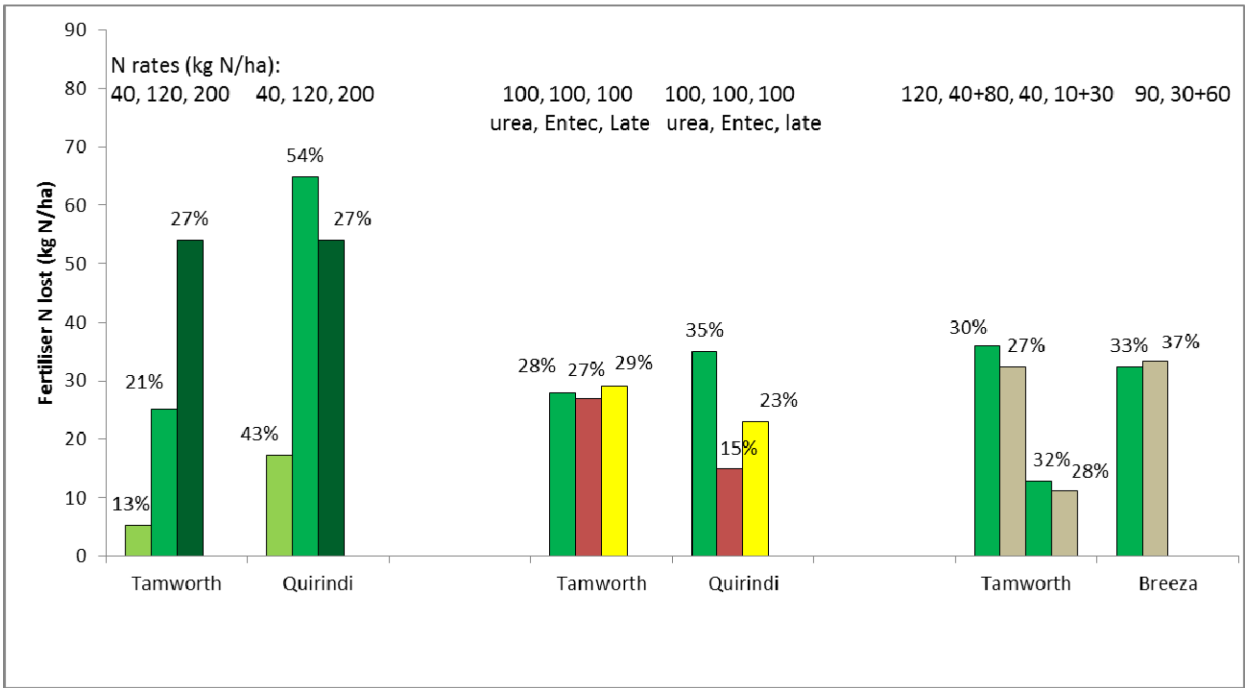

Figure 1. Losses of applied urea-N in field trials on Vertosol soils in northern NSW during the NANORP project. Losses were calculated from recoveries of 15N labelled urea in soil and plant material.

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.

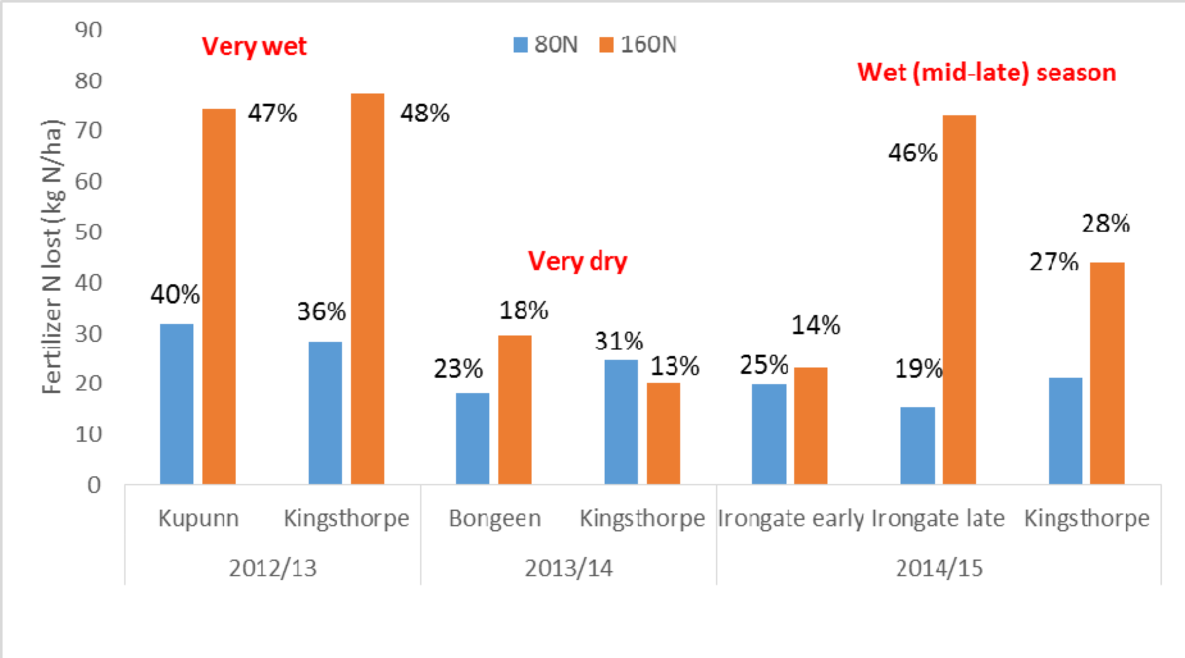

Figure 2. Losses of applied urea-N in field trials on Vertosol soils in Queensland during the NANORP project. Losses were calculated from recoveries of ^{15}N labelled urea in either soil or plant material.

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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Many people assisted with various aspects of field operations, sample processing and sample analyses. In NSW this included Matthew Gardner, Rick Graham, Peter Formann, Mustafa Kamal Hossain, William Keene, Kelly Leedham, Annabelle McPherson, Adam Perfrement, Peter Sanson, Zara Temple-Smith, Wayne McPherson, Guy McMullen, and Loretta Serafin (NSW DPI, Tamworth), while Leanne Lisle (UNE), Brad Keen, Stephen Kimber and co-workers (NSW DPI, Wollongbar) conducted various analyses.

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.

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Nematodes: Summer cropping options to manage root-lesion nematodes

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Key words

Root-lesion nematodes, *Pratylenchus thornei*, *Pratylenchus neglectus*, tolerance, resistance, mungbean, maize, sorghum, soybean

GRDC code

DAV00128

Take home messages

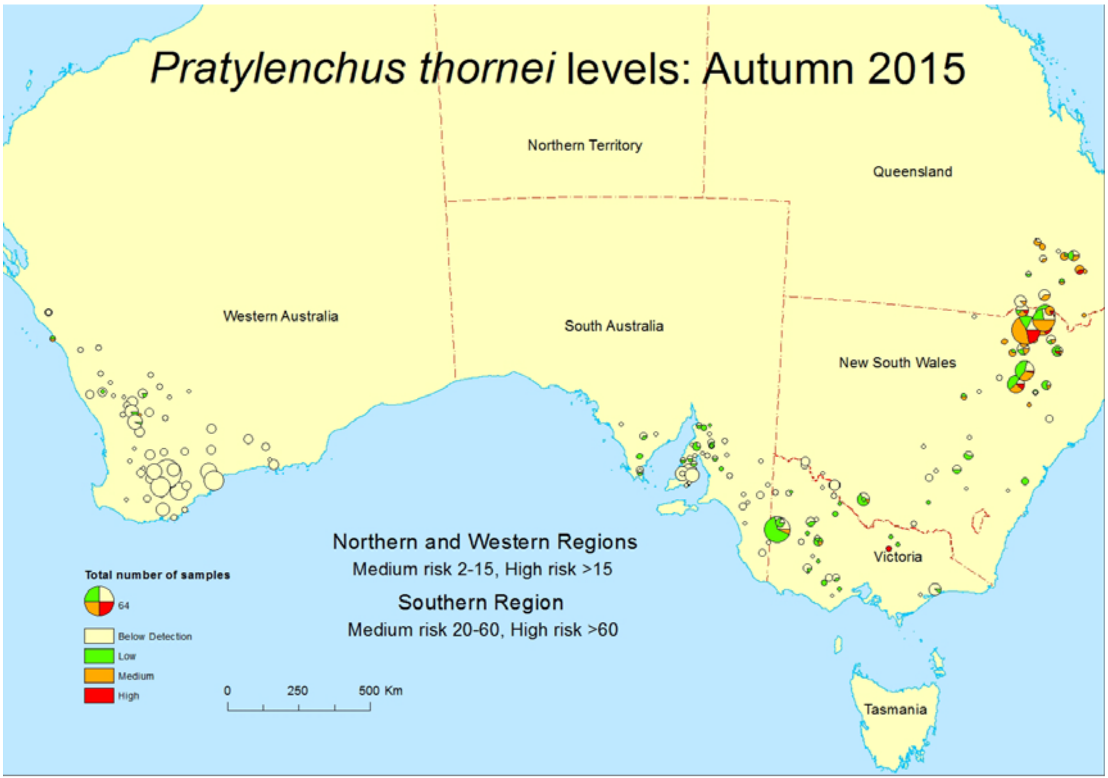
- Test soil for nematodes and plan crop rotations that target the correct nematode species identified.
- Mungbean cultivars are susceptible to *P. thornei*.
- Sorghum hybrids are susceptible to *P. neglectus*.
- Maize hybrids range from susceptible to moderately resistant to *P. thornei*.
- Soybean cultivars are highly susceptible to *P. thornei*.
- When root-lesion nematode populations are detected in large populations, avoid growing susceptible crops.
- Resistant crops will reduce high root-lesion nematodes but several consecutive resistant crops and fallow may be needed to reduce very high populations.
- Tolerant crops can produce good yields when root-lesion nematodes are present but you need to select tolerant varieties with high levels of resistance to have the biggest impact.

Current status of root-lesion nematodes in the northern grain region

Management of the root-lesion nematodes, Pratylenchus thornei and P. neglectus starts with knowing the populations you have present in your paddocks. PreDictaB (South Australian Research and Development Institute (SARDI)) offers soil tests for both species of root-lesion nematodes. Their website for contact details is:
http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b (or search for PreDictaB).

Maps of the distribution of *P. thornei* and *P. neglectus* from samples submitted to PreDictaB are available on-line and reproduced in this paper (Figure 1a and b). Results from autumn 2015 show that in the northern grain region, *Pratylenchus thornei* is more widely distributed and found in greater, more damaging populations than *P. neglectus*. In the northern region, paddocks with more than 15 *P.* thornei/g soil (or 15,000/kg soil) by the PreDictaB test are classified as high risk for crops. However, in the northern region, even populations of *P. thornei* are classified as medium risk by PreDictaB, that is 2–15/g soil (or 2,000–15,000/kg) soil can cause substantial yield loss of intolerant wheat varieties in warm wet growing seasons conducive to nematode reproduction in the roots. Therefore 2 nematodes/g soil (or 2,000/kg soil) should be regarded as the threshold for loss in intolerant crop cultivars.

