GRDC Grains Research Update

TOOWOOMBA

Tuesday, 21st June 2016

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Grains Research Update Toowoomba

Tuesday 21st June 2016, Wellcamp Airport

8:00am registration for a 9:00am start, finish 3:25 pm

Agenda

Time	Topic	Speaker (s)
9:00 AM	Welcome	GRDC
9:10 AM	**The Wellcamp airport**: its strategic role, implications and opportunities for agriculture in inland Southern Queensland.	*Sara Hales (Wellcamp Airport Communications and Business Development Manager)*
9:35 AM	**Practical applications of digital imaging**	*Peter Birch (B & W Rural/Satamap)*
10:00 AM	**Managing the major mungbean diseases**: halo blight, fusarium wilt, tan spot and powdery mildew.	*Lisa Kelly (DAF Qld) & Sue Thompson (USQ)*
10:35 AM	Morning tea	
11:05 AM	**Mungbean agronomy for a profitable crop**: plant population, row spacing, time of sowing, water use, varieties, nitrogen fixation and key yield drivers.	*Kerry McKenzie (DAF Qld)*
11:30 AM	**Mungbean insects:** what's new – late season mirids, Etiella and scouting.	*Hugh Brier & Liz Williams (DAF Qld)*
11:55 AM	**Optimising sorghum genetics and management for targeted situations:** How big is the current upside and what might be possible with new genetics?	*David Jordan & Daniel Rodriguez (QAAFI)*
12:35 PM	Lunch	
1:35 PM	**Minimising nitrogen losses to improve use efficiency in summer crops:** • Understanding loss pathways - how much is lost and factors influencing • The impact of N source - fertiliser type, organic N and N from pulse crops • Urease and denitrification inhibitors.	*Mike Bell (QAAFI)*
2:10 PM	**Tillage impacts of weed seed burial and subsequent management.**	*Michael Widderick (DAF Qld)*
2:35 PM	**Grower experience with new planter technology**: Auto downforce, variable rate seeding. Is it working, are differences being seen, will the investment pay-off?	*Dave Peters (grower, Allora) & Dale Jeude (grower, Bowenville)*
3:05 PM	**Chickpea and faba bean disease update**	*Kevin Moore (NSW DPI)*
3:25 PM	Close	

Contents

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The Wellcamp airport - its strategic role, implications and opportunities for agriculture in inland Southern Queensland

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Practical application of digital imaging in agricultural systems

Peter Birch, Senior Agronomist B&W Rural, Moree

Keywords

Digital Imagery, sensors, satellites, UAVs, Satamap

Take home message

A picture is worth 1000 words.

Background

As the technology revolution and in particular the digital revolution increases data and knowledge exponentially, sensing technologies are popping up everywhere.

Satellite technologies once the realm of the military and extraordinarily expensive are now becoming progressively more available, accurate and progressively cheaper.

UAVs likewise are becoming increasingly more high-tech and able to carry much more sophisticated sensors and perform autonomous operations at the same time becoming progressively cheaper.

Ground-based sensors and particularly the communications systems between them and back to a home base are also developing exponentially.

A few basics

Types of sensors

There are a myriad of sensors providing information or imagery. These include visible, red edge, infrared, radar, thermal, lidar, EM38 to name a few. I will mainly talk about the near infrared or NIR.

- Imagery comes back to earth as digital numbers provided by sensor (DN)
- Taking into account sun angle, atmosphere and sensor specs, DNs are converted to reflectance values
- The reflectance value is used to make images (true and false colour), and generate other information such as vegetation indices
- The sensor 'looks' at different bandwidths
- Blue, red and green bands which our eyes can see
- Near infrared, short wave infrared, thermal bands which our eyes cannot see.

Vegetation indexes

Satellites and most UAVs sensors see the world in distinct wave length bands. Live vegetation reflects in the near infrared but little in the visible. The amount of reflection in the near infrared differs between species and also depends on plant health. Vegetative indexes are used to show the differences and the most commonly used Normalised Difference Vegetative Index (NDVI) compares the difference between near infrared and red to the sum of the two. There are many different vegetative indexes which can be used for specific comparisons. For example Satamap uses the MTVI2 index to try account for some soil colour and reduce saturation in high biomass areas.

Pixel size

Pixel size ranges from

- Vast areas such as the 20 km pixels used by DHMM which are useful on a macro scale and in extensive areas
- Modus which is used by programs such as Pastures from Space which has a 250 m pixel but passes over every day and in the Pastures from Space application allows for a maximum chance of getting enough usable images every week to calculate average pasture growth et cetera.
- Landsat 7 and 8 which have 30 m pixels but also has a panchromatic 15 m band. This allows pan sharpening where the 30 m pixels are combined with visual (and NIR) bands to produce higher spatial resolution images. Landsat 7 & 8 pass over every 16 days alternately, i.e. an image is available for every spot on the earth every eight days.
- Sentinel 2A is the new European Space Agency satellite and has a 10 meter pixel. This allows enough accuracy to do most of what is required in broadacre cropping.
- Landsat and Sentinel both provide free data meaning that the data provider such as Satamap, PA source, Geosys, PCT et cetera accesses the raw data for free and you are paying for the processing and storage of the data and subsequent conversion of that data to usable information.
- There are a range of commercial satellites which provide information to increasingly more accurate pixel sizes such as Rapid Eye 5m through to World View 3 at 0.31 m in natural colour and 1.24 m near infrared. There is a cost to accessing this data which is reflected in the commercial offerings.
- UAVs can operate down to 1 or 2 cm pixel size. This depends on the sensor (camera) and the height at which it is flown.

What are the advantages and disadvantages of various systems?

Satellites

Advantages

- Cost-effective
- Remote access
- Rapidly increasing sophistication
- Increasing number of shots available

Disadvantages

- Cloud- both actual and shadows
- Not necessarily available when specific events occur such as hail, spray drift, specific growth stages for fertiliser application et cetera.
- Expensive once you get into very small pixel sizes due to having to sequence the high resolution satellites and minimum order is often around 2000ha.

The future

- Figure out what to do with Sentinel 2 'red edge' bands
- Use sensors that see through clouds

- Planet Labs – 100+ micro satellites to capture entire Earth every day at 3-5m resolution

UAVs

Advantages

- Very small pixel sizes
- On Demand i.e. can time the flights to the events or crop stages required
- Some are relatively cheap to buy and to operate and getting cheaper
- Can operate in variable cloud by timing flights
- Can have multiple sensors and interchangeable sensors
- Are extremely efficient at analysing field trials where vast numbers of plots need to be analysed

Disadvantages

- Limited coverage and flight times
- Can crash
- Can be taken down by eagles
- Still further to go with stitching programs and/or geo referencing
- Legal and CASA obligations

The future

- Fully autonomous
- Accuracy down to levels where crop emergence can be assessed
- New sensors and new ways to analyse the data will provide another massive amount of different information

Ground-based sensors

As I have not really discussed ground-based sensors I will give a few examples. The BOM radar would be a classic example where BOM turn the raw data into rain intensity and then other applications use this data to work out actual rainfall on specific areas.

One of the building blocks of the whole Climate Corp data system in the United States is the Doppler radar network which is very extensive and accurate allowing a very accurate analysis of rainfall and soil moisture on a sub paddock scale.

Yield data available from headers is built up into digital images from paddocks.

There are a range of tractor/vehicle mounted sensors which read nitrogen status in crops and build up a paddock image of the nitrogen status while conducting other operations such as spraying.

There are weather stations which use raw weather data and inputted crop/soil data to build up maps of plant growth and soil moisture.

Advantages

- Can be linked to provide area wide data

- Can be linked outside the traditional communications channels
- Weight is no limitation so any size sensor can be mounted

Disadvantages

- Enormous diversity of sensors giving different information and sometimes not talking to each other
- Is usually performed with another farming operation but if performed alone would be potentially expensive and unnecessary tracking in crops.

The future

- Sensors can be cheaply linked to provide area wide data in conjunction with other digital information.
- Sensors for disease, insects, weeds and a whole variety of nutrients are coming.

A picture is worth a thousand words but what do we do with it?

Some of the practical uses of digital imagery are

- 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

Some holy grails

- To create emergence maps to allow replanting or spot replanting in a timely fashion
- To identify various crops from their digital signature
- To identify weeds within crops
- Seamless application of digital imagery into usable data such as variable rate maps

Useful resources

http://landsat.usgs.gov/tools_spectralViewer.php

www.satamap.com.au

www.pct-ag.com

www.pasource.com

www.geosys.com

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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 – Improving grower surveillance, management, epidemiology, knowledge and tools to manage crop disease

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 1st or 2nd 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.

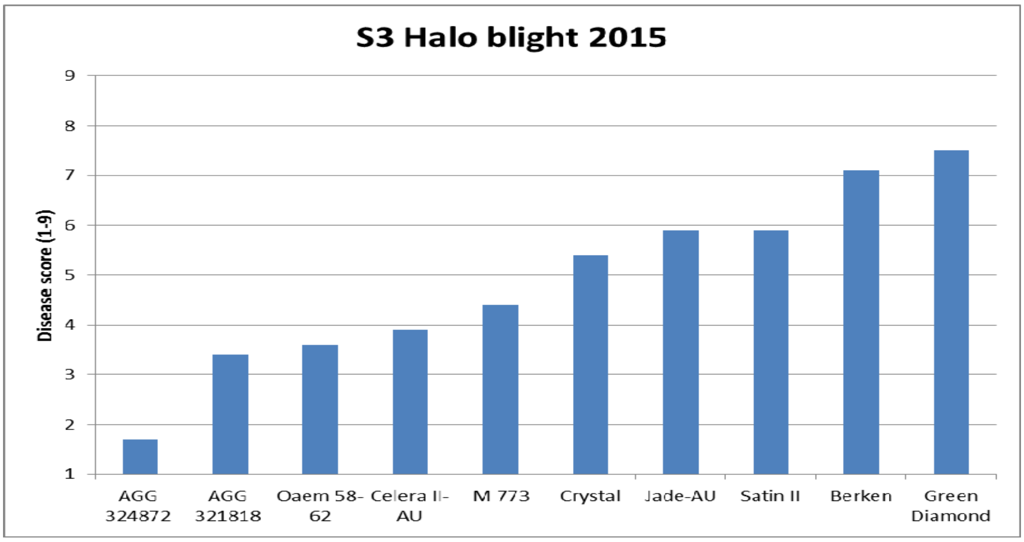

Figure 1. Relative resistance of the mungbean commercial cultivars and advanced breeding lines to halo blight in the 2015 halo blight disease nursery at the DAF Hermitage Research Facility. Disease is scored on a 1-9 scale, where 1 = no disease and 9 = high levels of disease.

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.

Acknowledgements

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Fungicide management of mungbean powdery mildew

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Key words

Mungbean, powdery mildew, management, fungicide

GRDC code

DAQ00186 - Improving grower surveillance, management, epidemiology knowledge and tools to manage crop diseases – USQ/QDAF

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).