(a)



(b)

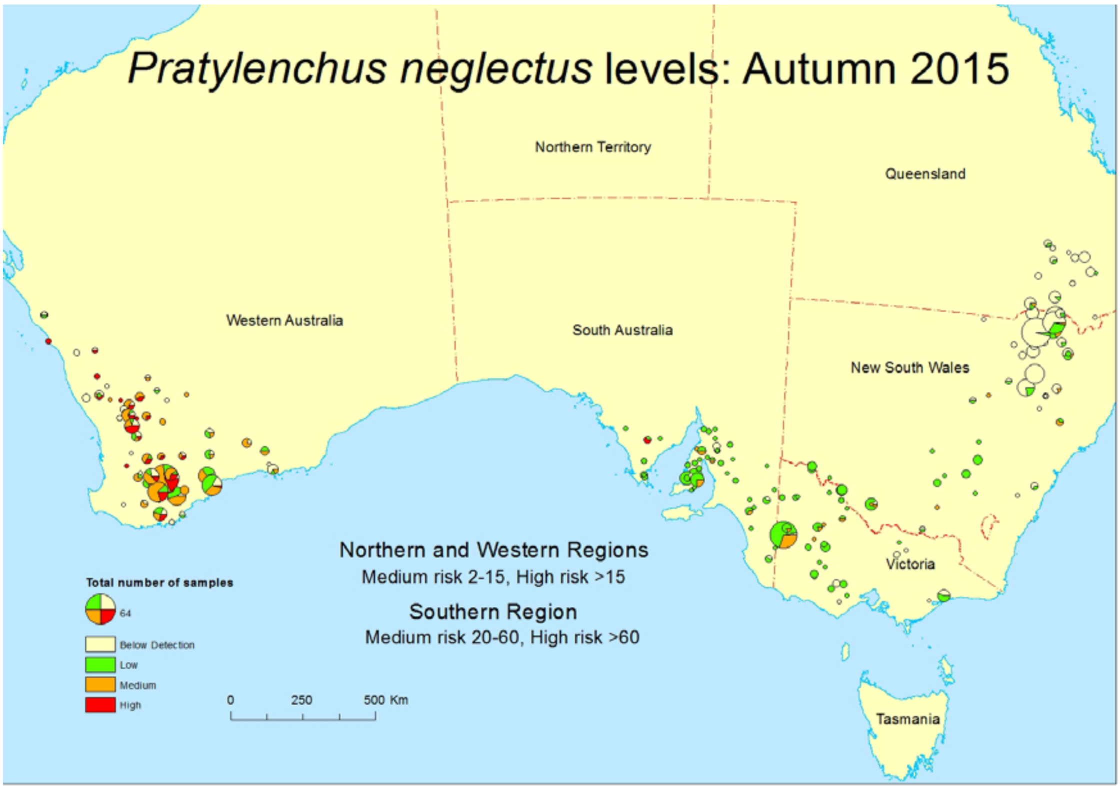


Figure 1. The distribution and risk of causing yield loss of samples submitted to PreDictaB, SARDI in autumn 2015 for a) *Pratylenchus thornei* and b) *P. neglectus*. Maps are reproduced with permission from http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

Once you know which root-lesion nematode species is present in your paddock and the population size, you can plan your crop rotations to 1) select tolerant varieties so that yields are maximised and 2) reduce the size of the populations by growing resistant crops. **Tolerance** is the impact of root-lesion nematodes on plant yield and **resistance** is the ability of the nematode to reproduce on the plant. Each species of root-lesion nematode has a unique and broad host range including cereals and legumes (Table 1). A summary of the host range of *P. thornei* and *P. neglectus* is available in the article '2015 Root-lesion nematodes Northern Region, GRDC Tips and Tactics'. Download a copy at the GRDC website (or search for root lesion nematodes northern grain region Tips and Tactics).

http://www.grdc.com.au/Resources/Factsheets/2015/03/Root-Lesion-Nematodes

Table 1. Comparison of the risk of build-up of *Pratylenchus thornei* and *P. neglectus* for crops (from *Tips and Tactics, Root-lesion nematodes Northern Region, GRDC 2015*)

Crop	*P. thornei*	*P. neglectus*
Cereals		
Barley	Medium to high	Low to medium
Canary seed	Low	Low
Maize	Low	Low
Millet	Low	Low
Oats	Low	NT
Sorghum (grain)	Low	Medium to high
Triticale	Medium to high	Low
Wheat	Low, medium to high	Low, medium to high
Legumes		
Blackgram	High	Medium (p)
Chickpeas	Medium to high	Low to medium
Cowpeas	High	NT
Faba beans	Medium to high	Low
Field peas	Low to medium	NT
Navy beans	High	NT
Mungbeans	Medium to high	Low
Pigeon peas	Low	NT
Oilseeds		
Canola, mustard	Low to medium	Medium to high
Cotton	Low	Low
Linseed	Low	Low
Soybeans	High	Low
Sunflowers	Low	Low
Pastures, forage		
Brassica (forage)	Low to medium (p)	NT
Lablab	Low	NT
Sorghum (forage)	Low	Medium to high

Within some crops there is variation in the susceptibility and resistance of varieties, and this is indicated where a range of risk ratings is shown. New varieties or hybrids may differ in their risk ratings from the overall rating for a crop species. NT, Not tested; p, provisional rating.

Our previous field experiments with summer crops have demonstrated that crops such as sorghum and millet are moderately resistant to *P. thornei* and crops such as soybean and mungbean are susceptible (Figure 2). However, one moderately resistant crop in a sequence is not enough to reduce damaging populations of *P. thornei*. Two or more resistant crops grown consecutively are needed to get on top of root-lesion nematodes. Figure 3 shows populations of *P. thornei* increased after growing most cultivars of mungbean and soybean compared to fallow and sorghum hybrids.

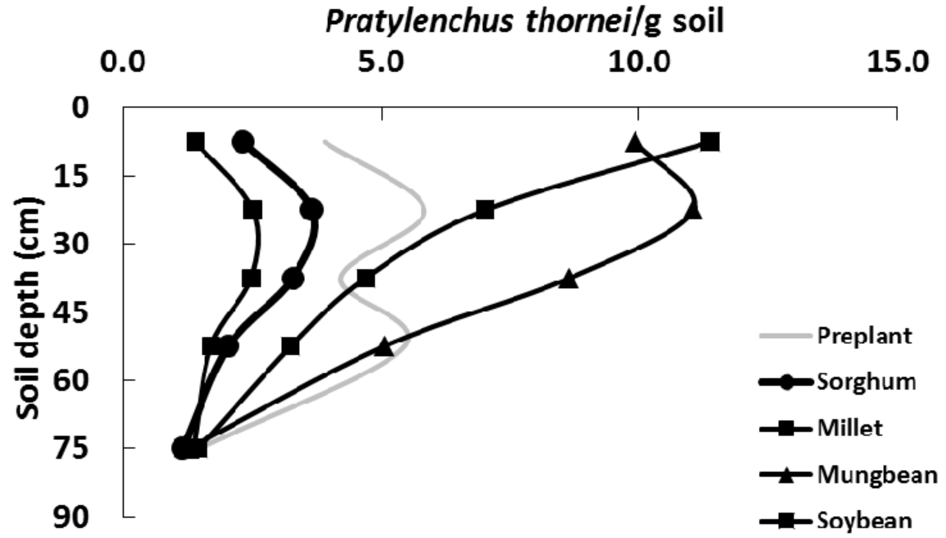


Figure 2. Compared to the populations of *P. thornei* at planting (grey line) sorghum and millet caused populations to decrease throughout the soil profile, however mungbean and soybean caused populations to increase markedly.

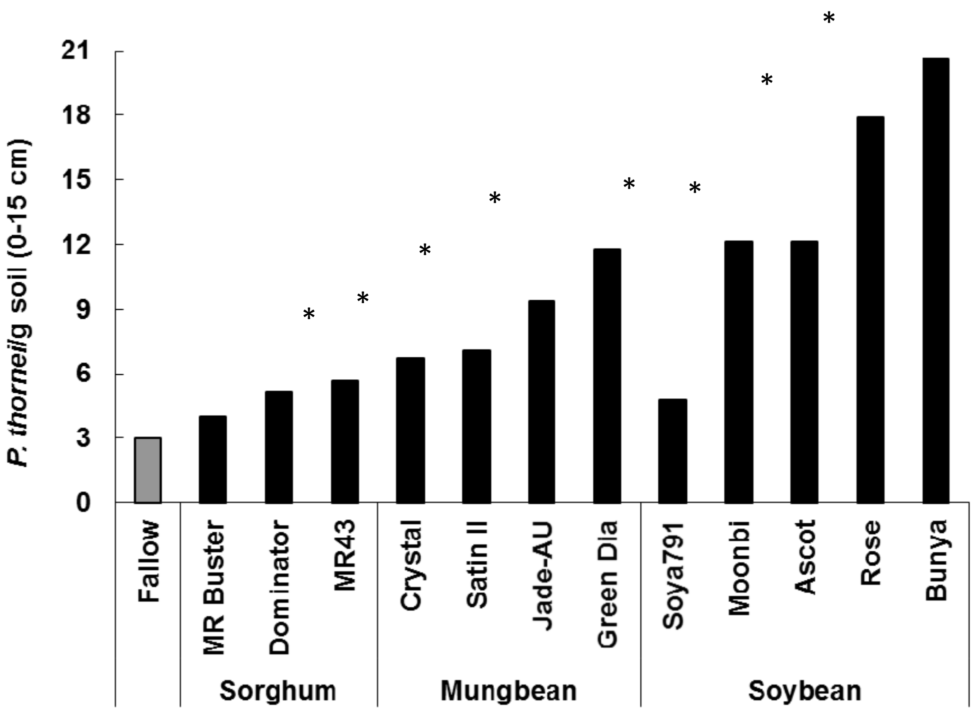


Figure 3. After harvest of the summer crops, *Pratylenchus thornei* was found in highest populations following mungbean and soybean cultivars. * indicates significantly larger *P. thornei* populations than the fallow treatment ($P<0.05$). Green Dia is mungbean cv. Green Diamond.

All varieties listed are protected under the Plant Breeders Rights Act 1994.

New Results

Mungbeans and P. thornei

Mungbeans are **susceptible** to *P. thornei* but are poor hosts of *P. neglectus*. New results from a field experiment showed when *P. thornei* populations started, on average, at 6 *P. thornei*/g soil, nematode populations increased to 12 to 39 *P thornei*/g soil. The change in *P. thornei* populations for each cultivar is shown as the reproduction factor in Figure 4. *P. thornei* increased between 2 and 2.7 times after growing mungbean cultivars and up to 8.5 times after growing blackgram cv. Regur (Figure 4). Our previous field trials have not detected any yield loss in mungbeans due to *P. thornei* indicating that they are **tolerant**. The take home message for mungbeans is to be aware that they will cause *P. thornei* to increase and should not be included in rotations where you are trying to reduce populations of *P. thornei*.

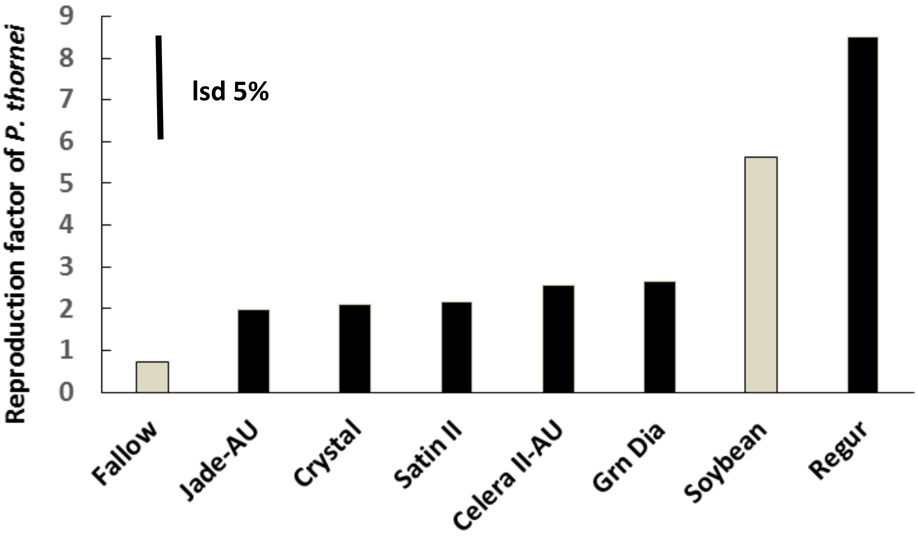


Figure 4. Mungbean and blackgram cultivars are susceptible to the root-lesion nematode, *Pratylenchus thornei*. Plants were grown in the field at Formartin on the Darling Downs, Queensland, with the average starting population of 6 *P. thornei*/g soil. Reproduction Factor = the final *P. thornei* population ÷ the initial *P. thornei* population. Soybean cv. Bunya was included as a susceptible control; Grn Diamond is mungbean cv. Green Diamond; Regur is a cultivar of blackgram.

All varieties listed are protected under the Plant Breeders Rights Act 1994.

Sorghum and P. neglectus

Sorghum is an excellent crop to include in rotations where ***P. thornei*** is present because it is moderately resistant. However, **sorghum is susceptible to *P. neglectus***. Recently hybrids of sorghum were screened in glasshouse experiments for resistance to the root-lesion nematode, *P. neglectus*. New results show there are a range of responses for sorghum from susceptible to moderately susceptible (Figure 5). Our previous results have shown that forage sorghum hybrids are also susceptible to *P. neglectus* with the sweet sorghum hybrids being most susceptible and the grain sorghum x Sudan grass hybrids being moderately susceptible. Growing sorghum will cause populations of *P. neglectus* to increase and nematodes will remain in high numbers to attack the next crop. These results highlight the importance of testing soil for root-lesion nematodes to identify which species is present in your paddocks.

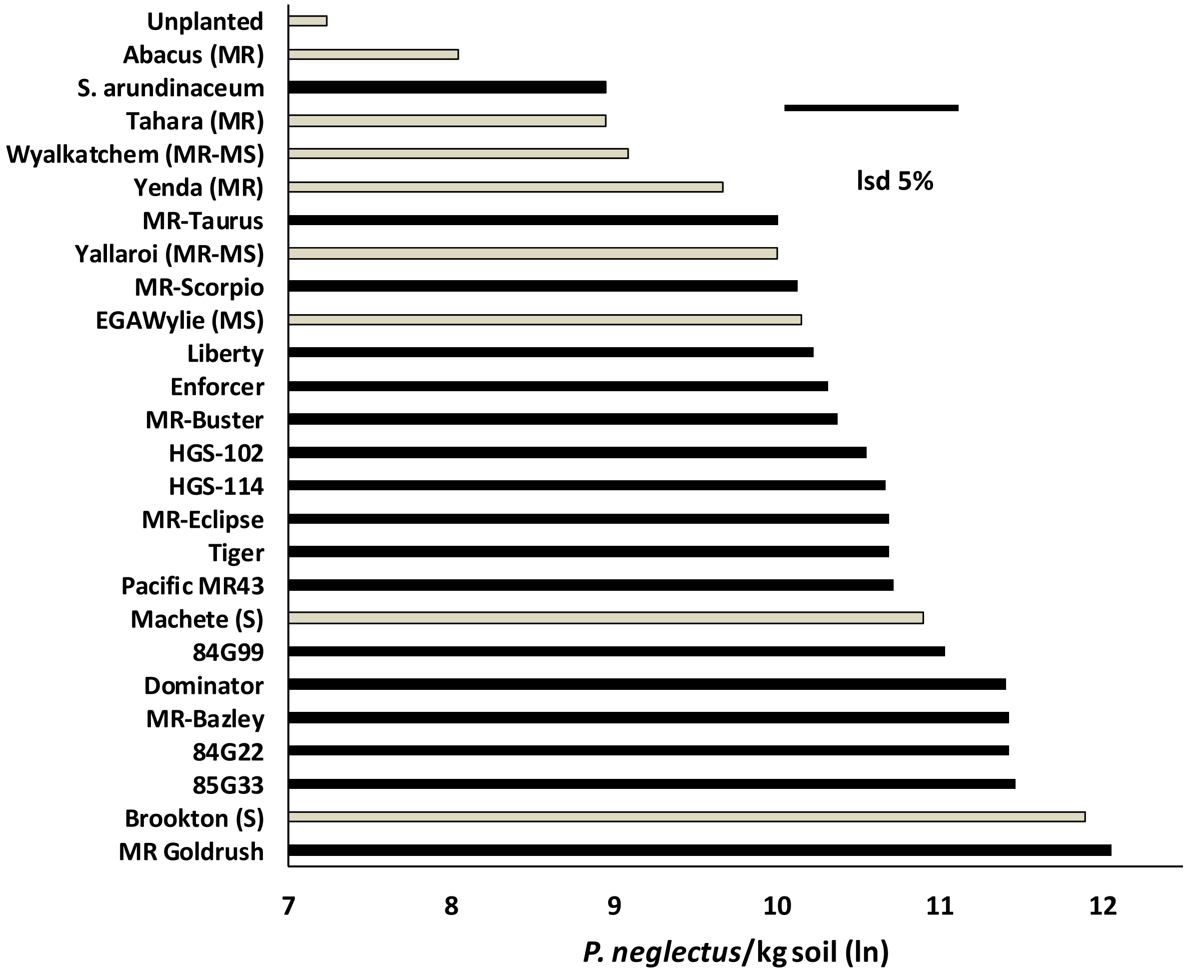


Figure 5. New data shows that sorghum hybrids range from susceptible to moderately susceptible to the root-lesion nematode, *Pratylenchus neglectus*. Plants were grown for 18 weeks in the glasshouse after inoculation. Grey bars indicate cereal and unplanted standards with known resistance/susceptibility to *P. neglectus*.

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Maize and P. thornei

Recently hybrids of maize were screened in glasshouse experiments for resistance to the root-lesion nematode, *P. thornei*. New results show there are a **range of responses to *P. thornei* for maize** from **susceptible to moderately resistant** (Figure 6). Our previous field trials have not detected any yield loss in maize indicating that they are tolerant. Although maize may not suffer yield loss due to *P. thornei*, some hybrids of maize will cause populations of the nematode to build up and nematodes will remain in high numbers to attack the next crop.

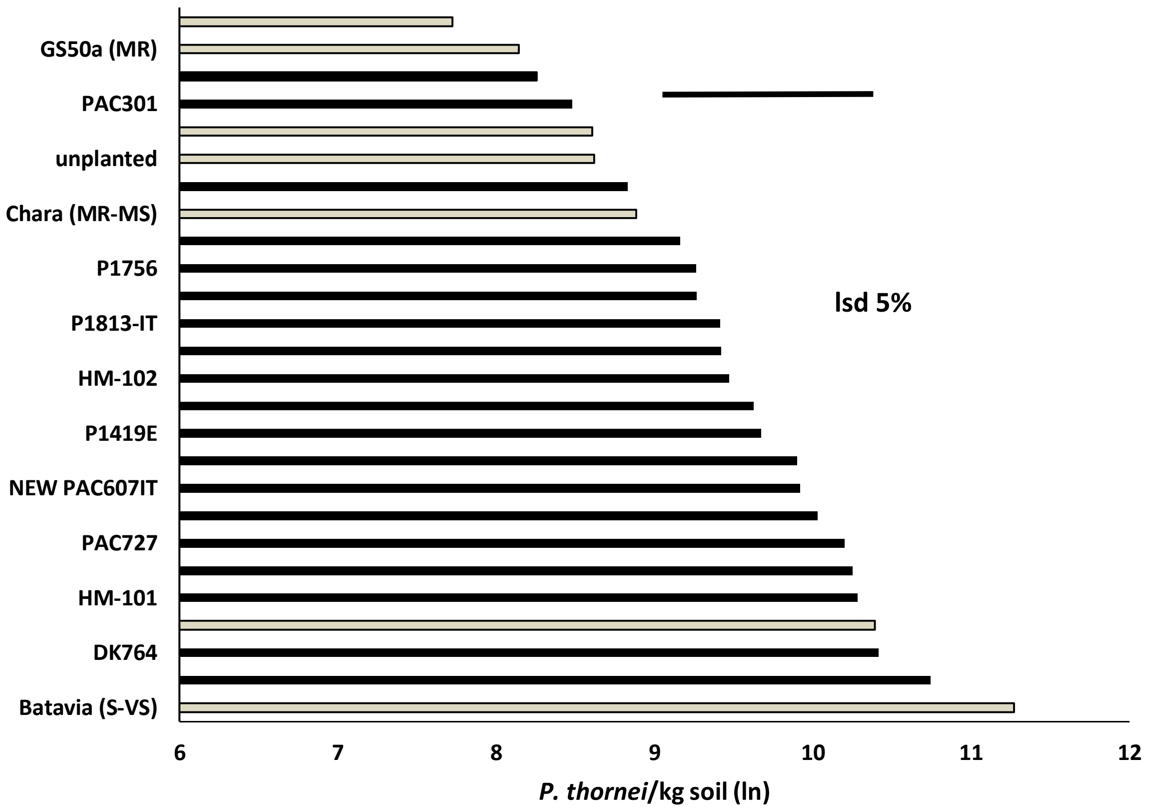

Figure 6. New data shows that maize hybrids range from susceptible to moderately resistant to the root-lesion nematode, *Pratylenchus thornei*. Plants were grown for 18 weeks in the glasshouse after inoculation. Grey bars indicate cereal and unplanted standards with known resistance/susceptibility to *P. thornei*.

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Wheat and barley

Each year, new varieties and advanced lines of wheat varieties are tested as part of the National Variety Trials for tolerance (which is the impact of root-lesion nematodes on plant yield) and resistance (which is the ability of the nematode to reproduce on the plant). Barley varieties are tested for resistance to root-lesion nematodes. The results of repeated experiments from the field and glasshouse are shared nationally with other nematode researchers and a consensus rating of tolerance and resistance is produced. These results are available at the NVT website (http://www.nvtonline.com.au/)

How do you use this information to manage root-lesion nematodes?

When you have your soil test results, plan your crop rotations to reduce the root-lesion nematode populations. Rotations will differ depending on whether you have *P. thornei*, *P. neglectus* or both species. Very high nematode populations are reduced by increasing the number of resistant crops grown consecutively in rotations. It may take two or more resistant crops to reduce damaging populations. When root-lesion nematodes are present, tolerant crops will produce higher yields than intolerant crops. However not all tolerant crops are resistant. The NVT website lists ratings of tolerance and resistance for wheat and barley and the GRDC Tips and Tactics factsheets are available for information on other crops. Keep an eye on how root-lesion nematode populations change during rotations and consider testing soil again in 3-5 years. You can't eliminate root-lesion nematodes from soils, but with careful planning you can minimise their impact on your farm profits.