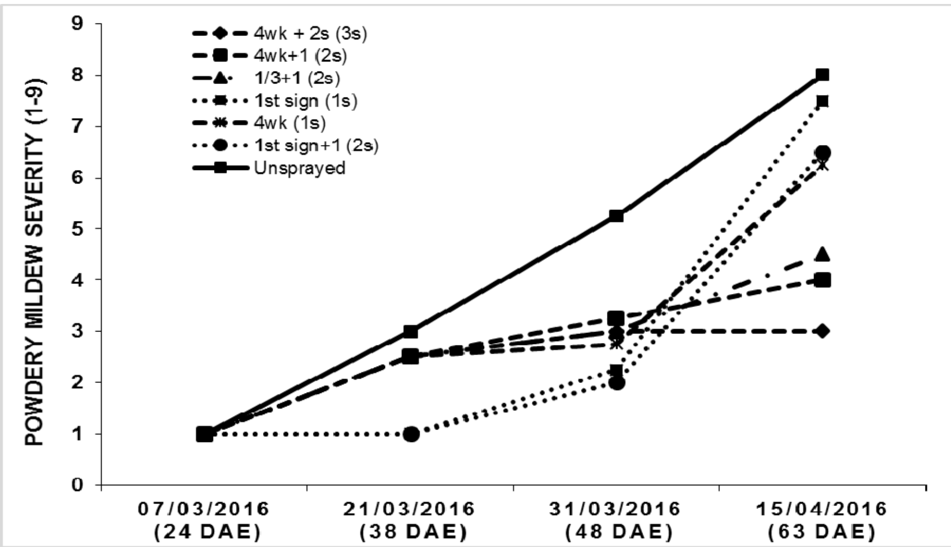

Figure 1. Development of powdery mildew on mungbean cv. Jade-AU in the 2016 Hermitage Research Facility trial (the bar represents the LSD value at P=0.05)

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⟮D⟯. 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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Growing mungbeans successfully: plant population, row spacing, varieties yields and nitrogen fixation

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Key words

Mungbeans, soybeans, agronomy, row spacing, population

GRDC code

UQ00067

Take home message

- Get the basics right – paddock selection, general agronomy
- Reducing row spacing to 50cm and below will maximise summer pulse yields
- The improvement in yield is evident in differing environments and seasons
- Reducing row spacings may also increase the amount of nitrogen fixed
- Plant population has less influence on yield – continue with current recommendations

Background and aims

Despite the potential environmental and economic benefits, the adoption of summer pulse crops in the Queensland Grains Region is around 4% of total cropping. To increase the share of pulses in the total cropping area, strategies are required to enable growers to more consistently realise the potential productivity and profitability of pulse cultivars in their farming systems.

One of the main aims of the project is to not only get an increase in yields for summer (and winter) pulses, but to also improve the reliability of yields. When the risk in reliable yields in varied environments and seasons is reduced, then pulses will not just be considered as a break crop in a cereal rotation or as an opportunistic cash crop but rather as a crop that can be considered a reliable and profitable part of the farming enterprise.

As prices for mungbeans have risen and remained high in recent years, there has been increased interest in growing them. New growers are considering trying them for the first time, previous growers are returning to growing mungbeans and growers who regularly include them in their cropping programs are looking to maximise the crop's yield.

With mungbean yields averaging around 1t/ha in southern Queensland and a long term price of $750/t, an increase in yield of 10% could mean an extra return of $75/ha. Across a growing area of approx. 40,000ha this could mean an additional $3 million of returns to growers.

Mungbeans basics

Paddock selection

When considering planting mungbeans choose paddocks based on:

Good soil moisture – paddocks with less than 75mm of Plant Available Water (PAW) will often produce unreliable or unprofitable crops. The most profitable crops are grown on blocks with high stored moisture from long fallow or early season rains.

Stored moisture should be available to the crop down to 80cm and with no restrictions on rooting depth due to salt, sodicity, compaction or high bulk density.

Table 1. Mungbean yield potential for Dalby

Starting PAW (mm)	Grain Yield (kg/ha)				
	Drier 10% years	Drier 30% years	Average	Wettest 30% years	Wettest 10% years
170	1298	1685	2049	2451	2880
110	927	1248	1774	2254	2752
55	549	758	1204	1775	2392

Source: M. Robertson CSIRO

Herbicide residues – can be a significant problem in mungbeans, particularly if treated as an opportunistic planting. Ensure any residual chemicals have had the appropriate time since the required rainfall amount for mungbean plant back. Refer to herbicide labels.

Soil nitrogen – to get the maximum amount of nitrogen fixed by the plant use a block with low soil nitrates. If planted with high levels of soil nitrate there will be a greater reliance by the plant on this soil nitrate and less nitrogen will be required to be fixed by rhizobia. This may lead to soil nitrate levels being depleted by the mungbean crop.

Soil constraints – mungbeans are extremely sensitive to salinity and sodicity, leading to poor root development, water extraction and reduced, variable yields. It can also lead to uneven crop development and maturity which can lead to difficulties with desiccation and harvest.

Avoid soils with Exchangeable Sodium Percentages (ESP) above 16 in the top 10cm, sodicity at depth has less of an impact on yield, but may restrict root development and water extraction.

Saline soils with EC levels above 2 ds/m will cause yield reductions.

Inoculation

To ensure the crop can reach its full potential the crop needs to be well inoculated so that the rhizobia can meet the nitrogen requirements – this tends to be the most neglected part of growing pulse crops.

Ensure the right group of inoculant is chosen – Group I. Look for the Green Tick which is independently quality assured inoculant.

Keep inoculant in a cool place, but do not freeze. Ideally keep at 4°C, if not possible below 15°C is acceptable.

Choose the formulation that best suits your situation – peat or freeze dried for seed application or water injection, clay or peat granules to be placed with the seed in the soil at planting. Each product and technique has its pros and cons, seek further information to determine what will best suit your operation.

When the crop is at 4-6 weeks of age, gently dig up plants and wash the roots to check the effectiveness of inoculation. In low nitrate soils, well nodulated plants should be able to meet their nitrogen requirements from nitrogen fixed from the atmosphere by rhizobia.

Row spacing and population trials

The first summer pulse trials were established in the 2013/14 seasons and replicated again in 2014/15. The initial trials were based on a population trials with 3 varieties (Jade-AU⍉, Crystal⍉, and a pre release lines from the breeding program), planted at 10, 20, 30 and 40 plant/m^2, on 50cm rows with 3 reps of each. In the first season 2 sites were planted at Warra and Dalby on the Darling Downs. In the season just gone, 4 sites were planted, again at Warra and Dalby, with additional sites at Billa Billa and Miles.

Row spacing trials were planted with a target population of 25plants/m^2. The row spacing treatments were 25, 50, 75 and 100cm in 2013/14 and 25, 50 and 100cm in 2014/15.

The comparison of the weather between the 2 years of trials is quite stark with 2013/14 being very hot and dry, while the 2014/15 season was relatively mild for a summer plant mungbean crop. Figure 1 depicts the weather for Warra over the 2 seasons with above average high temperatures and limited rainfall (55mm in 11 falls) in 13/14, while milder high temperatures and much more in crop rain lead to a doubling of yields at this site.

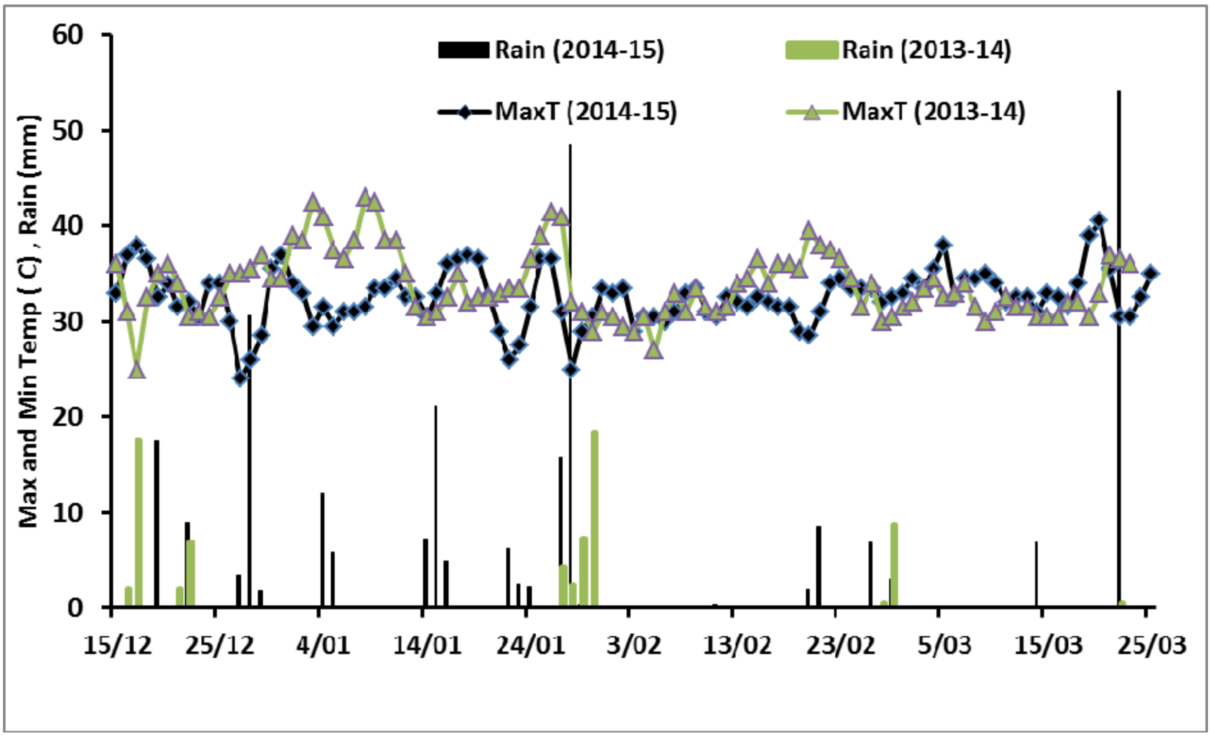
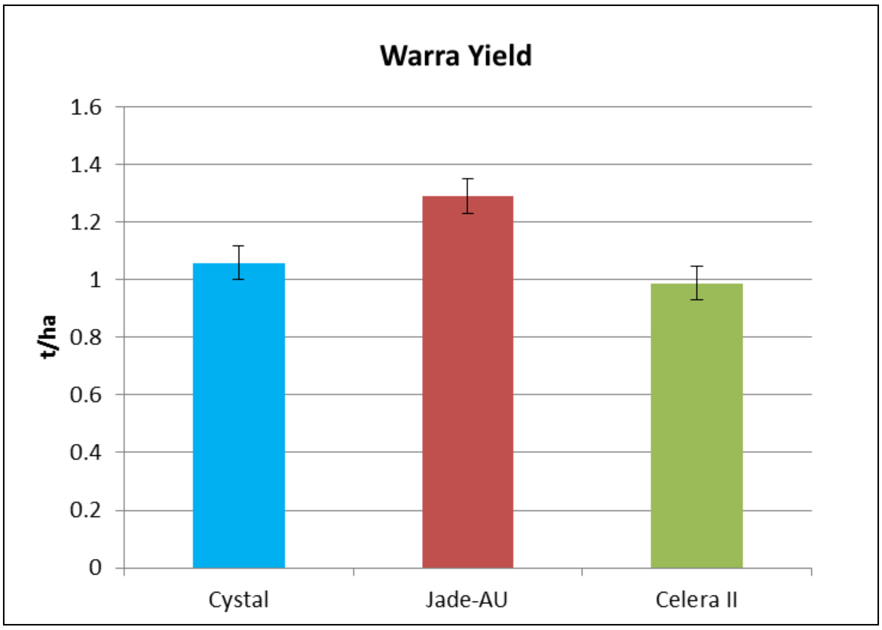


Figure 1. Comparison of 13/14 and 14/15 summers at Warra

In the 2 sites for 13/14 Jade-AU⍉ was the highest yielding variety across all row spacing treatments, followed by the other large seeded commercial variety Crystal⍉. The small seeded pre-release variety MO9246 (since released as Celera II⍉) was much quicker to flowering and maturity and prior to harvest a portion had shelled out of the pods, losses were estimated to be as high as 30%, however the stated results are as harvested and not adjusted for loss.



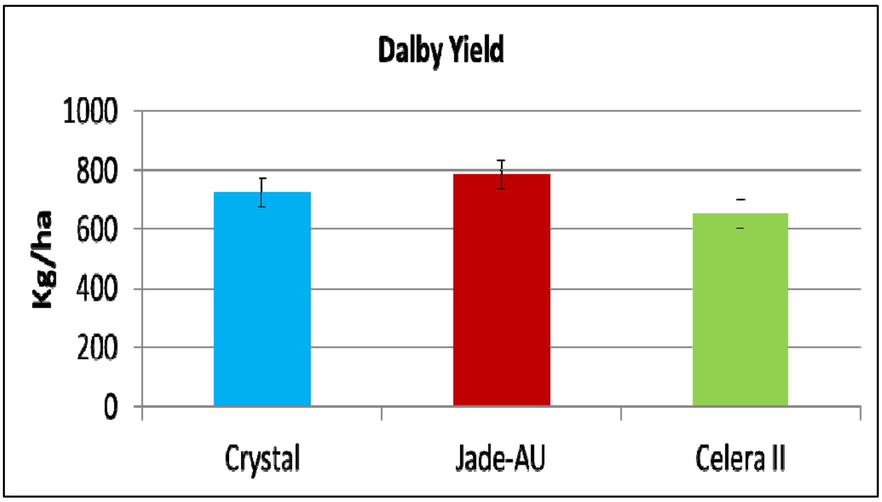


Figure 2. Variety grain yield for all row spacings at Warra (LSD 5% 119.2) and Dalby 13/14 (LSD 5% 101.2)

The highest yields at Warra were in the 25cm row spacing at 1.219 t/ha, although this was not significantly better than the other row spacing treatment, with the lowest of 0.972 t/ha for the 1m treatment.

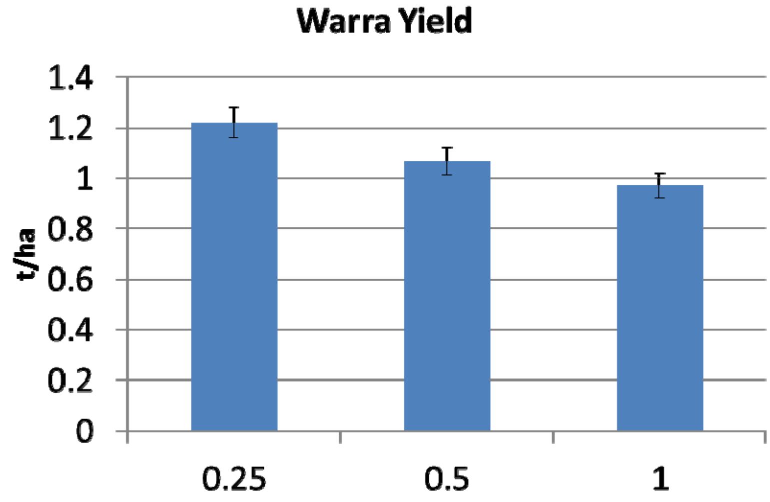


Figure 3. Warra row spacing yields for all varieties 2013/14 (LSD 5% 258.2)

The highest yield at Dalby in 2013/14 was from the 50cm row spacing treatment, but there was no significant difference between the 25cm and 50cm treatments, however there was a significant difference to 1m row spacing.

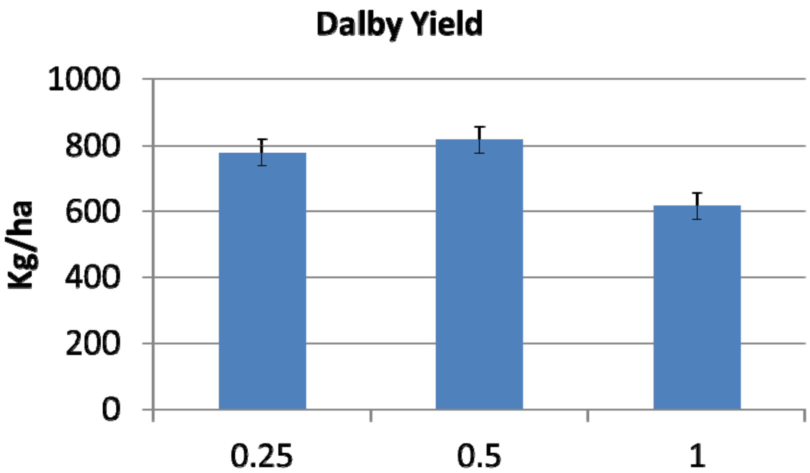


Figure 4. Dalby row spacing yields for all varieties 2013/14 (LSD 5% 81.6)

When the Warra row spacing by variety is graphed as in **Figure 5**, it can be seen that there is no effect of row spacing on the yield of Celera IIϕ. There is an effect on Crystalϕ which is significant when row width is increased from 25cm to 50cm with a nearly 300kg/ha yield drop, with a further significant drop out to 1m rows.

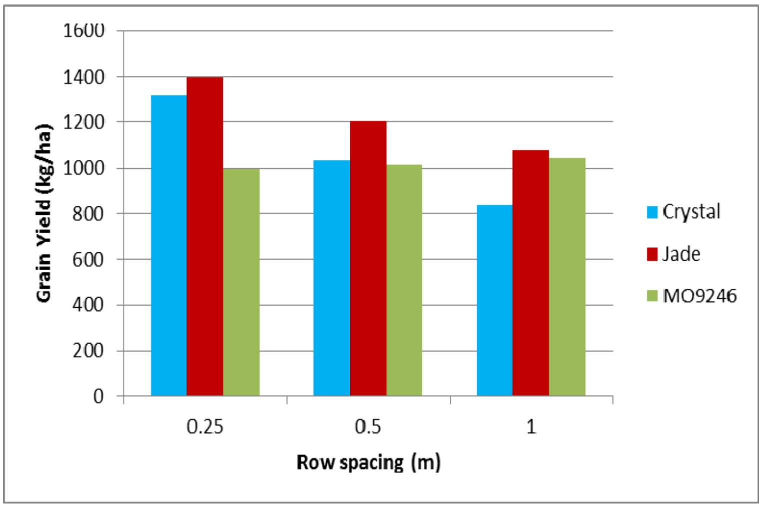


Figure 5. Grain yield of mungbeans at Warra by variety and row spacing treatment (LSD 5% 370)

As the plot size is the same and the plants on different row spacings had access to the same volume of soil the differences in yield are due to the narrower rows being more efficient at converting soil moisture to grain as in **Table 2**.

Table 2. Water use efficiency (WUE) of row spacing treatments at Warra 2013/14 (LSD 5% 2.3)

Row space (m)	**0.25**	**0.5**	**1**
WUE (kg grain/mm)	11.1	9.7	8.9

The 2014/15 results have not been fully analysed at the time of writing however some of the results from the Warra site have been included as a comparison to the much drier season before. In the much better weather conditions of 2014/15 yields were doubled that of the previous season.

The 2014/15 results have confirmed that Jade-AU⊕ has performed better than Crystal⊕ and 2 pre release lines (discussion limited to the commercial available varieties).

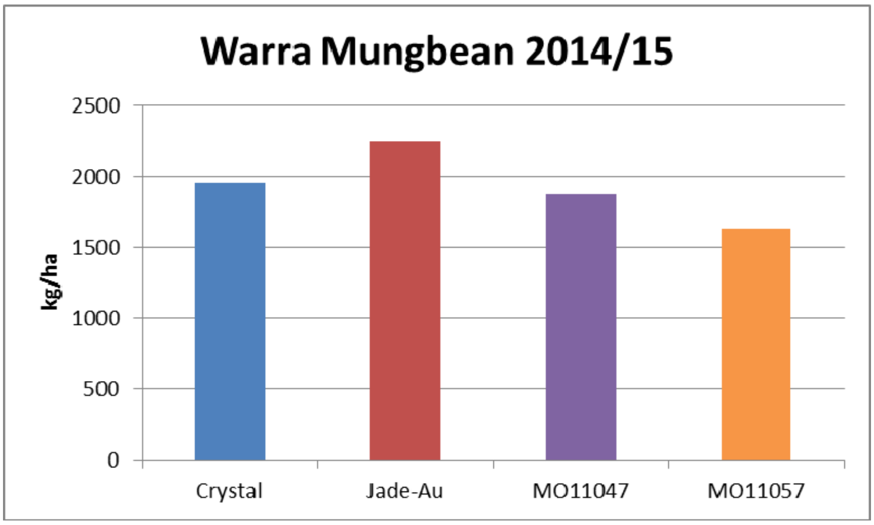


Figure 6. Warra 2014/15 mungbean variety yields, all row spacings (LSD 5% 562)

The yield differences between the varieties were not significant, there is significant difference between 0.25 and 0.5m and the 1m spacing. Crystal⊕ was the only variety that had not significant difference across row spacings, the other varieties all had lower grain yields at 1m.

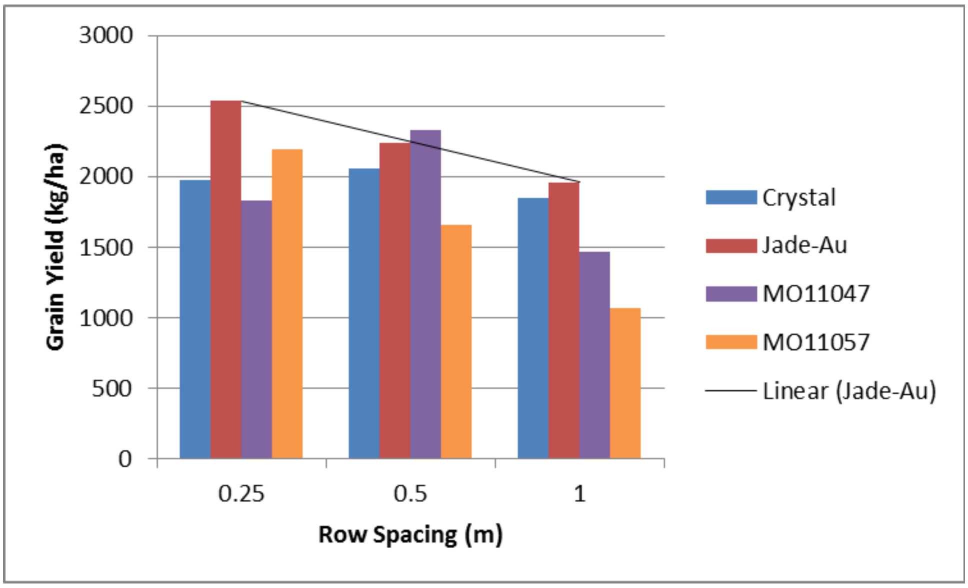


Figure 7. Warra 2014/15 mungbean grain yields variety x row spacing (LSD 5% 704)

In the first year there was no statistical difference in grain yield at the differing plant populations, however there was a trend for lower yields at 10 plants/m^2 and a flat yield response in 20, 30 and 40 plants/m^2. In the 2014/15 Warra results, which was a much higher yielding season, there appears to be yield increase in line with increases in the population across all varieties (not significant). This may suggest in high yielding environments that the target population should be above the current recommendation of 30 plants/m^2.