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.
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Biological suppression of root-lesion nematodes in northern grain-growing soils

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Key words

Pratylenchus thornei, biological suppression

GRDC code

DAQ00164

Take home message

- Biological suppression does occur in most soils we tested from the northern grain-growing region, showing that populations of *P. thornei* are being reduced by parasites and predators.
- Suppression was found to be greater in the top 10cm of soil than at deeper layers (e.g. 30-45 cm). Practices such as zero tillage with stubble retention enhanced suppression. Without these practices, we estimate that RLN multiplication would be significantly greater, especially in top soils, and this would result in much greater losses in the productivity of susceptible crops.
- Several antagonists of *Pratylenchus* were found in northern grain-growing soils such as nematode trapping fungi, predatory nematodes, parasitic bacteria and root-colonising fungi that enhance the plant's resistance to nematodes. Further research is focussing on these organisms as they are likely to be contributing to the suppressiveness of the soils.

Root-lesion nematodes (*Pratylenchus thorne*i and *P. neglectus*) cost Australian growers in excess of $250 million/annum. Control of this pest relies on an integrated management program that includes the use of tolerant or resistant varieties, crop rotation and good farm hygiene, but even then costs to production can be high. Enhancing the suppressiveness of soil to root-lesion nematodes is a control option that deserves some consideration. Disease suppression is defined as the ability of a soil to suppress disease incidence or severity even in the presence of the pathogen, host plant and favourable environmental conditions. The vast array of organisms in the soil can provide a degree of biological buffering against pathogens. Disease reduction results from the combined effects of many antagonists acting collectively and mediated through inputs of organic matter (general suppression) and direct antagonism by a limited number of organisms (specific suppression) .

A recent GRDC-funded project aimed to better understand the suppressive nature of grain-growing soils and provide growers with methods to enhance suppressiveness of their soils to root-lesion nematodes.

Over 4 years, a total of 24 different sites were sampled to test the suppressiveness of the soils. This included several farmer paddocks and 3 long-term farm management trial sites with several fertiliser or tillage treatments. Also, seven of the sites were comparisons of cropped and pasture or native/scrub remnant soils that were in close proximity to gain an understanding of the impact cropping may have on suppressiveness to root-lesion nematodes.

Repeated studies over 4 years of multiple soils from northern NSW and southern Qld consistently showed general suppressiveness to root-lesion nematodes does exist in a variety of soils. In glasshouse tests, we also found that a 10% addition of suppressive field soil to a sterilised soil (heated at 60°C for 45 mins) is sufficient to reduce RLN multiplication by 60-90%, showing that the suppressive effect was biological and could be transferred or added to a less suppressive soil.

Table 1. Final *Pratylenchus thornei* numbers in a glasshouse pot-based suppression assay for soil from three different sites (Numbers followed by the same letter within each site are not significantly different *P* = 0.05)

Site	Final *P. thornei* population (nematodes/g soil)		
	Sterilised soil	Unsterilised soil	Sterilised + 10% unsterilised
Hermitage Fallow Management trial, Warwick, Qld	86 a	12 b	12 b
Billa Billa, Qld (ex-wheat and remnant scrub soil)	71 a	18 b	24 b
Billa Billa, Qld (ex-sorghum soil)	89 a	21 b	25 b
Colonsay fertiliser trial, Norwin, Qld	66 a	24 b	53 a

General suppression of plant parasitic nematodes was also found to be much greater in soil from 0-15cm than soil from lower in soil profile. The figure below indicates that there are less plant parasitic nematodes at 0-15cm (coinciding with the higher levels of microbial populations) and that heating removes the microbial community and hence the suppressive effect.

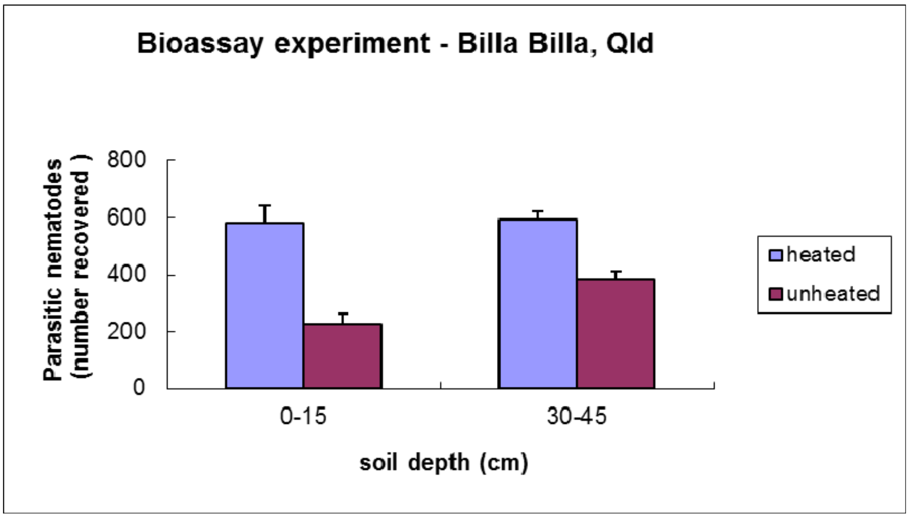

Figure 1. Results of one bioassay on a soil from a cropped (wheat/sorghum) paddock from Billa Billa showing that biological suppression of parasitic nematodes (difference between numbers recovered after adding nematodes to the heated and unheated soils) is greater in the 0-15cm layer of soil than in the 30-45 cm layer

Surveys of over 130 soils from the northern region found a range of natural enemies that could suppress RLN. These included *Pasteuria*, a bacterial parasite (found in 25% of soils), nematode-trapping fungi (in 42% of soils) and predatory nematodes (in 77% of soils). Of the 25% of grain-growing soils where root lesion nematodes and *Pasteuria* spp. were present, only 6% of the RLN population were infected. This bacterium has the potential to infest and kill root-lesion nematodes but populations appear too low to currently be having any great impact. More study is required to better understand the lifecycle and ecology of this highly specialised parasite as prior to this project, it had never been previously observed in Australia on *Pratylenchus thornei* .

Figure 2. Root-lesion nematode (*Pratylenchus thornei*) infested with parasitic bacteria (*Pasteuria* sp.) as indicated by the red arrows.

Four different species of nematode-trapping fungi were found in 26 different soils from the northern region using traditional isolation techniques. A method was also developed to detect these fungi using DNA extraction from soil (DAQ00164/ DAV00105 collaboration).

The addition of a fungal endophyte (*Fusarium nygamai*) previously isolated from wheat roots growing in a soil from a property near North Star, NSW reduced *P. thornei* multiplication by 40% in a pot assay. More studies are required to confirm these results and determine whether this fungus is a potentially useful biocontrol organism. Several other endophytic fungi were isolated from roots but are yet to be tested for suppressive activity. Overseas work has shown that the presence of endophytic strains of *Fusarium* in roots enhance the plant's capacity to defend itself from nematode attack.

Key farm practices that may enhance suppressiveness to root-lesion nematodes were examined. A field trial at Hermitage Research station, near Warwick, Qld, was specifically designed to study the impact of organic amendments (0, 5, 10 and 20 t organic matter/ha, incorporated into the top soil on application) and various cropping regimes (continuous fallow, sorghum with residue retained, sorghum with no residue retained) on RLN (*P. thornei*) multiplication in wheat grown after these treatments. In the first year, we found more beneficial nematodes and lower RLN numbers in surface soils, only in the highest organic matter treatment and where sorghum was grown and stubble was retained. Two and three years later, these earlier seen increases in suppression were not as evident and did not affect crop yield. However improved soil biology, especially in the surface soils, was still present when soil was cropped continuously compared to fallow. The trial showed that intensive cropping is more influential on RLN suppressiveness than addition of up to 20t/ha of organic matter. Soil chemical and physical differences measured did not appear to influence suppressiveness significantly and fertiliser (N, P) applications did not alter suppressiveness.

Implications

Suppression does occur in most soils we tested from the northern grain-growing region showing that populations of *P. thornei* are being reduced due to biological activity. Suppression was found to be greater in the top 10cm of soil than at deeper layers (e.g. 30-45 cm), and practices such as zero tillage with stubble retention enhanced suppression.

Maintenance of a healthy topsoil through diverse organic matter inputs will preserve the suppressive potential of soils against RLN .

Heavy rates of stubble (up to 20t/ha) increased general suppression of RLN in the short term. This coincided with high levels of microbial activity.

The presence of a crop for longer periods of time and the associated input of root exudates may have provided a better environment for sustained microbial activity and hence suppression of RLN.

Growers using no-till, stubble retention practices and cropping when soil moisture allows are probably doing a great deal toward enhancing the suppressiveness in their top soil. Without these practices, we estimate that RLN multiplication would be significantly greater especially in top soils and therefore lead to much greater losses in productivity of susceptible crops.

More work is required to confirm the biological control agents found to be present in our grain-growing soils can have a significant impact on RLN populations on a broad-scale.

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.

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Sorghum following canola – Is there an issue?

Anthony Mitchell, Brendan Burton and Richard Daniel, Northern Grower Alliance

Key words

Sorghum, canola, myccorhizae, Arbuscular Mycorrhizal fungi, AM, VAM

GRDC code

NGA00004

Take home messages

1. Field observations suggest that sorghum can be less thrifty when following canola in the rotation

2. Duplicate trials were planted in adjacent canola and durum stubble, with a 3-5 fold difference in levels of Arbuscular Mycorrhizae (AM) fungi shortly prior to planting

3. Sorghum following canola had delayed head emergence and yields were ~1.4t/ha less than same trial following durum

4. Application of Granulock Z Extra to 80kg/ha at sowing did not have any impact

5. These trials strongly suggest AM may be involved but need to be repeated in a planned design to allow proper evaluation

The issue?

Liverpool Plain's agronomists have commented that sorghum performance following canola often appears less thrifty than after other crops. Some of the possible causes for difference include soil moisture quantities, soil nutrition, presence of imidazolinone herbicide residues following use of Clearfield chemistry or differential levels of Arbuscular Mycorrhizal (AM) fungi (previously known as VAM).

AM form symbiotic relationships with the crop root system and can improve the access to scarce or immobile nutrients such as phosphorous and zinc. AM are commonly associated with Long Fallow Disorder, where levels of these fungi decline during periods without cropping and the performance of the next crop can suffer. Linseed, cotton, sunflower, corn, mungbean and chickpea are considered highly dependent on AM with sorghum and soybean considered moderately dependent.

Canola and lupins are two species that are not dependent on AM but also do not host the fungi. As a consequence, AM levels after canola may be low and be of similar impact as a Long Fallow.

Trial establishment

Two trials were established in a paddock near Mullaley in November 2015 which had been previously farmed as one management unit. In 2014, canola was planted under marginal moisture conditions with establishment impacted. Areas of canola were sprayed out and 'replanted' with durum. Although not ideal, this provided a scenario with canola and durum stubble side by side.