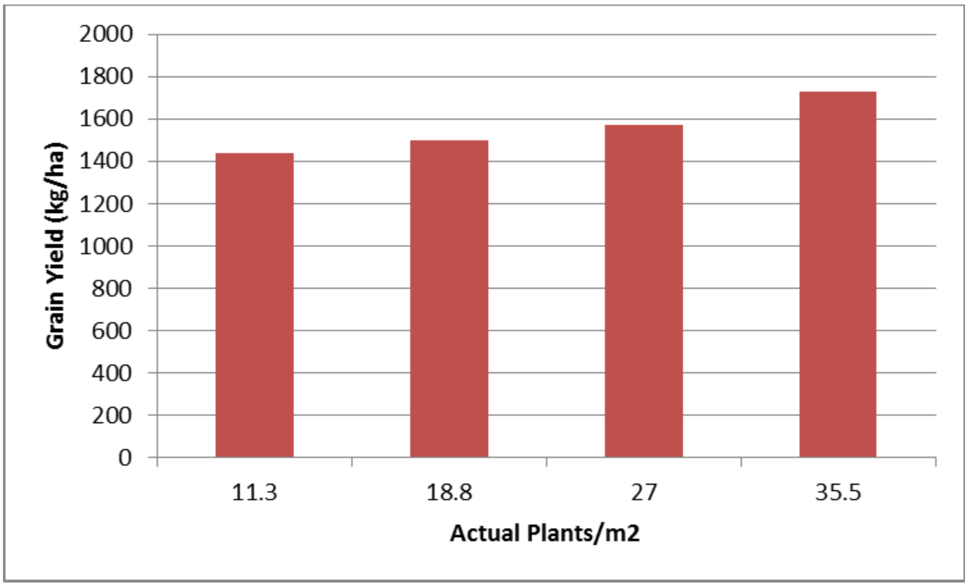


Figure 8. Warra 2014/15 plant population yields (LSD 5% 318)

Mungbean nitrogen fixation

It has been shown that agronomic practices can influence the amount of nitrogen fixed by pulse crops. The 2013/14 mungbean trial at Dalby was sampled for number of nodules per plant, nitrogen in dry matter and grain and the proportion of that nitrogen that was derived from the atmosphere (%Ndfa). The site had an inherently high nitrogen of 150kg/ha and this in conjunction with the low yields at the site limited the amount of nodules to less than 1 per plant when sampled and the %Ndfa figures also showed that the amount of nitrogen in the plant from fixation by rhizobia varied from less than 9% to 16% with no distinct trends due to changes in row spacings.

This is in contrast to previous work at Kingaroy in the 2012/13 season. In this trial differences in the amount of nitrogen fixed was evident between varieties and the row spacings across all varieties (Figure 9).

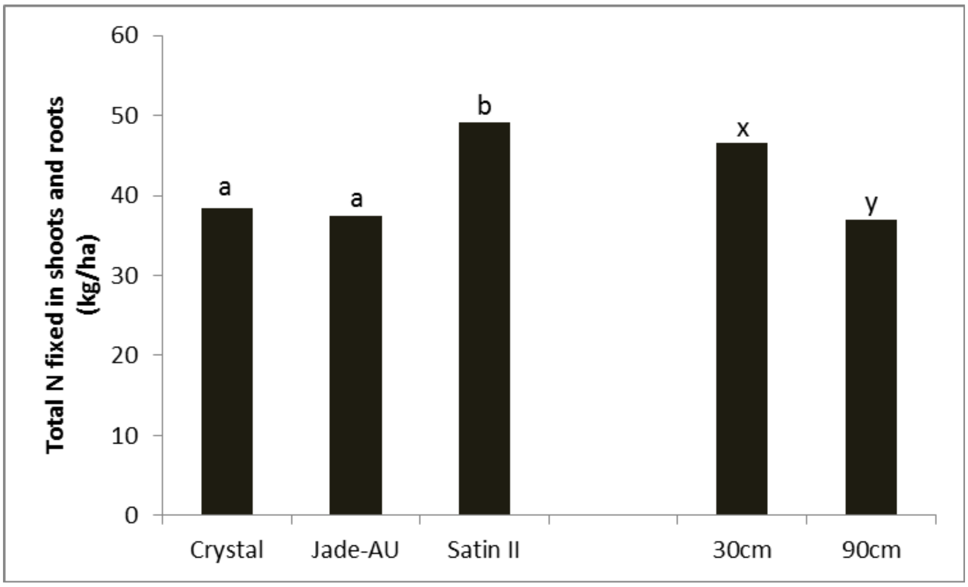


Figure 9. Differences in total shot and root nitrogen by variety (LSD 5% = 7.65) and row spacing (LSD 5% = 6.24), Kingaroy 2012/13

The differences in the amount of N in the shoots and roots (Figure 9) can be influenced by the amount of total dry matter produced or the percent of nitrogen derived from the atmosphere (%Ndfa). It can be seen in Figure 10 that the amount of nitrogen derived from the atmosphere for CrystalΦ and Jade-AUΦ was different with changes in row spacings, however Satin IIΦ kept the amount of N from the atmosphere constant at the varying row spacings.

As we have shown with the other trial results narrower rows are producing higher yields which must be supported by higher dry matter production. The crop then has a higher nitrogen demand that is being met by an increase in the nitrogen fixed by rhizobia and provided to the plant.

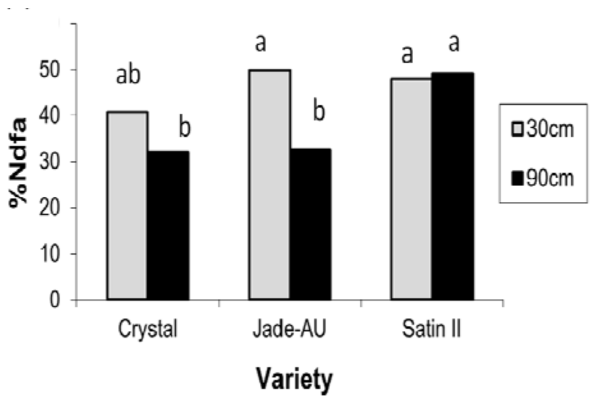


Figure 10. %Ndfa of different varieties at 2 row spacings, Kingaroy 2012/13 (LSD 5% = 9.28)

Summary and conclusions

Mungbean yields can be improved by planting at narrower row spacings. This has been evident in both a below average and above average seasons. The reasons are not fully understood but are suspected to relate to root morphology and how they explore the soil volume for water and also the larger crop canopy on narrow row spacings intercepting more of the light energy and reducing soil evaporation.

Populations are not as important in determining yields and the current industries recommendations should remain as the target populations. The fact that lower populations are not reducing yields significantly may help in making replanting decisions when establishment is affected by other factors.

Both of these factors, row spacing and population, and their effect on maximising yields in varied climates, along with improved varieties, will lead to greater confidence in the ability to grow a profitable crop. This will ensure mungbeans are a viable cropping option in the farming enterprise and not just a break crop for the cereal dominated systems.

Acknowledgements

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

The Queensland Pulse Agronomy group would also like to extend their appreciation to the trial co-operators who have hosted our trials.

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Mungbean and soybean insects - what's new in 2016?

Hugh Brier and Liz Williams, DAF Qld, Kingaroy

Key words

helicoverpa, etiella, mirids, lucerne crown borer, mungbeans, soybeans, sampling

GRDC code

DAQ00196

Take home message

- Mirids at late podfill are not nearly as damaging as podsucking bugs, but watch this space for confirmatory research
- Preliminary results suggest that 0.5 m row spacing is a compromise between yield, pest abundance accuracy and crop health
- Delta traps with a combination lure of etiella pheromone and Magnet plant pheromone appear to be the superior trap/lure combination for the early detection of etiella moths
- Don't forget pests that haven't occurred recently

Introduction

Once again the past season has shown that no two seasons are alike. In other words, what was a major pest issue in previous seasons was not necessarily a problem this past season. Conversely, some pests not regularly present in damaging numbers on the Downs made their presence felt this summer.

Significant pest issues raised by consultants and growers include sampling in narrow rows, very high mirid numbers with rapid re-invasion post spraying, and late mirid damage in mungbeans. Etiella was also a concern but in most crops, populations were far lower than in previous years and were too low to be of economic concern. Conversely, soybean aphids, not regularly present in damaging numbers on the Downs, were present in significant numbers in some crops on the central Downs (Branch View and Pampas). The other issue raised in this and other regions was lucerne crown borer in soybeans. Finally mysterious crop greening phytoplasma-like symptoms were reported on the Central Downs. At the time of writing, the exact causative agent is not determined, but if a phyoplasma, it could be vectored by the common brown leafhopper *Orosius orientalis.*

Note: some of the comments in this article refer to a half label rate of dimethoate for mirid control in mung beans. Always check and follow the label before using insecticides.

Row spacing background

It is increasingly recommended that narrow row spacing in various crops can improve yield output. This is often dependent on multiple factors, including crop type, variety, soil moisture availability and other environmental variables (Verrell and Jenkins 2014, McKenzie et al. 2015). However, narrow rows can increase the risk of negative issues, such as a higher incidence of pathogens (e.g. Andrabi et al. 2011) and cause difficulties in pest sampling with traditional soft beatsheets (personal communications with agronomists).

Research trials at two locations were conducted to determine pest population dynamics in different row spacings, including whether alternative sampling methods may alleviate pest sampling difficulties.

Row spacing RD&E

Trials were conducted on black soil (Warra) and red soil (Kingaroy) in mungbean crops with row spacings of 0.25 m, 0.5m and 1m. Sampling was conducted on two occasions at both locations, during flowering and podding. Additionally, two types of beatsheets were evaluated at the second time sampling – the traditional soft cloth beatsheet and a rigid aluminium beatsheet (Figure 1). This rigid beatsheet was designed to be more easily inserted between narrow rows and retain insects more effectively than the soft beatsheet.

Figure 1. The traditional soft cloth beatsheet (left) and a rigid aluminium beatsheet (right) with collecting trough at the base, as used in 0.25 m rows of mungbeans.

The numbers of pests, beneficials and total insects varied considerably between row spacings, whether examined at linear row length or by the square metre. Specifically, on a linear row length basis, lower pest numbers were detected in the 0.25 m rows compared to 0.5 m and 1 m rows. In contrast, at the one square metre scale, 0.25 m rows had much higher values compared to the other row spacings. As economic threshold values were developed on 1 m wide row spacing, these differences in pest numbers detected in these trials may mean that these thresholds need to be adjusted depending on the row spacing in the crop being sampled. Further modelling is currently being undertaken to determine the influence of row spacing on pest and total insect sampling numbers, specifically in relation to the accuracy of these threshold values. Preliminary results suggest that 0.5 m rows collected similar pest numbers to the 1 m rows and were, in practice, easier to sample than 0.25 m. As there is some evidence that yield in 0.5 m row spacing is comparable or minimally less than narrower rows (e.g. Raymond et al. 2016), we tentatively recommend this as a compromise between yield, pest accuracy and crop health.

Further support for this comes from the evaluation of soft and rigid beatsheets, with comparable abundance and richness values between 0.5 m and 1 m rows. At 0.25 m rows, abundance was reduced with the soft beatsheet compared to the rigid, likely from insects being dislodged during beatsheet insertion (more difficult with a soft structure in tight rows) or not being retained at the base of the beatsheet (sliding off due to no flat area or a collecting lip). Thus, the soft beatsheet, which consultants and growers routinely use for counting pests and for determining whether to use pesticides, did not collect an accurate representation of pest presence (or underestimated the number of pests present, in the case of mirids by ≈20%)

Etiella background

The threat of etiella (*Etiella behrii*) damage was a concern for many consultants and growers this summer given the pest's very high incidence in the summer of 2014-2015. While populations were much lower in the summer of 2015-2016, the issue of early etiella detection was frequently raised. This was prompted in part by DAQ00196 research showing that once inside pods, the larvae are 'out of reach' of insecticide sprays. In response, trials were initiated to determine an appropriate monitoring method for the early detection of moth activity. Specifically, if moths can be detected before eggs hatch or larvae enter pods, then insecticides with residual activity may have the potential to control the pest.