In October 2015, soil samples were taken from twelve sampling points (in two transects) following each previous crop. Soil depths were assessed in 15cm intervals to 30cm depth and then in 30cm intervals to 120cm.

- **Soil moisture**: Gravimetric soil measurements indicated both profiles were full with ~ 270mm of PAW.

- **Nutrition**: Comprehensive soil test did not indicate any obvious difference in nutrition between the samples. Colwell P means ranged from 22-24mg/kg in the 0-15cm layer with levels of 5-6mg/kg following both crops at 15-60cm. There was also a bulge at depth with ~13 mg P/kg at 60-90cm and ~18mg/kg at 90-120cm. BSES P was 140-147 in the 0-15cm layer and 120-150 between 15 and 60cm. PBI was ~200 at all depths. DTPA Zn means varied from 0.9 to 1.3mg/kg. Nitrate levels were ~130kg N/ha down to 120cm, excluding mineralisation quantities.
- **Herbicide residues**: Testing did not reveal any herbicide residues including imazapyr and imazamox.
- **Root-lesion nematode*s***: PreDicta B testing indicated low to medium levels of *Pratylenchus thornei* with no clear difference in numbers between the previous crops. Sorghum performance is generally unaffected by this nematode. There was no detection of *Pratylenchus neglectus.*
- **Arbuscular Myccorhizae**: Soil samples were submitted for both microscopic examination and PreDicta B assessment. Manual counts showed the durum samples had ~3-4 fold increases in AM spore counts. PreDicta B assessment showed similar differences for AMFa and AMFb populations.

Key point: Testing of the factors considered most likely to vary only showed differences for AM magnitude between the two trial sites. However there may be other factors that differed between the sites which were not assessed.

Trials 2015/16

Treatments evaluated were a factorial combination of two sorghum hybrids (MR Buster and G33) four fertiliser rates. Granulock Z Extra (12N, 20P, 5S and 2Zn) was applied at 0, 20, 40 and 80kg/ha with the seed. Urea was applied to 'balance' the applied N rate for all Granulock Z Extra treatments but sulphur was not balanced (rates varied from ~1-4kg S/ha). The untreated did not receive any additional nutrition.

Results

Because the two trials were separate (even if only 12m apart), we cannot statistically compare the results between trials. However:

- There was no significant difference in plant stand between hybrids or fertilizer treatments in either trial. In both trials the mean population was ~4 plants/m^2
- A count of emerged heads at 74 days after planting showed no significant difference between hybrids or fertilizer treatments in either trial. However the mean number of heads in the durum trial was 6.8/m^2 compared to 4.3/m^2 following canola
- A count of heads at 102 days after planting showed no significant difference between hybrids or fertilizer treatments in either trial. The final number of heads in the durum trial was 10.7/m^2 and similar to 10.0/m^2 following canola
- There was no significant difference in yield between hybrids or fertilizer treatments in either trial. However the mean yield in the durum trial was 8.4t/ha compared to 7.0t/ha following canola
- Plant samples from both trials were taken ~8 weeks after planting to evaluate the extent of AM colonization of sorghum root material. These results were not available at the time of paper preparation.

Conclusions

The enforced design did not permit easy statistical comparison between the two trials. However it was a good opportunity to generate ‘proof of concept’ data.

Plant stand establishment appeared similar between the two trials but the sorghum following canola trial appeared to delay head emergence compared to the same treatments following durum. Although the final head counts were similar between the trials, sorghum following canola was 16% lower yielding (-1.4t/ha) than the identical treatments following wheat.

The application of Granulock Z Extra (to 80kg/ha) had no apparent impact on yield in either trial. These treatments were applied to evaluate whether high rates of P and Zn at planting may be a management tool to reduce the impact of low AM levels following a non-host crop. There was no suggestion of any benefit in this situation.

The next step is to establish trial designs which allow for more effective evaluation of the impact of the previous crop. This is underway in winter 2016 and should enable sorghum evaluation in 2017/18.

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Management of the major mungbean diseases in Australia

Lisa Kelly, Department of Agriculture and Fisheries, Toowoomba, Qld

Key words

Halo blight, tan spot, fusarium wilt, pathogen, bacteria

GRDC code

DAQ00186

Take home message

- For management of halo blight and tan spot: Plant seed with the lowest possible levels of infection, use varieties with higher levels of resistance, clean harvesting equipment, control weeds and volunteers, and use suitable crop rotations.
- For management of fusarium wilt: Avoid paddocks previously affected by the disease, plant seed into well-drained soils, and avoid plant stress

Introduction

With an increase in mungbean production in recent years, there has also been an increase in reported diseases. Disease surveys and samples submitted for diagnosis have revealed an increase in many diseases across a number of crops, particularly those pathogens that survive in stubble.

Halo blight has been the major issue for mungbean growers in southern Qld in the last two years, presumably due to the cooler, wet start to the growing seasons. These weather conditions are less favourable for tan spot which has been less of an issue for most growers across the northern region during this time, although the disease remains a concern when sourcing disease-free seed. Fusarium wilt is becoming an increasing threat to growers, with some paddocks having as many as 80% of plants affected by the disease. Further research is vital to better understand these diseases and will aid in the development of future integrated disease management strategies.

Halo blight

Halo blight, caused by the bacterium *Pseudomonas savastanoi* pv. *phaseolicola*, has become a significant issue to growers across the northern region in recent years. On younger leaves, halo blight is characterised by small, water-soaked lesions that are surrounded by a yellow-green halo. Symptoms are often visible at the 1st or 2nd trifoliate leaf stage and are often the result of seed borne infection. Infected seedlings typically survive and become the major source of inoculum for later infection in the crop. Older lesions have less pronounced haloes and lesions often coalesce to produce larger necrotic regions. Lesions are visible on both sides of leaves. Circular brown or red water-soaked lesions may develop on pods, with clumps of bacteria often oozing from the lesions and often forming a crusty drop. Often seed directly below pod lesions will be internally infected with halo blight, whilst the surrounding seed often become externally infected as they come into contact with the bacteria or infected plant tissue.

The bacterium is spread from infected plant tissue to healthy plants by water droplets from rainfall or overhead irrigation, and contact between adjacent wet leaves. The bacterium invades plant tissue via wounds and natural plant openings during periods of high humidity, and can survive on the surface of both resistant and susceptible plants, even when there are no obvious symptoms of the disease. Under ideal environmental conditions symptoms appear on plants 7-10 days after infection. Temperatures of 18-23ºC have been recorded as optimal for the development of the disease.

Multiple putative pathotypes

Outside of Australia numerous pathogenic races of halo blight have been identified in beans based on differential host reactions. A few years ago the Department of Agriculture and Fisheries (DAF) mungbean pathology team identified two separate putative pathotypes (Pt). One of those putative pathotypes has the capacity to overcome the improved sources of resistance recognised in the National Mungbean Improvement Program (NMIP). About 350 halo blight isolates have been collected from breeding trials and growers' paddocks across the northern region since July 2013. Most isolates have been collected from southern Qld, where the disease has been more prominent in recent years. A differential set of six mungbean genotypes, consisting of both commercial cultivars and advanced breeding lines are being used as a differential set to identify halo blight pathotypes diversity. From 80 halo blight isolates, 12 putative pathotypes have been identified, with pathotypes 1, 2 and 4 occurring more frequently (Table 1). At least six of these putative pathotypes were virulent on lines (M773 and OAEM58-62) previously resistant or immune to halo blight isolates prior to 2012, and which have been used extensively in the mungbean breeding program as sources of resistance. Table 1 details the mungbean genotypes and the differentiation of the halo blight pathotypes. Further screening of halo blight isolates will be conducted to confirm this diversity of pathotypes and determine whether the dominant pathotypes (1, 2 and 4 shown in Table 1) are the same in all regions. The findings from this research will lead to investigations into any genetic differences between the identified pathotypes and the genetics of resistance.

Table 1. Identification of putative pathotypes (Pt) in halo blight (*Pseudomonas savastanoi* pv. *phaseolicola*) isolates from mungbean (Y = inoculated plants displayed symptoms; N = no symptoms)

Genotype	Pt 1	Pt 2	Pt 3	Pt 4	Pt 5	Pt 6	Pt 7	Pt 8	Pt 9	Pt 10	Pt 11	Pt 12
AusTRC 321818	N	Y	Y	Y	Y	N	N	N	Y	N	Y	N
M773	N	Y	Y	Y	Y	Y	N	Y	N	N	N	N
OAEM58-62	N	Y	Y	Y	Y	Y	Y	N	N	N	N	Y
ATF2074	N	N	N	Y	Y	N	N	N	N	Y	Y	N
AusTRC 324872	N	N	Y	N	Y	N	N	N	N	N	Y	N
Crystal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Frequency isolated (%) (n=81)	*9.9*	*40.7*	*2.5*	*23.5*	*6.2*	*4.9*	*1.2*	*4.9*	*2.5*	*1.2*	*1.2*	*1.2*

Tan spot

Tan spot (also known as bacterial scorch and wilt) is caused by the bacterium, *Curtobacterium flaccumfaciens* pv. *flaccumfaciens*. Symptoms in seedlings, often resulting from seed borne inoculum, can be seen on the 1^{st} or 2^{nd} leaf trifoliate when large chlorotic areas develop on leaves. As the seedlings grow, they often wilt and die rapidly. Surviving seedlings are often stunted and are the major sources of inoculum for later infection in the crop. Leaves on older plants develop a scorched appearance, with interveinal necrotic lesions surrounded by a distinct chlorotic margin. The scorching gradually expands towards the midrib and may eventually cover the entire leaf. Affected lesions become tan in colour and may disintegrate during high winds, giving the leaves a ragged appearance. The disease can result in death of florets, and small pods may abort or remain stunted. The bacterium is thought to be systemic within plants and can infect seeds.

It is thought that the bacterial cells enter plants through the vascular system from infected seeds, or though wounds on aboveground plant parts. Unlike halo blight, tan spot is not easily spread in rain or through contact with wet foliage, and is thought to be able to infect tissues in the absence of rain. The disease is favoured by high temperatures (>30º) and plant stress. Storms with high winds, rain, and hail that wounds plants provide the perfect opportunity for tan spot to become established and transfer from infected plant tissue to healthy plants.

Breeding for disease resistance

As part of the NMIP advanced breeding germplasm is screened in both field disease nurseries and in glasshouse trials to determine their relative levels of resistance to the two bacterial diseases. Plants are scored for disease resistance using a 1-9 scale close to maturity. Disease screening within the NMIP has identified sources with major genes of resistance to halo blight and improved resistance to tan spot and has incorporated those into their breeding program. Figure 1 demonstrates the improved sources of resistance in a few advanced breeding lines to the halo blight pathogen from a field trial in 2015 at the DAF Hermitage Research Facility. Although improved sources of resistance have been identified for halo blight, current breeding efforts have become more difficult with the recent identification of multiple pathotypes that may overcome this resistance. Further research is needed to investigate the genetics of resistance to both halo blight and tan spot.