Generally, the early detection of etiella moths is performed by either light traps (typically by researchers) or delta traps with female etiella pheromone capsules (by agronomists and growers); however, both methods have their limitations. Light traps are very effective at collecting *E.behrii* moths, but require a power source and regular sample collection and maintenance, meaning they are less user-friendly for growers and agronomists, therefore making their widespread use impractical. In contrast, delta traps with pheromone attractants are an inexpensive and easy to use option. However, the effectiveness of pheromone capsules attracting etiella is questionable (based on preliminary field trials and user communications).

Etiella RD&E

To evaluate the typical grower etiella monitoring method (delta trap with etiella pheromone lure) with other potential moth monitoring methods, trials at two locations near Kingaroy were implemented in late peanut crops. Twelve combinations of traps + lures were assessed, with three different trap types (delta, ball, funnel) and four different lure configurations – 1) single etiella pheromone capsule, 2) two etiella pheromone capsules, 3) Magnet® (a plant pheromone mimic) and 4) Magnet + a single etiella pheromone capsule.

Over the two week operational period, 20 of the 88 traps collected a total of 30 individuals. Delta traps were the superior trap type, capturing 24 moths in 14 traps (Figure 2). Although delta traps with the combination lure of Magnet + pheromone capsule captured etiella more frequently than the other lure types, low capture rates overall mean that statistical inferences cannot be calculated. However, considering Magnet attracts both male and female moths (in contrast to the pheromone capsules which only attract males), it is logical that the use of this chemical would increase the probability of collecting flying etiella. Interestingly, ball and funnel traps only collected etiella when the lure contained Magnet only, yet pheromone only traps (single or two capsules) were the only type to collect multiple etiella per trap. Magnet lures did result in increased numbers of bycatch, including many beneficial invertebrates such as pollinators and parasitoids, which leads us to recommend that its use (volume of chemical or number of traps/vesicles) be limited to what is necessary.

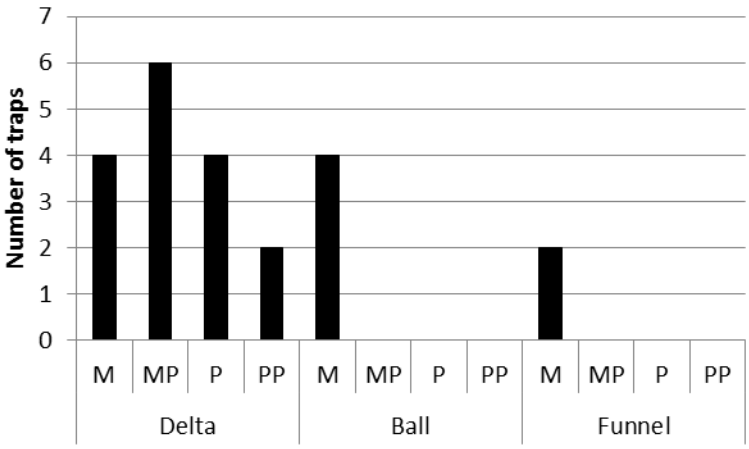

Figure 2. Number of traps that collected etiella moths. For lures, M = Magnet only, MP = Magnet + single etiella Pheromone, P = single Pheromone capsule and PP = two Pheromone capsules.

A proposed Stage 2 of this research for next summer includes the installation of a subset of the above traps (that collected the most etiella moths) in a number of growers' paddocks throughout the Northern Region that were affected by etiella in 2015-2016. This would further refine which trap and lure type is the most effective for the early detection of etiella moth activity at a spatial density (i.e. number of traps per paddock) that is more similar to real practise. It should also be noted that due to their small size, etiella thresholds in mungbeans and soybeans are reasonably high, being in the order of 16 and 36 larvae per square metre, respectively. Although these thresholds are not exceeded in many seasons, by the time larvae are detected, they are inside pods and stems and cannot be controlled. An effective moth trapping programme will facilitate the early detection of the pest before larvae infest pods or stems, and allow for pre-emptive (more timely) action in years with major etiella outbreaks, as occurred in 2014.

Mirid background

Mirids (*Creontiades* sp.) are a regular mungbean pest, with most crops being sprayed at least once for this pest. In soybeans they are also quite common, but the thresholds are much higher ($\approx 6/m^2$), which is considerably higher than the mungbean threshold of $\approx$ 0.3 to $0.5/m^2$. However this year, mirid populations of $\geq 10/m^2$ were common in both crops at the podfill stage. Most mungbean crops were sprayed for mirids by early flowering, but rapid mirid re-invasions were widely reported, with many consultants switching to synthetic pyrethroids (SP's) such as deltamethrin (registered in the crop but not against mirids), claiming better residual control. The residual activity of the half label rate dimethoate (250mL/ha + salt) recommendation was also questioned by some consultants.

To add to the challenge, podsucking bug (PSB) populations were very low in many crops. Consequently, the usual PSB sprays of deltamethrin® were not applied, and late mirid populations were not co-incidentally controlled during the podfill stage. Growers/consultants were therefore also left with the question as to whether they should apply a late mirid spray to protect seed quality.

In response to these two issues, trials were initiated to compare the residual activity of dimethoate @ 250 mL/ha + 0.5% w/v salt, with Ballistic (deltamethrin) @ 500mL/ha + salt, as well as with a potential new but not yet registered bug insecticide (Product X). Trials were also initiated to evaluate mirid damage to mungbean seeds during late podfill (the R4 stage).

Mirid control trials 2016

In 2016, treatments were applied at the crop's R3 stage (beginning seed) at 48 DAE. The results below (Figs.3-4) show that at 3 DAT (the 1st post-spray check), mirid numbers for all insecticide treatments were significantly reduced. However, by 10 DAE, mirids had recovered to pre-spray levels, although still significantly lower than the untreated control, which showed a temporary increase post spray. Note that differences in the rate of mirid resurgence between insecticides were not significant.

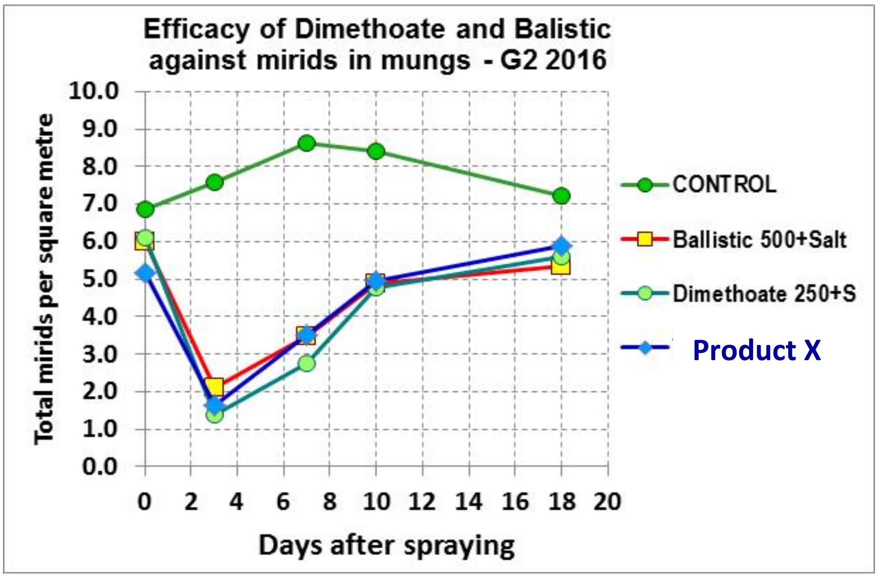

Figure 3. Efficacy of Dimethoate and Ballistic and potential new mirid insecticide (Product X) against a high mirid population in mungbeans.

The data in Figure 4 below quantifies the post-spray mirid pressure in cumulative mirid days for 0-7 days post spray (CUM0-7) and for 0-10 days (CUM 0-10), and shows no significant differences between the pesticides trialled. So in summary, in a high mirid pressure scenario, the SP deltamethrin gave no advantage over dimethoate and mirids resurged rapidly for all treatments. The data also shows that new product X has potential under high mirid pressure. Note that in this trial, sprayed plots were re-infested from adjacent non-sprayed bulk crop, which may not occur to the same degree in a commercial crop.

Regarding the rate of dimethoate, a previous trial in 2015 (see Fig. 5) showed that dimethoate applied at the IPM-recommended rate of 250mL/ha rate (+0.5 salt) was as effective as the full registered rate of 500 mL/ha. Finally, this half rate dimethoate + salt is (currently) the IPM preferred option as it has less impact on beneficials than the full dimethoate rate or SPs such as deltamethrin.

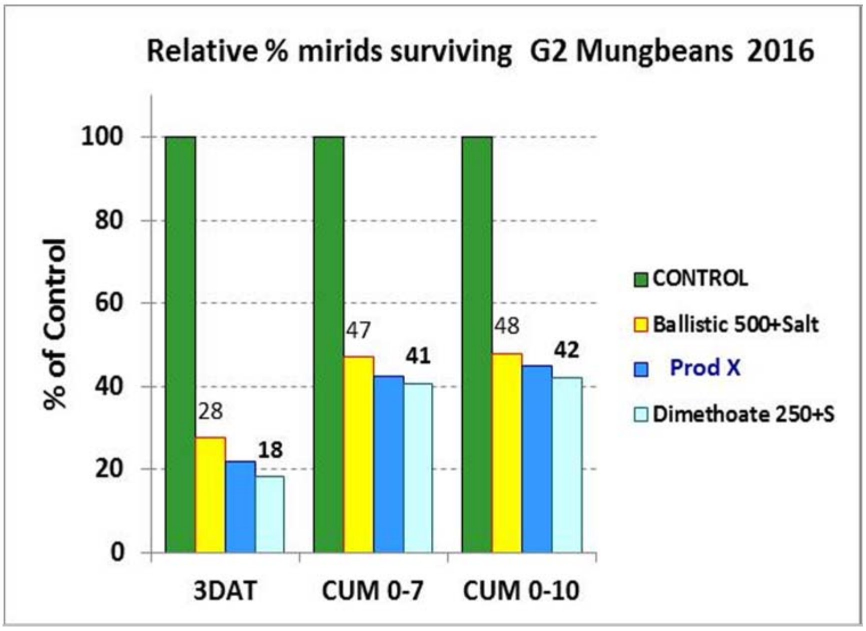

Figure 4. Mirid activity post spray relative to the uninfested control. 3DAT = @ 3 days after treating, and CUM = cumulative mirid days from 0-7 days & 0-10 DAT.

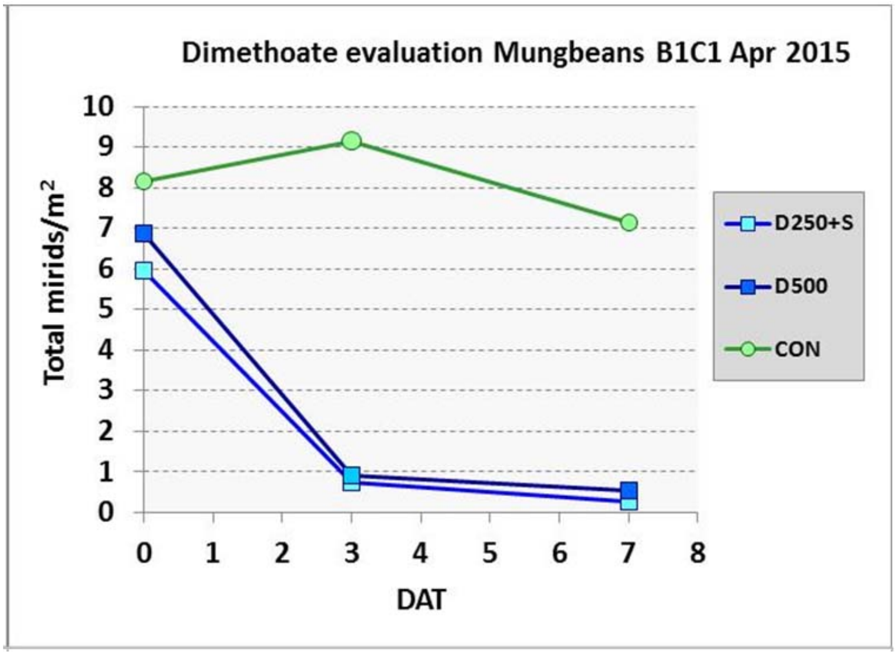

Figure 5. Efficacy of dimethoate at 250 mL/ha + salt (0.5% w/v) (D250 +S) and dimethoate at 500 mL/ha against mirids (*Creontiades* sp.) in mungbeans.