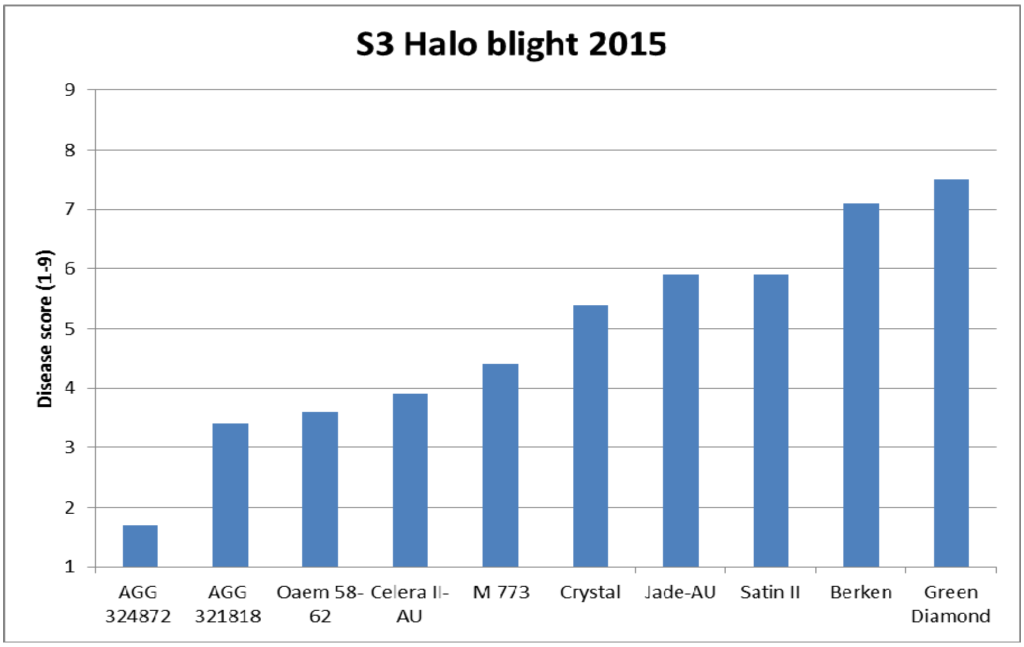

Figure 1. Relative resistance of the mungbean commercial cultivars and advanced breeding lines to halo blight in the 2015 halo blight disease nursery at the DAF Hermitage Research Facility. Disease is scored on a 1-9 scale, where 1 = no disease and 9 = high levels of disease.

Management of the two bacterial diseases

There are currently no registered chemicals for the control of halo blight and tan spot on infected plants or seed.

The risk of a halo blight and/or tan spot epidemic occurring in a crop can be minimised by:

- *Selecting resistant varieties*

  The variety Celera II-AU⊕ provides the best levels of resistance to the halo blight pathogen, rated as Moderately Resistant. All other commercial varieties are either susceptible or moderately susceptible to both tan spot and halo blight, although Jade-AU⊕ and Crystal⊕ have the next best levels of resistance.

- *Using low risk planting seed*

  Infected seed is thought to be the major source of infection within a crop. Only one halo blight infected seed per 10,000 is enough to produce an epidemic under ideal environmental conditions. Avoid using seed from an infected mungbean crop. Australian Mungbean Association (AMA) approved seed is sourced from crops inspected for disease symptoms during the growing season.

- *Crop rotation*

  The following crops and pasture plants are potential hosts for one or both of the bacterial diseases; French bean, navybean, lima bean, cowpea, adzuki bean, soybean, pigeon pea, guar, faba bean, siratro, native glycine, kudzu, and lablab. Mungbean should be rotated with a non-host crop for at least two years to provide sufficient time for residue decomposition. Burying stubble will also assist in this process.

- *Control host weeds and volunteers*

  Volunteer plants and weeds such as cowvine, bellvine, morning glory, *Desmodium* and *Centrosema* are known hosts of one or both diseases and should be managed effectively.

- *Restrict movement through the crop*

  Movement should be restricted through the crop to avoid wounding the foliage and spreading the pathogen further. Harvesting equipment should be thoroughly cleaned of mungbean residues, preferably with an antibacterial solution, to avoid spreading the bacterial cells from infested residues to the surface of seed during harvest.

Fusarium wilt

Fusarium wilt is becoming an increasing problem to mungbean growers across the northern region. The disease is usually found at a low incidence (1-10%) in most paddocks, although in recent years it has caused extensive damage to several paddocks (greater than 70% incidence).

Fusarium wilt often occurs in paddocks experiencing stressful conditions, such as excess water. Heavy clay soils are more often affected, particularly on the edge of paddocks and in low lying areas. Both seedlings and older plants can be affected by the disease. Affected seedlings wilt and their lower roots rot and may develop a basal rot on stems. If infection occurs in older plants, the leaves wilt and the xylem tissue becomes discoloured.

Little is currently known of the disease in Australia, including which species are responsible. Isolations from affected plants across the northern region have consistently isolated two *Fusarium* species; *F. oxysporum* and *F. solani*. Both species have been isolated from approximately 80% of plants affected with the disease, as seen in Table 2. Both species have been associated with the disease in mungbean and other bean or *Vigna* species outside of Australia. Preliminary glasshouse trials suggest both species are involved, although further research is required to confirm this. Future research plans to investigate the relative levels of resistance to the pathogen/s in the current commercial varieties and advanced breeding lines; alternative hosts; and other integrated disease management strategies.

Table 2. Relative abundance of *Fusarium* species isolated from mungbean plants with fusarium wilt

Fusarium species	**Frequency isolated (%) (n=61)[a]**
F. solani	39.3a
F. oxysporum	39.3a
F. moniliforme species complex	9.8b
F. incarnatum-equisetti species complex	8.2b
F. proliferatum	3.3b

[a]Values followed by a common letter are not significantly different (P>0.05)

Management of fusarium wilt

It is recommended that growers avoid planting mungbean into paddocks previously affected with fusarium wilt for a number of years. Ideally seed should be sown into well-drained soils that has been optimally fertilised and avoid stress, such as excess water.

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Fungicide management of mungbean powdery mildew

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Key words

Mungbean, powdery mildew, management, fungicide

GRDC code

DAQ00186

Take home message

- Timely fungicide sprays are the key to effective management of mungbean powdery mildew
- The most practical time of the first fungicide application is at first sign of powdery mildew in the crop
- In most situations two sprays are better than one spray
- Incidence and severity will be determined by weather conditions – cooler humid conditions favour the disease

Background

Powdery mildew of mungbean is caused by the fungus *Podosphaera fusca*. In Australia, yield losses of up to 40% have been recorded in highly susceptible varieties such as cv. Berken. Plants are susceptible to powdery mildew from the seedling stage onwards, with the first sign of infection being small, circular, white powdery patches on the lower leaves. The disease can develop rapidly on individual leaves and also up mungbean plants; under the right weather conditions every leaf can be covered with the white powdery growth. Stems and pods may also be infected by the powdery mildew pathogen, resulting in discrete white patches. The visible white powdery growth consists of the spores (conidia) and spore-bearing structures (conidiophores)

Generally powdery mildews such as *P. fusca* need a living host for its' survival from mungbean cropping season to season. Volunteer mungbean plants, phasey bean and perhaps other leguminous species are sources of infection. There is no evidence that the mungbean powdery mildew pathogen can survive on plant residues, in seed or in the soil. Infection of mungbean plants occurs when the spores produced in the white powdery patches become airborne, spread in the wind and land on leaves. There they germinate, infect the upper layers of the leaf (epidermis) and fine fungal strands (hyphae) grow across the leaf surfaces. The spore-bearing structures develop later on these fungal strands. A cycle of infection from spore germination to the production of the spore-bearing structures can take as little as 5 days. Disease outbreaks are generally favoured by mild temperatures and high humidity.

Management

Management of mungbean powdery mildew relies on the use of varieties with the highest possible levels of resistance and on the strategic application of fungicides. The variety Jade-AU has the highest level of resistance to *P. fusca* (moderately susceptible; MS), with all other Australian varieties apart from cv. Green Diamond being susceptible (S) or highly susceptible (HS). It is unlikely that significant gains in resistance to the powdery mildew pathogen will be made in the near future, so the targeted use of fungicides is vital to minimising the disease's impact.

Fungicide trials

Four GRDC-funded trials were undertaken by USQ staff in collaboration with the DAFQ Regional Agronomy Initiative and Mungbean Improvement teams in 2015/16 to develop fungicide spray strategies for the control of powdery mildew on cv. Jade-AU⚳. The trials were conducted in 2015 at Hermitage Research Facility, Warwick; HRF) and in 2016 at HRF, J Bjelke-Petersen Research Facility (= Kingaroy Research Facility; KRF) and Emerald Research Facility (ERF), with 6 treatments in the first year and 7 treatments in 2016 (Table 1). Spreader rows of cv. Berken were used in all trials.

The fungicide Folicur® 430 EC (active ingredient tebuconazole 430g ai/L) was applied at 145mL product/ha in >100L of water using hand-held boom sprayers. Fungicides containing tebuconazole are currently under APVMA permit (permit number 13979 – permit expires June 2017 and is only valid in Qld and NSW) for the control of mungbean powdery mildew.

Trials were rated for powdery mildew severity at 3 dates using a 1-9 scale where 1 = no sign of powdery mildew and 9 = colonies of powdery mildew to top of 100% plants, with leaf drop. All plots were harvested at crop maturity. The results of the trials are present in Figure 1 and Tables 1 and 2.

Figure 1 displays the progression of powdery mildew in the 2016 trial at the Hermitage Research Facility. Powdery mildew developed rapidly in the unsprayed plots over the course of the trial, reaching a mean value of 8 at the last rating date (63 days after emergence (dae)). The two treatments involving a spray at the first sign of powdery mildew controlled the disease for at least 14 days, but then powdery mildew developed rapidly.

In all of the other fungicide treatments powdery mildew developed relatively slowly until 48 days after emergence, when it increased rapidly in the single 1st sign, 1st sign + 1 and the single 4 week spray treatments. On the last rating date, the 4wk + 2 spray, 4wk +1 spray and 1/3 +1 spray treatments had the lowest disease severities. Powdery mildew, as measured by the mean severity of the unsprayed treatment, was more severe at Hermitage (mean severity value of 8) and Kingaroy (8.3) than at Emerald (4.5).

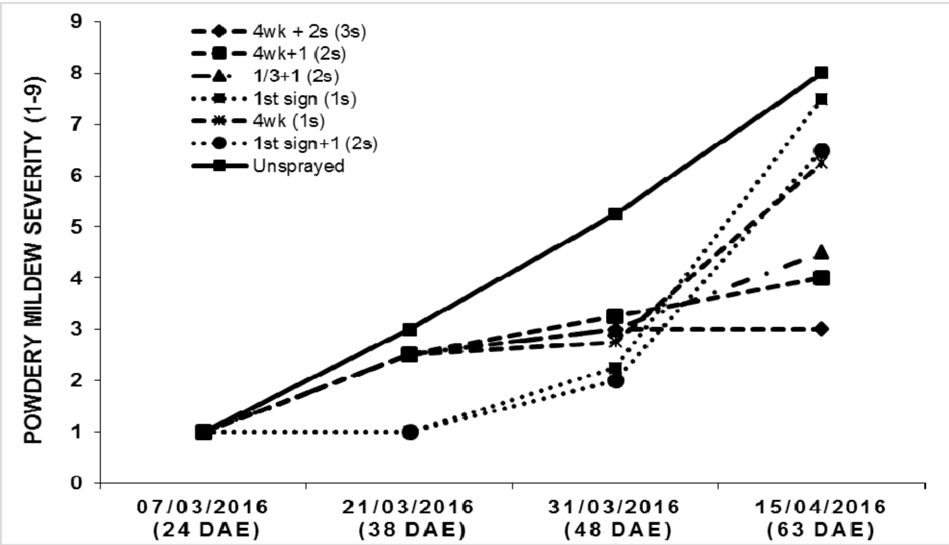

Figure 1. Development of powdery mildew on mungbean cv. Jade-AU⚳ in the 2016 Hermitage Research Facility trial (the bar represents the LSD value at P=0.05)

In the 2015 trial at HRF the treatment which increased yield the most was the 3 spray treatment of the first spray 4/5 weeks after emergence (when there was no sign of powdery mildew in the plots) followed by 2 sprays, 14 days apart (9.5% increase) (Table 1). The second best treatment was the treatment involving a spray at the first sign of powdery mildew followed by 1 spray 14 days later (6.6%), and the next best was the treatment in which plants were sprayed when powdery mildew was 1/3 the way up plants followed by a spray 14 days later (3.3%). A single spray at the first sign of powdery mildew was not effective.