Late mirid damage to mungbean seeds

Two trials were initiated to determine whether mirids damage mungbean seeds during late podfill. In the first, caged mungbeans (2x 1.5 m of row = 3m) were infested with brown mirid adults (*Creontiades pacificus*) at a density of 30 per cage (equivalent to 10 per row metre for 12 days). Uninfested control cages were also set up, and were disinfested with a deltamethrin spray for podsucking bugs and mirids. Mungbeans were at the R6+ stage with >50 % black pods. All black pods were removed prior to infestation to allow mirids to concentrate on the remaining green and turning (green to black) pods. After 12 days, all pods were hand harvested and assessment for potential mirid damage, including discoloured stained seeds, and/or visible sting marks.

In the second trial, field grown mungbeans were assessed at the R6+ stage. Six (6) racemes with 4-5 green pods were cupped and infested with 4 brown mirid adults per cup for 5 days. Six uninfested racemes were also cupped for 5 days. After 5 days, racemes with cups attached were cut from the plants and the number of live mirids counted, and pods assessed for damage. Mirid survival in the infested cups averaged 92%.

In both trials, podsucking bugs (green vegetable bug GVB and brown bean bugs) and mirids (mostly brown) were present in low numbers prior to infestation. For this reason, there were unavoidable levels of background damage in the un-infested controls in both trials. However, it was anticipated that if mirids were as damaging to seeds as podsucking bugs, any background damage would be surpassed by a large margin.

Mirid damage results and conclusions

The results for both trials (see table 1) show very low rates (not significant) of damage at only 4% and 10% of that expected from a GVB in the field cage and cupped pod trial respectively. This suggests mirids are far less damaging to mungbean seeds than podsucking bugs. However, further trials with more replications are required to determine if the low rates of damage recorded are accurate or significant. Certainly none of the post-damage spotting, as observed by Melina Miles in faba beans, has been observed in this and other mungbean trials.

Theoretically, if the low rates of damage is accurate, and hypothetically only 5% of that for GVB damage, then the corresponding mirid threshold at late podfill would be 20 times that for a GVB, and would be approximately 7 mirids/m^2 for a 1t/ha crop.

Table 1. Seed damage in mungbeans infested with brown mirids (*Creontiades pacificus*)

Field cage trial 10 mirids/m for 12 days	**Damaged seeds per cage**	**Damaged seeds per mirid day**	**Equivalent damaged seeds per GVB day**	**Trial damage as % of GVB**
Control	60.9			
Mirids	90.4			
Difference	**29.5**	**0.08**	**2**	**4%**
Cupped pod trial. 4 mirids per 5 pods for 5 days	**Damaged seeds per cup**	**Damaged seeds per mirid day**	**Equivalent damaged seeds per GVB day**	**Trial damage as % of GVB**
Control	9.7			
Mirids	13.2			
Difference	**3.5**	**0.19**	**2**	**10%**
LSD (cup trial)	11.5 NS			

Lucerne crown borer progress report

Lucerne crown borer (LCB - *Zygrita diva*) has been active in soybeans in many regions. While not reported specifically from the Downs, it is always a potential threat, particularly in early plantings and in very hot summers. In some recent NSW trials, over 80% of plants were infested with LCB. Current recommendations are to strategically till soybean stubble to kill overwintering larvae and to avoid very early soybean plantings. Also, if significant infestation levels are detected by splitting stems open, harvesting should be carried out as soon as possible. Project DAQ00196 is currently trialling seed dressings to combat this pest, with initial results showing significant reductions in infestation and plant girdling levels. However, registration for the product is still some time away with residue trials required to establish maximum residue levels (MRLs).

Mystery soybean greening on Downs – soybean aphids, virus or phytoplasma?

Figure 6. Common brown leafhopper (*Orosius orientalis*

In early May, large areas of soybeans (300+ ha) on the central Downs were reported with a mystery plant greening and phytoplasma-like pod symptoms (see Figure 7a). Some plants had witches broom (phytoplasma) like symptoms (masses of immature pods) while other less-affected plants showed well-developed green pods that , given the crop's age, should have been harvest-ready. The magnitude of the symptoms only added to the confusion as typically, phytoplasma only affects isolated plants.

Some of the affected crops had significant soybean aphid (*Aphis glycines*) infestations that were not controlled until pod fill; however, although soybean aphids can delay maturity (see Figure 7b), pods on affected plants do not normally exhibit the extreme symptoms shown in Figure 7a. Additionally, soybean aphids do not vector phytoplasma, which is usually transmitted in Australia by the common brown leafhopper (*Orosius orientalis*; Figure 6). Although no such leafhoppers were observed in the crops in early May, it is possible that a wave of brown leafhoppers moved through the affected crops between scoutings; however, this is purely speculative. At the time of writing, experts are leaning towards a phytoplasma being responsible, but the exact cause is yet to be confirmed.

Finally, in regards to soybean aphids, to avoid aphid-induced delayed crop maturity, spray aphids if they exceed the threshold (250 aphids per plant) by flowering. As a rule of thumb, aphids are above threshold if they are visible on the main stem.


Figure 7a (left). Green plants from downs with phytoplasma-like symptoms. Unlike the green aphid-infested plants, these plants had bunched immature pods, as well as green fully developed pods.

Figure 7b (right). Unsprayed plants at plot ends in trial heavily infested with soybean aphids (*Aphis glycines*) showing greatly delayed maturity in comparison the harvest-ready main trial area.

Final observations

- Report any unusual or extreme pest activity
- Don't forget pests that haven't occurred recently
- Scout regularly to detect major pest outbreaks before they inflict commensurate damage
- Mirids at late podfill no nearly as damaging as podsucking bugs, but watch this space for confirmatory research
- From preliminary results, it is suggested that 0.5 m row spacing is a good compromise between yield, pest abundance accuracy and crop health
- Delta traps with a combination lure of etiella pheromone and Magnet plant pheromone appear to be the superior trap/lure combination tested in trials for the early detection of flying etiella moths

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The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC. The authors would like to thank them for their continued support. Hugh Brier also thanks the GRDC for their funding of new grains entomologist Dr Liz Williams.

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Optimising sorghum genetics and management for targeted situations. How big is the current upside and what might be possible with new trait combinations?

David Jordan & Daniel Rodriguez, QAAFI

Key words

Yield gap, GxExM, sorghum, agronomy

GRDC codes

UQ00075, UQ00070

Take home message

- Yield in sorghum is not just agronomy or hybrid choice, what really matters is to understand how to match hybrids and management to sites and expected seasonal conditions.
- Substantial opportunities exist to increase productivity by providing growers access to hybrids with a wider range of trait characteristics.

How are improvements in crop productivity achieved?

Historically productivity gains in cereals have come from changes in improved agronomy and varieties. The biggest increases in productivity have come from the interaction between changes in genotype and management that target particular environments, often described as GxExM or specific adaptation. These GxExM advances have often come from trial and error rather than specific research specifically designed to identify good combinations. Advances in our understanding of factors influencing crop yield mean that we are now in a better position to identify new and better match existing agronomy and variety to deliver higher yields.

Specific adaptation

Plant breeders typically use one of two strategies for developing new hybrids, either they select for broadly adapted hybrids that work well on average across environments but may sacrifice yield in particularly good or poor environments; or, they select for specifically adapted hybrids to perform well in particular environments but have poor average performance.

Australia’s variable climate and sorghum growing environments offer the opportunity to design the crop (GxM) that best matches the site, as well as prevailing and expected seasonal conditions. This is, water availability driven by starting soil moisture and nitrogen, soil water holding capacity, and expected in crop rainfall and temperature.

This requires managing the balance between designing the crop to achieve maximum yield by using as much of the available water as possible, and the risk of substantial yield reductions and lodging caused if water stress occurs during grain filling.

Adaptation to particular environments can be achieved by designing the crop matching the hybrids, this is maturity and canopy sizes (mainly tillering); and by modifying management, population, nitrogen supply and row spacing.

Australian sorghum breeders have tended to develop hybrids with broad adaption because of our small seed market and highly variable environments. Growers can achieve some specific adaptation to their situations by management changes such as planting time population, nitrogen supply and row spacing to adapt sorghum to their environments. Despite this focus on broad adaption, some varietal differences exist that provide opportunities to maximize performance by optimizing management for existing varieties grown in specific situations as well as determining if there are opportunities to breed for specific adaptation.

GRDC is funding research in both areas, project UQ00075 is producing sorghum hybrid type and agro-ecology specific recommendations in the Northern Region that are helping growers match commercially available varieties to environments and seasonal conditions. GRDC project UQ00070 is focused on the development of sorghum breeding lines incorporating variation in traits predicted to improve productivity in the northern region combination with particular managements. Both projects are being led by the Queensland Alliance for Agriculture and Food Innovation (QAAFI) at the University of Queensland, in collaboration with the Queensland Department of Agriculture and Fisheries, grower groups, agribusinesses and seed companies.

What opportunities exist with current hybrids?

We conducted on farm research trials at 19 locations across Queensland investigating the performance of twelve commercial and experimental hybrids representing the major types available, with variations in density and row spacing. More than 2000 plots were planted between 2014 and 2016. Hybrid types were defined by the maturity and tillering characteristics of the hybrids. Maturity in the hybrids varied from 55 to 62 days to flowering; and from 106 to 113 days to maturity. High and low tillering hybrids produced 3.5 and 2.5 tillers per plant (at flowering); though both types produced around 2.1 heads per plant at maturity.

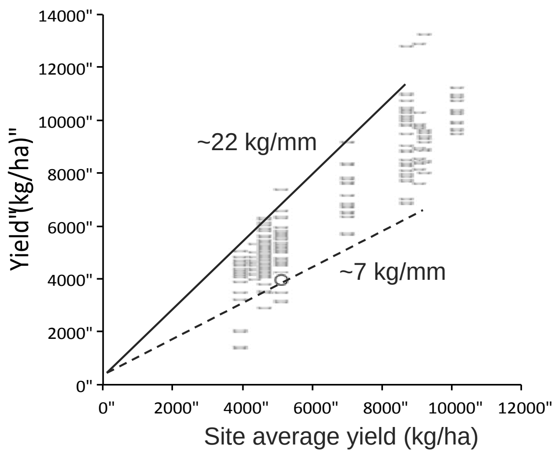

Figure 1. Example of a performance graph representing the yield of different hybrids across a number of sites having different yield potential.