In the 2016 trials, the % increases in seed yield of the fungicide treatments over the unsprayed treatments ranged from -2.7% to +32.7% (Table 1). However, statistical analyses revealed that there were no significant differences in seed yield between any of the treatments (fungicide treatments and unsprayed treatment) at Kingaroy and Emerald and therefore the figures for % yield increase can only be used as a guide.

On the other hand, the trial at Hermitage was the only one in which differences in yield and therefore differences in % yield increase between treatments can be used with confidence. There, the yields of the four best treatments (first spray 4/5 weeks after emergence +1 spray or 2 sprays, first spray 1/3 up the plant + 1 spray, first sign of powdery mildew + 1 spray) did not differ significantly from each other and increased the seed yields by between 30.4% and 27.6%.

At Kingaroy there was a trend for three of these treatments (first spray 4/5 weeks after emergence +1 spray, first spray 1/3 up the plant + 1 spray, first sign of powdery mildew + 1 spray) to have the highest % yield increases, similar to the Hermitage trial. However, at Emerald there was no such trend, with the single spray treatments (first spray at the first sign of powdery mildew and first spray 4/5 weeks after emergence) having the highest % yield increases. These inconsistencies between sites could be due to low disease levels at Emerald (disease levels at Hermitage and Kingaroy were similarly high), and high variation in yield of treatments between replicate plots at Emerald and Kingaroy.

Table 1. Yield increases of mungbean cv. Jade-AU⫯ under different fungicide spray regimes in 2015 and 2016 trials at different localities

Treatment (total no. of sprays)	% yield increase [1]			
	2015	2016		
	HRF	HRF	KRF	ERF
4/5 weeks +1 spray 14 days later (2)	-	30.4*	32.7	3.4
1/3 up plant + 1 spray 14 days later (2)	3.3	28.8*	19.2	-2.7
First sign + 1 spray 14 days later (2)	6.6	28.7*	18.2	0.5
4/5 weeks + 2 sprays 14 days apart (3)	9.5	27.6*	9.7	5.3
First spray 4/5 weeks after emergence (1)	-	22.6	30.6	8.1
First spray at first sign of PM (1)	-3.3	17.9	14.5	14.9
First spray when PM is 1/3 up plant	0.9	-	-	-

[1] % yield increase = (mean yield of treated plots – mean yield of unsprayed plots) x100 / mean yield of unsprayed plots

* the yields of these treatments were significantly greater than that of the unsprayed treatment; differences between these treatments were not significant

Differences in the performances of the treatments between years can be caused by differences in (i) weather factors, eg., temperature, humidity and rainfall, (ii) time of appearance of powdery mildew relative to plant age, and (iii) timing of sprays relative to appearance of powdery mildew. For example at Hermitage Research Facility in **2015** powdery mildew appeared late in the trial, with the first spray for the first sign of powdery mildew being applied 50 dae, the 4/5 weeks after emergence treatment being applied earlier (35 dae) and the 1/3 canopy treatment later (57 dae). By contrast, in the **2016** trial at HRF, powdery mildew appeared early, with the first spray for the first sign of powdery mildew being applied at 24 dae and the first sprays for the other two treatments both being applied at 34 dae.

Table 2 provides an example of the financial impact of applying fungicide sprays to manage powdery mildew on the cv. Jade AU⟃. Based on the assumptions outlined in the footnotes of the Table and the yields of the treatments at Hermitage Research Facility, all of the fungicide treatments would have resulted in increased returns, the best 3 treatments being those with 2 sprays, irrespective of when the first spray was applied. The cost of the sprays far outweighed the returns, and this fact would also be true at lower yields and lower seed values.

Table 2. $ Returns of fungicide spray treatments in the 2016 Hermitage Research Facility mungbean powdery mildew trial

Treatment (total no. of sprays)	$ gross return [1]	$ net return [2]	$ increase over unsprayed
4/5 weeks +1 spray 14 days later (2)	2057	2017	439*
1/3 up plant + 1 spray 14 days later (2)	2033	1993	415*
First sign + 1 spray 14 days later (2)	2030	1990	412*
4/5 weeks + 2 sprays 14 days apart (3)	2013	1953	375*
First spray 4/5 weeks after emergence (1)	1934	1914	336
First spray at first sign of PM (1)	1861	1841	263
Unsprayed	1578	1578	

[1] Assumes $1000/t seed
[2] Gross return – spray costs at $20/ha/spray
* the yields of these treatments were significantly greater than that of the unsprayed treatment; differences between these treatments were not significant

Researchers in the summer field crops pathology team at USQ are collaborating with plant disease epidemiology modellers at the Western Australia Department of Agriculture and Food (DAFWA) to develop a model, based on weather conditions, which predicts the first outbreak powdery mildew in a mungbean crop. This model will assist in determining the timing of the critical first fungicide spray.

Conclusions

- The fungicide tebuconazole is an effective fungicide for the management of powdery mildew on mungbean crops
- In general, the cost of applying a fungicide to control mungbean powdery mildew will be far outweighed by the resultant increase in yield
- The efficacy of different spray schedules varies from year to year depending on weather conditions which influence the time of appearance of powdery mildew in the crop and its subsequent development
- In most years, applying the first spray at the first sign of powdery mildew in a crop will be effective
- Application of a second fungicide spray, 14 days after the first, is highly recommended

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Part I: New pathotypes of wheat leaf rust: potential impacts and what to look for and Part II: Adult plant resistance and rust management decision making

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Key words

Leaf rust, wheat, minimum disease standards, resistance, pathotype

GRDC codes

US00063, US00064, US00067

Take home messages

- Rust pathogens spread freely and rapidly through the Australasian region. While this is predominantly in a west-to east direction, recent years have seen two examples of east-to-west transport.
- Monitor for the presence of the green bridge, and if present, make sure it is destroyed at least 4 weeks before crops are sown, either by heavy grazing or herbicides.
- Warm, moist autumn conditions favour the development of leaf rust.
- Monitor crops of vulnerable varieties for leaf rust in 2016 and send samples for pathotype analysis to the Australian Rust Survey. This service is free to all, and is funded by the grower levy paid to the Grains Research and Development Corporation.
- The identification of rust pathotypes involves greenhouse tests in which seedlings of indicator varieties are infected, and takes about 3 weeks. These tests are increasingly being supplemented with DNA-tests that are much quicker (less than 48 hours). The DNA tests provide useful basic information but are nowhere near powerful enough to identify pathotypes.
- Genetic resistance to rust in cereals delivers significant benefit to Australian grain growers, estimated at $1.1 billion annually with wheat alone, and remains the basis of rust control.
- Minimum disease standards remain important for industry-wide benefit from genetic resistance.

New pathotypes of wheat leaf rust: potential impacts and what to look for

Australian wheat crops are infected by 3 different rust pathogens: stem rust (caused by *Puccinia graminis* f. sp. *tritici*), stripe rust (caused by *Puccinia striiformis* f. sp. *tritici*), and leaf rust (caused by *Puccinia triticina*).

What is a rust pathotype?

Many people who have an interest in cereal production would have heard the term “pathotype” (pt., aka “races” or “strains”). Pathotypes are variants within a pathogen that differ in their ability to overcome rust resistance genes in cultivars. A good recent example of this concerns stripe rust and the wheat cultivar Mace. Like many current wheat varieties grown in WA, Mace carries the stripe rust resistance gene *Yr17*, a gene that is expressed at all growth stages (often referred to as seedling resistance genes, major resistance genes, all stage resistance genes; see below). While Mace is resistant to the “WA stripe rust pathotype”, first detected in 2002, the resistance provided by *Yr17* was overcome in eastern Australia by a new pathotype, 134 E16 A+ Yr17+, first detected in 2006. To date, the latter Mace-virulent pathotype has not been detected in WA. For this reason Mace is regarded as susceptible to stripe rust in eastern Australia, and resistant to stripe rust in WA.

Thirteen pathotypes of wheat leaf rust have been detected in north eastern Australia since 2000, of which six have been common in recent years (**Table 1**).

Rust pathotype surveillance

The existence of rust pathotypes was first shown in the early 1900s in the USA. Not long after, Australian annual rust surveys were initiated at the University of Sydney, and continue to this day at the University's Plant Breeding Institute (PBI). The identification of rust pathotypes at the PBI is a free service that is open to anyone who would like to submit a sample for analysis. Directions on how to do so are provided at the end of this paper. Following this procedure is vital if the viability of a rust isolate is to be ensured.

Pathotype identification involves infecting seedlings of a set of cereal varieties, each carrying a different rust resistance gene, with a field collected sample of rust. The ability or inability of the rust isolate to overcome the resistance gene in each variety allows the pathotype or pathotypes present to be identified. These tests take about 3 to 4 weeks to complete, and if a new pathotype is suspected, often a longer time is needed to confirm this. The pathotype identification work at PBI is increasingly being supplemented by DNA profiling, which is comparatively quicker and may only take several days. However, while providing important information and a means by which exotic rust incursions can be recognised rapidly, as yet, DNA profiling is nowhere near powerful enough to identify individual pathotypes.

The long-term studies of pathogenic variability of rust pathogens conducted at PBI have clearly established that Australia and New Zealand comprise a single rust epidemiological unit, within which rusts migrate freely and rapidly. This is why a nationally coordinated approach to the genetic control of cereal rusts (i.e. the Australian Cereal Rust Control Program) is fundamental to success.

The annual surveys of rust variability carried out at PBI have and continue to form the basis of all gene-based rust control efforts. They monitor the effectiveness of rust resistance genes in commercial cultivars; determine the implications of new rust pathotypes in the rust responses of current cereal cultivars; facilitate the discovery and introduction of new resistance genes into locally adapted germplasm; and allow pre-emptive resistance breeding.

Table 1. Current common wheat leaf rust pathotypes detected in north eastern Australia

Pathotype	Year first detected	Comments
104-1,2,3,(6),(7),11	1989	Derived by mutation from pt. 104-2,3,(6),(7),11
104-1,2,3,(6),(7),11 +Lr37	2002	Derived by mutation from pt. 104-1,2,3,(6),(7),11
76-1,3,5,7,9,10,12 +Lr37	2011	Derived by mutation from pt. 76-3,5,7,9,10,12 +Lr37
76-3,5,7,9,10,12,13 +Lr37	2013	Derived by mutation from pt. 76-3,5,7,9,10,12 +Lr37
76-1,3,5,7,9,10,12,13 +Lr37	2014	Derived by mutation from pt. 76-3,5,7,9,10,12,13 +Lr37
104-1,3,4,6,7,8,10,12 +Lr37	2014	Exotic incursion, origin unknown

Recent changes in the wheat leaf rust pathogen in eastern Australia

A new pathotype of the wheat leaf rust pathogen, *Puccinia triticina*, was detected in a sample of leaf rust collected from a crop of the wheat cultivar SQP Revenue at South Bool Lagoon (South Australia) in mid-August 2014. The new pathotype, 104-1,3,4,6,7,8,10,12 +Lr37, was considered to be an exotic incursion based on its unique virulence profile and SSR fingerprint. This pathotype is the 12th documented incursion of an exotic wheat rust pathogen since Australia-wide cereal rust surveys conducted by University of Sydney staff began in 1922.

Following its initial detection in SA, pt. 104-1,3,4,6,7,8,10,12 +Lr37 spread rapidly throughout much of the eastern Australian wheat belt and in late September 2015 it was identified in samples of leaf rusted wheat collected from four separate locations in the northern region of the WA wheat belt.

Pt. 104-1,3,4,6,7,8,10,12 +Lr37 carries virulence for the resistance genes *Lr27*+*Lr31*, and the adult plant resistance (APR) gene *Lr12*, and combines this with virulence for *Lr13* and *Lr37*. All four resistances occur in Australian wheat varieties, and consequently this pathotype has resulted in increased leaf rust susceptibility in some varieties.

Of the 37 varieties for which detailed information is available, the leaf rust responses of 31 are not expected to change (**Table 2**). The remaining six carry resistance genes either singly or in combination that prior to the detection of the new pathotype would have provided some protection against leaf rust. While all of these varieties are now more susceptible to leaf rust, it is very fortunate that all except Mitch and Wallup carry a level of residual resistance due to the presence of uncharacterised APR. Growers of these varieties are nonetheless advised to monitor crops for the presence of leaf rust.

The leaf rust responses of the newer varieties B53, Buchanan, Flanker, Kiora and Mansfield are currently not well known, and further data will be collected during the 2016 cropping cycle.

If any rust is found on any cereal crop, it can be sent to the Australian Rust Survey (see below), where it will be analysed and the sender will be notified of the results. This is a free service, and its success in establishing the distribution and occurrence of known rust pathotypes, and in detecting new rust pathotypes, depends entirely on the collection and submission of samples.

Table 2. Leaf rust response and genotype for wheat varieties grown in north-eastern Australia[a]

Change in response due to new pathotype?	Cultivar	Leaf rust response	Rust resistance genotype	
			All Stage	Adult Plant
No	Adagio	MSS	*Lr37*	Uncharacterised
No	Baxter	S	*Lr17a*	***Lr34***[b]
No	Beckom	S	*Lr3a, Lr37*	***Lr34***
No	Bolac	S	Nil	***Lr34***
No	Cobra	MR	*Lr3a*, ***Lr23***	Uncharacterised
No	Dart	SVS	*Lr1, Lr13*	***Lr34***
No	EGA Gregory	MR	*Lr3a*, ***Lr23***	***Lr34***
No	EGA Wedgetail	MS	Nil	***Lr34***
No	EGA Wylie	MS	*Lr3a, Lr17a*	***Lr34***
No	Elmore CL Plus	RMR	*Lr24*	***Lr34***
No	Forrest	MS	*Lr1, Lr13*	***Lr34***
No	Gauntlet	MS	*Lr3a, Lr37*	***Lr34***
No	Gazelle	MR	*Lr24, Lr37*	Uncharacterised
No	Impala	SVS	*Lr37*	***Lr34***
No	Janz	MRMS	*Lr24*	***Lr34***
No	Lancer	RMR	*Lr24*	***Lr34***
No	Livingston	MSS	*Lr1, Lr13, Lr37*	***Lr34***
No	Manning	MRMS	***Lr23***, *Lr26, Lr37*	Uncharacterised
No	Merlin	MS	*Lr1*	Uncharacterised
No	Naparoo	S	*Lr13, Lr24*	Nil
No	Orion	R	*Lr20, Lr37*	Uncharacterised
No	Scenario	MSS	*Lr37*	Uncharacterised
No	Sentinel	R	*Lr26*	***Lr34***
No	SF Ovalo	MSS	*Lr13*	Uncharacterised
No	Spitfire	S	*Lr1*	***Lr46***
No	SQP Revenue	SVS	*Lr13, Lr37+*	Nil
No	Sunguard	MR	*Lr24+*	***Lr34***
No	Sunvale	S	*Lr37*	***Lr34***
No	Sunzell	MS	*Lr1, Lr13, Lr37*	***Lr46***
No	Ventura	MSS	*Lr13, Lr37*	Uncharacterised
No	Viking	MSS	*Lr13*	***Lr34***
Yes	Mitch	SVS	*Lr13, Lr27+Lr31*	Nil
Yes	Sunlamb	MRMS	*Lr37, Lr27+Lr31*	Uncharacterised
Yes	Sunmate	MS	*Lr1, Lr37, Lr27+Lr31*	Uncharacterised
Yes	Suntime	MS	*Lr1, Lr37, Lr27+Lr31?*	Uncharacterised
Yes	Suntop	MRMS	*Lr1, Lr27+Lr31, Lr37*	Uncharacterised
Yes	Wallup	SVS	*Lr13, Lr20, Lr27+ Lr31?*	Nil
?	B53	S	*Lr?*	Nil
?	Buchanan	MR	?	Uncharacterised
?	Flanker	MRMS		***Lr34***
?	Kiora	MRMS		***Lr34, Lr46***
?	Mansfield	MS		Uncharacterised

[a]For full genotypes (i.e. stem rust, stripe rust and leaf rust), see Cereal Rust Report 2016 **14**(4) [http://sydney.edu.au/agriculture/plant_breeding_institute/cereal_rust/reports_forms.shtml]

[b]Genes in bold font are effective against common pathotypes of the leaf rust pathogen

Pathotype surveys and rust control

To have maximum impact in disease control, surveys of pathogenic variability in rust pathogens must be closely integrated with the development and management of new wheat cultivars. Where this has been practiced, surveys have provided both information and pathogen isolates that have underpinned rust control efforts, from gene discovery to post-release management of resistance resources. Information generated by pathotype surveys has been used to devise breeding strategies, inform selection of the most relevant isolates for use in screening and breeding, define the distribution of virulence and virulence combinations, allow predictions of the effectiveness/ineffectiveness of resistance genes, and issue advance warning to growers by identifying new pathotypes that overcome the resistance of cultivars before they reach levels likely to cause significant economic damage.

Maintaining and improving current levels of rust control

It has been estimated that 50% of the cost of plant improvement involves breeding to maintain current yield and quality levels to meet the challenges of degrading growing environments and evolving pathotypes of major pathogens ("maintenance breeding"). Protecting the *ca*. $1 billion savings to the Australian wheat industry from resistance breeding and reducing the current impact of rust diseases will only be possible if resistance remains a priority in breeding programs, and if the wheat industry as a whole continues to support genetic approaches to rust control.

Adult plant resistance and rust management decision making

Many people in the cereals industry would be familiar with the expression that a variety's disease resistance has 'broken down'. This expression can be misleading because it suggests that the variety itself has changed in some way. However, the shift in a variety's response to rust is actually caused by a change in the pathogen that causes the disease. This is why monitoring rust populations for new pathotypes is critical to informing knowledge of how a variety's resistance stacks up.

The emergence of a new rust pathotype can result in a resistant variety becoming more susceptible to rust. Because this shift is often subtle, describing the change in a variety to a new rust pathotype accurately can be difficult.

Changes in a variety's response to new pathotypes are influenced by the nature and number of genes that confer resistance to the disease. Such resistance genes protect against the disease either at all growth stages, which is called all stage resistance (ASR; also referred to as 'seedling' or 'major' resistance), or at adult plant growth stages only, which is called adult plant resistance (APR; also referred to as minor gene resistance).

Genes that confer ASR usually provide very high levels of protection against rust, while those conferring APR usually provide moderate levels of protection. A variety may carry one or both gene types, resulting in different effects on resistance levels.

Where a variety only carries an ASR gene, and this is overcome by a new rust pathotype, its resistance rating may change from highly resistant to highly susceptible.

There are many examples of such changes in a variety's resistance levels – known as the 'bust' part of what is known as the 'boom and bust cycle'. One of the first examples of this shift was recorded in the Eureka wheat variety's resistance to stem rust. Eureka was highly resistant to stem rust when it was released in 1938. However, because this variety only has one ASR gene (*Sr6*) to protect it against stem rust, it became highly susceptible to the disease when this single gene was overcome by a new rust pathotype in 1942. Similarly, the stripe rust resistance rating of Mace was downgraded from highly resistant to very susceptible because it only has one ASR gene (*Yr17*), which was overcome by a new pathotype in eastern Australia. However, in other grain growing regions such as Western Australia, Mace remains highly resistant to stripe rust because its single ASR gene has not been overcome.

Adding another dimension of complexity are the many wheat varieties that carry a combination of ASR and APR genes. Having both these genes means a pathotypic change can result in a slight increase in susceptibility that occurs when the ASR gene is overcome by a new pathotype, but the APR gene is still effective in providing 'back-up' resistance .

Field testing is the only reliable way to determine the levels of back-up resistance provided by the APR gene. For example, the full impact of the new wheat leaf rust pt. 104-1,3,4,6,7,8,10,12 +Lr37 will not be known until further field tests are completed this year.

While many years of painstaking genetic research has led to a sound understanding of ASR genes, intensive genetic analyses of APR genes began only about 20 years ago. Consequently, information about the APR genes in Australian wheat varieties is incomplete, and varietal information on rust response such as that which appears in the University of Sydney's Cereal Rust Update reports (see: http://sydney.edu.au/agriculture/plant_breeding_institute/cereal_rust/reports_forms.shtml) has partial information only. The rust response and rust genotype (i.e. which rust resistance genes are present) of varieties that are currently grown in north eastern Australia are provided in **Table 2**. Where a variety is rated as having useful resistance (i.e. either: R, MR, MR-MS), and does not carry an effective ASR gene, the resistance present must be due to APR. For example, from **Table 2**:

- Sentinel carries the ASR gene *Lr26*, which is not effective to currently prevailing leaf rust pathotypes (in the table, the ineffectiveness of *Lr26* is indicated by "*Lr26*" not being in bold font). It does however carry the APR gene *Lr34*. This variety is rated as highly resistant to leaf rust (R), which is due to the APR.
- Gazelle carries the ASR genes *Lr24* and *Lr37*, which again are not effective against currently prevailing pathotypes. This variety is rated as Moderately Resistant (MR), which must be due to APR. The genetic basis of this APR is, however, unknown ('uncharacterised').
- Note that although the variety Dart carries the APR gene *Lr34*, it is rated as being highly susceptible to leaf rust (S-VS). This is because some APR genes on their own do not provide strong levels of resistance (and is why they are sometimes referred to as 'minor genes', or 'genes of minor effect').

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