To understand what combination of hybrids and managements perform best across the different sites, results are being analysed by comparing the performance of each treatment at each site as a function of the average yield of each site i.e. an indication of the yield potential at each site (Fig 1). Figure 1 presents the data for 2.14/15, and shows that at each site (columns of points) some treatments yielded twice as much as others. Comparing the best and worst yields at each site showed a 3-fold increase in water use efficiency i.e. from 7 to 22 kg/mm/ha. Figure 1 indicates that understanding what treatments are the top performers across the range of tested sites, can give us an idea of what combination of hybrids and management maximised yields for sites that in average yielded between 4 and 11t/ha.

When the different hybrid traits were dissected we found that the longer cycles tended to yield more in the better environments i.e. higher environmental index (left panel in Figure 2. We also observed that that newly released hybrids tended to perform better than MR Buster in the poorer environments, though similarly in the better environments (Figure 2 right panel). This is probably associated with the effort by breeding programs to develop drought tolerant hybrids. Figure 3 shows that solid configurations outperformed single skip configurations, though it is important to note that none of these trials experienced dry conditions during the 2014/15 season. Figure 3 (right panel) also shows that more recently released hybrids performed better than MR Buster in single skip configurations.

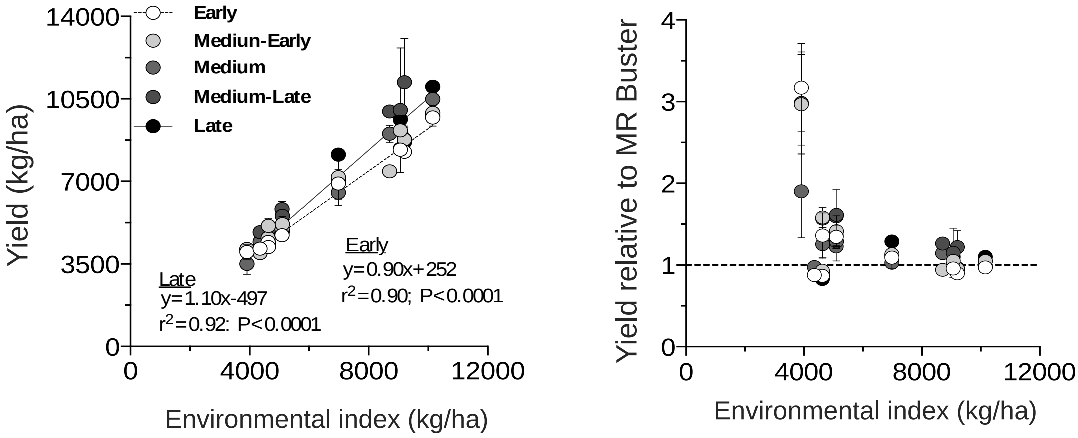

Figure 2. Sorghum yields as a function of the environmental index grouped by maturity type (left panel), and treatments yield relative to the yield of MR Buster (hybrid check) (right panel).

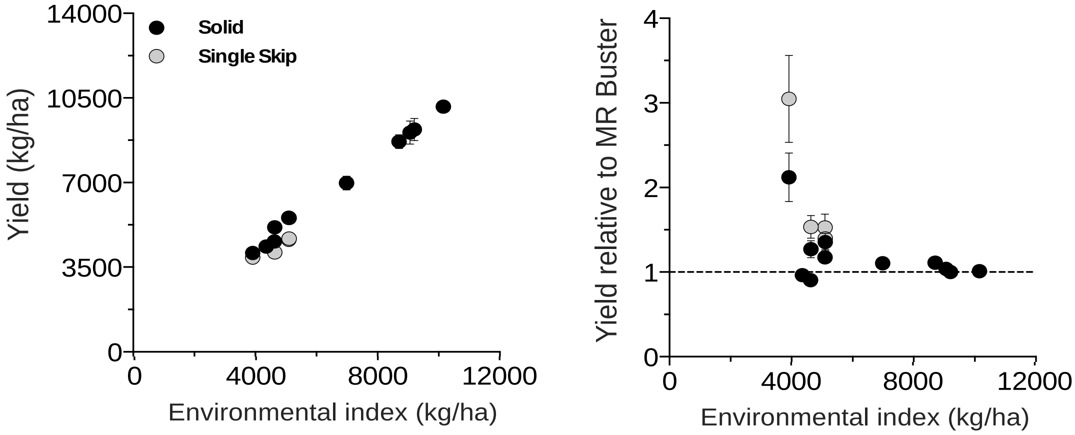

Figure 3. Sorghum yields as a function of the environmental index grouped by configuration (left panel), and treatments yield relative to the yield of MR Buster (hybrid check) (right panel).

Figure 4 below shows that tillering type did not influence the final yield across the tested environments, though it is again important to note that at the sites we had these trials we didn't had dry conditions. Low tillering hybrids would have been expected to perform better under dryer conditions. It was interesting to observe the high compensation capacity of sorghum when planted at contrasting plant densities (Figure 5). At low densities i.e. below 50,000 plants / ha, more than half of the yield was produced on tiller panicles, while above 70,000 plants / ha most of the yield was produced on main stem panicles.

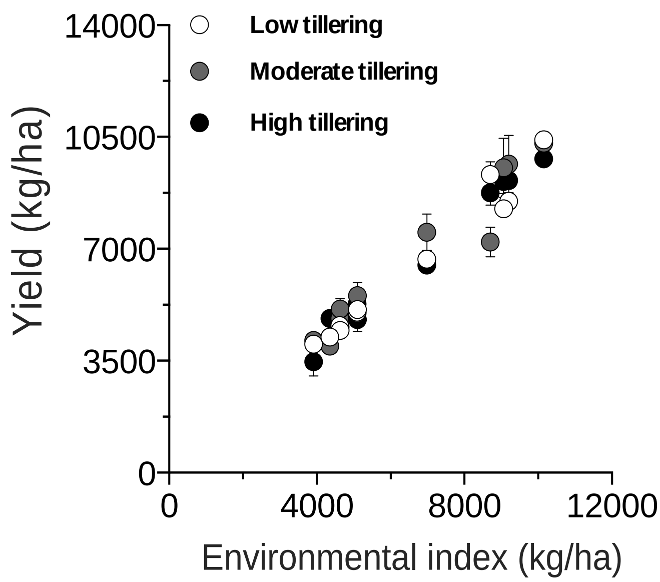

Figure 4. Sorghum yields as a function of the environmental index grouped by tillering type.

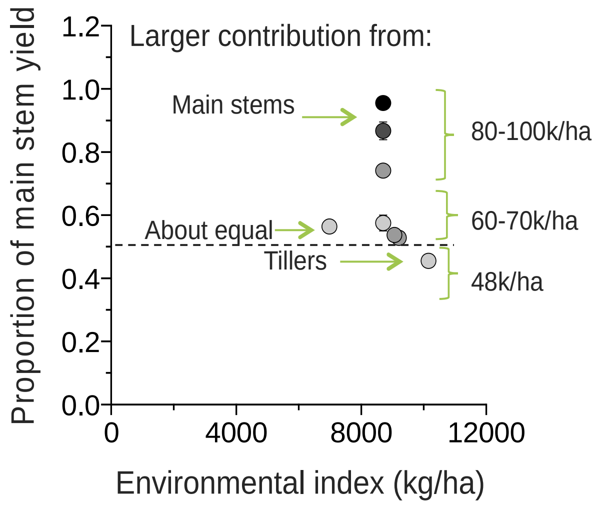

Figure 5. Sorghum yields as a function of the environmental index grouped by plant density relative to the yield of the hybrid check (MR Buster).

Future hybrids

The sorghum pre-breeding program currently GRDC project UQ00070 has been delivering traits to growers through the private seed industry since the1960s. The program produces new screening methods and breeding lines that are licensed to the commercial seed industry with 100% of current commercial hybrids containing genetics from the program. Commercial licensing started in 1989 since that time more than 2400 lines have been licensed and currently 85% of commercial hybrids generating royalties for core breeding program which are reinvested into sorghum research. Licensed lines are either used directly as hybrid parents or indirectly by crossing licensed lines to commercial material to produce new parents within the company's breeding program.

A major focus of the current pre-breeding activity is to develop germplasm with adaptation to Australian environments that have useful variation in key traits associated with water capture and adaptation. These variations include: maturity, tillering potential, transpiration efficiency, plant height and root architecture, high temperature tolerance and grain fill duration

Tiller number

Sorghum plants react to space and water availability to producing tillers. Tillering is favoured by conditions of high light intensity and lower temperatures as occurs in early planted crops. Tillering can compensate for poor establishment but it also limits the control that growers have over crop water use as tillering reduces the impact of reducing in plant population on water use. Prolific tillering early in the season may lead to excessive leaf area and the onset of drought later in the season. Potentially varieties with low or no tillers could provide advantages to growers trying to optimize water use. Current varieties have relatively low variation in tillering potential. Figure 6 below shows the variation in tillering potential available in experimental hybrids grown in 7 sites from northern NSW to Central Queensland. Site yields ranged from 3-7 tonnes per ha. Analysis of these trials indicated no negative effects on yield or lodging of low tillering, showing the potential feasibility of low tillering hybrids.

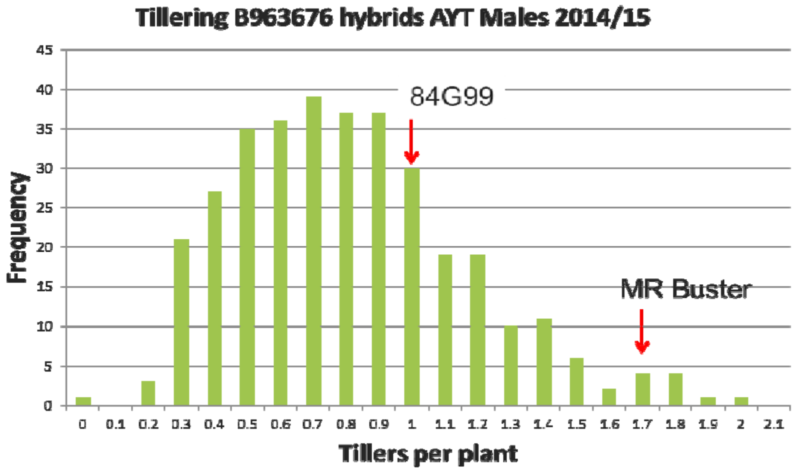

Figure 6. Tillering potential in experimental hybrids compared to high and low tillering commercial hybrids

Root angle

Sorghum plants vary in seedling nodal root angle (Figure 7), which in turn has been shown to influences the timing and water extraction patterns of mature plants. Plants with narrow angle tend to extract more water at depth while plants with narrow root angles extract more water in the inter-row. Varieties with narrow root angle are likely to have advantages when grown in solid row configurations or in soils where water is available at depth. Wide angle genotypes, on the contrary, may be more suited to shallower soils where wide row spacing is used.

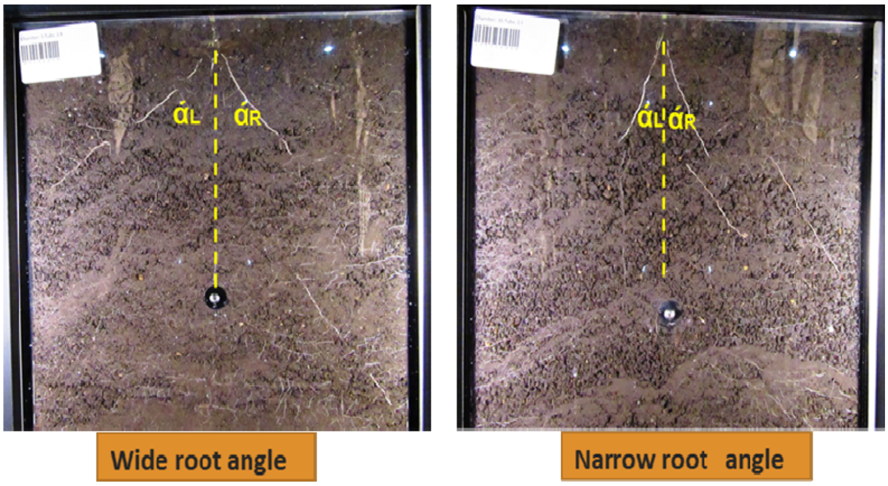

Figure 7. Variation in nodal root angle in sorghum seedlings

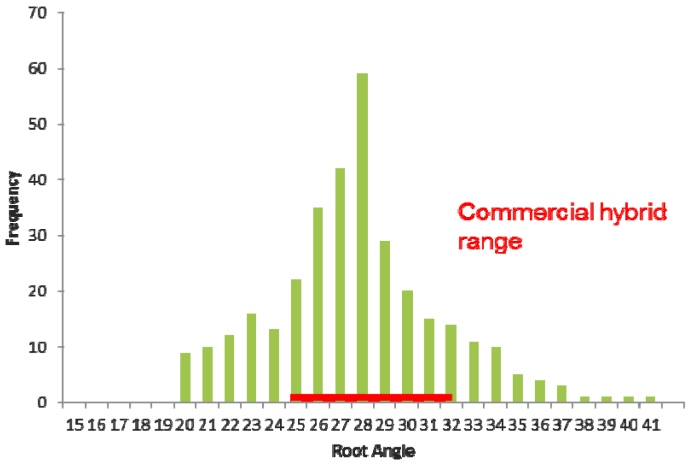

Figure 8. Root angle of 333 experimental hybrids compared with the commercial range

Data from recent screening of commercial and experimental hybrids (figure 8) indicates that variation in root angle of commercial hybrids is limited (25-32 degrees) while substantially more variation is available in experimental materials (20-40 degrees). This result indicates opportunities to develop hybrids with specific adaptation to the deep soils of the higher yielding regions of the Liverpool plains and Darling Downs; and hybrids designed to perform better in wider or skip row configurations in the more marginal environments of the Western Downs and Central Queensland.

Conclusions

- Results from our first season of agronomy trials showed almost a two-fold increase in yield that could be achieved by better matching agronomy to hybrid type across the tested sites. These findings question the idea that agronomy outweighs genetics in sorghum yield; and emphasises that ***what really matters is to understand how to match hybrids and management to sites and expected seasonal conditions.***
- For the high yielding environments the highest yields were obtained with higher tillering and later maturity hybrids planted in solid configurations at medium to high plant populations.
- In the medium yielding environments, highest yields were obtained with medium tillering and medium maturity hybrids planted in solid configurations at medium to high plant populations.
- In the low yielding environments, highest yields were obtained with low tillering and earlier maturity hybrids planted in solid configurations at low plant populations.

- Considerable genetic potential exists to develop hybrids with specific characteristics that when combined with management would enhance crop yield in particular types of sorghum environments

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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

01202.027; 0102.004

Take home message

- Over the past 3 years, we have had 6 experiments with isotope-labelled (^{15}N) urea fertiliser in northern NSW and a further 11 in southern Qld, all focussed on measuring the fate of applied N fertiliser in summer sorghum. 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.

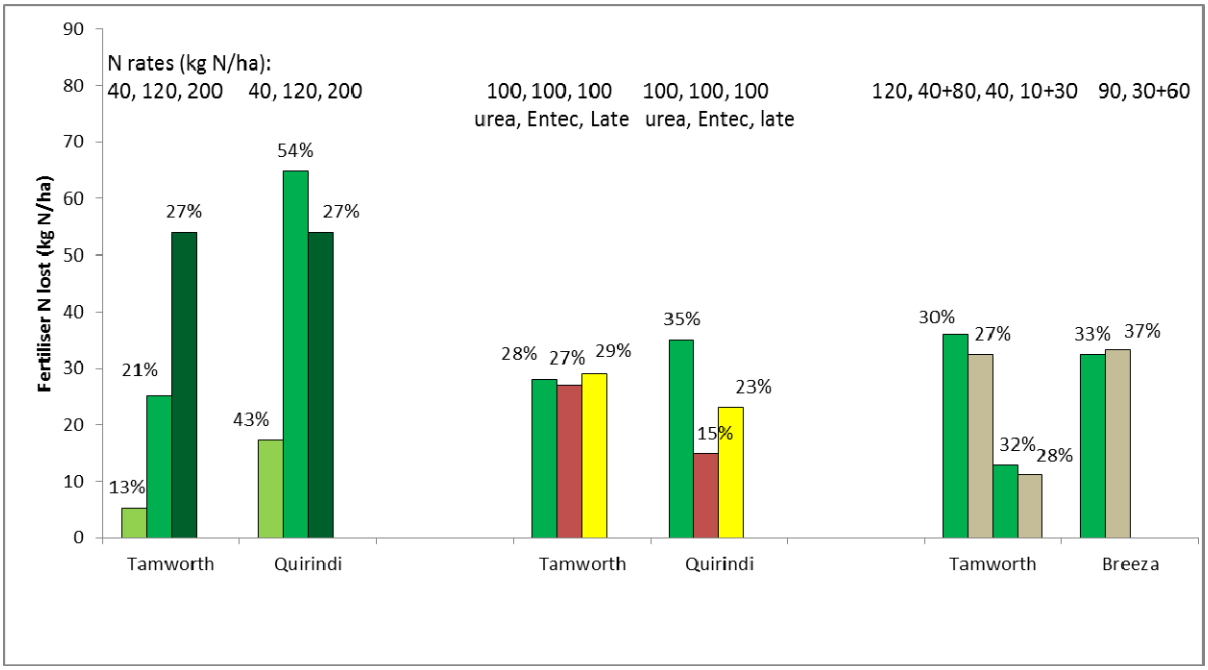

Figure 1. Losses of applied urea-N in field trials on Vertosol soils in northern NSW during the NANORP project. Losses were calculated from recoveries of 15N labelled urea in soil and plant material.

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.

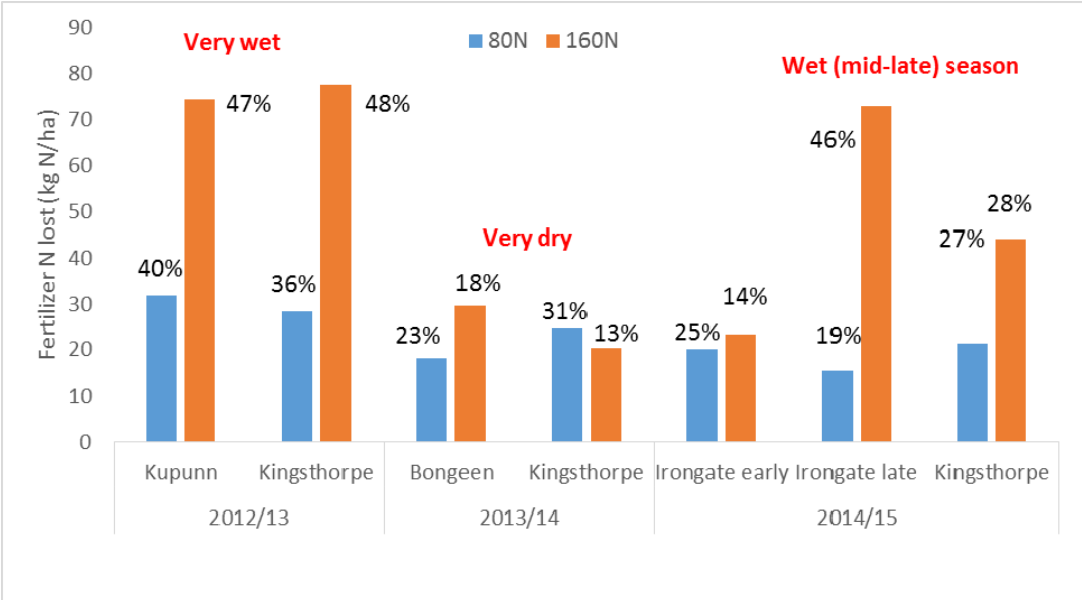

Figure 2. Losses of applied urea-N in field trials on Vertosol soils in Queensland during the NANORP project. Losses were calculated from recoveries of ^{15}N labelled urea in either soil or plant material.

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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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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Tillage impacts of weed seed burial and subsequent management

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Key words

Tillage, cultivation, weed seed, burial, emergence

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Take home message

- Weed seed ecology (emergence and persistence) need to be taken into consideration when considering the potential role of tillage as a weed management tactic.
- In a zero till system, effective control of seedlings will rapidly deplete the weed seed bank of most of our key weeds. This is especially the case for feathertop Rhodes grass, windmill grass, fleabane and sowthistle.
- Herbicide resistance threatens our ability to effectively control emerged weeds.
- Applying cultivation may reduce weed emergence compared with a zero tillage system, especially in a wetter season. However, in a dry season, tillage may increase emergence.
- Seed burial is likely to increase the persistence of weed seeds.
- A second pass of cultivation can result in subsequent emergences of weeds as a result of seeds being brought closer to the soil surface.
- New approaches are being investigated to apply tillage in a targeted manner to minimise soil disturbance and weed seed burial.

Background

The widespread adoption of no-till farming has resulted in reliance on herbicides for the control of weeds. As a result of this reliance, the weed spectrum in the northern grain region has changed and become difficult to control. Herbicide resistance has become a common problem and weeds have shifted toward surface germinating species such as common sowthistle, fleabane and feathertop Rhodes grass. Continued reliance on herbicides will result in further cases of herbicide resistance and proliferation of these weeds.

The change in weed spectrum has forced industry to investigate alternative approaches for weed management, including judicious or targeted use of tillage. The challenge with the reintroduction of tillage is to retain the benefits gained through zero tillage (improved soil structure, reduced erosion and improved soil water conservation) while addressing the weed management issues mentioned above.

Tillage can be applied to target mature, uncontrolled plants or to manipulate the seedbank and thereby improve weed management. This paper primarily addresses the use of tillage to manipulate the weed seed bank.

The importance of weed seed bank ecology

Each weed species has a different seed bank ecology, including depth from which it can emerge and duration seed persist in the soil, as affected by burial depth. These ecological factors are important to understand when considering the potential role and consequences of using tillage.

Emergence

In a zero tillage system, where soil disturbance is largely removed, most weed seeds will remain in the soil surface layer (0-2cm). Germination of some of our most common weeds is favoured from these layers and helps to explain their prevalence in zero tillage systems. For example, feathertop Rhodes grass seeds emerge mostly from the top 2cm of soil with a greatly reduced emergence from 5cm (Table 1). Over 12 months, 43% of seed buried near the surface germinated, compared with 5% at 5 cm and 0% at 10cm depths.

Similarly, sowthistle will mostly emerge from the top 1cm of soil, with limited emergence from a depth of 2cm (Figure 1). Fleabane will only emerge from the top 1cm of soil, with no emergence at or below 2cm.

Other species, such as liverseed grass and barnyard grass, are able to emerge from deeper in the soil profile (Table 1). While awnless barnyard grass still prefers to emerge from a depth of 2cm, it is also capable of emerging from a depth of 5cm. Liverseed grass prefers to be buried to 5cm for optimal emergence and can even emerge from a depth of 10cm (Table 1). As a result, liverseed grass is less common in zero tillage systems.

Table 1. Cumulative emergence (% of viable seed sown) of summer grasses at 24 months following burial at different depths (cm)

Depth of burial (cm)	Feathertop Rhodes grass	Barnyard grass	Liverseed grass
0-2	43*	27	36
5	5*	5	74
10	0	0.8	16

*emergences ceased after 12 months in all studies conducted on this grass

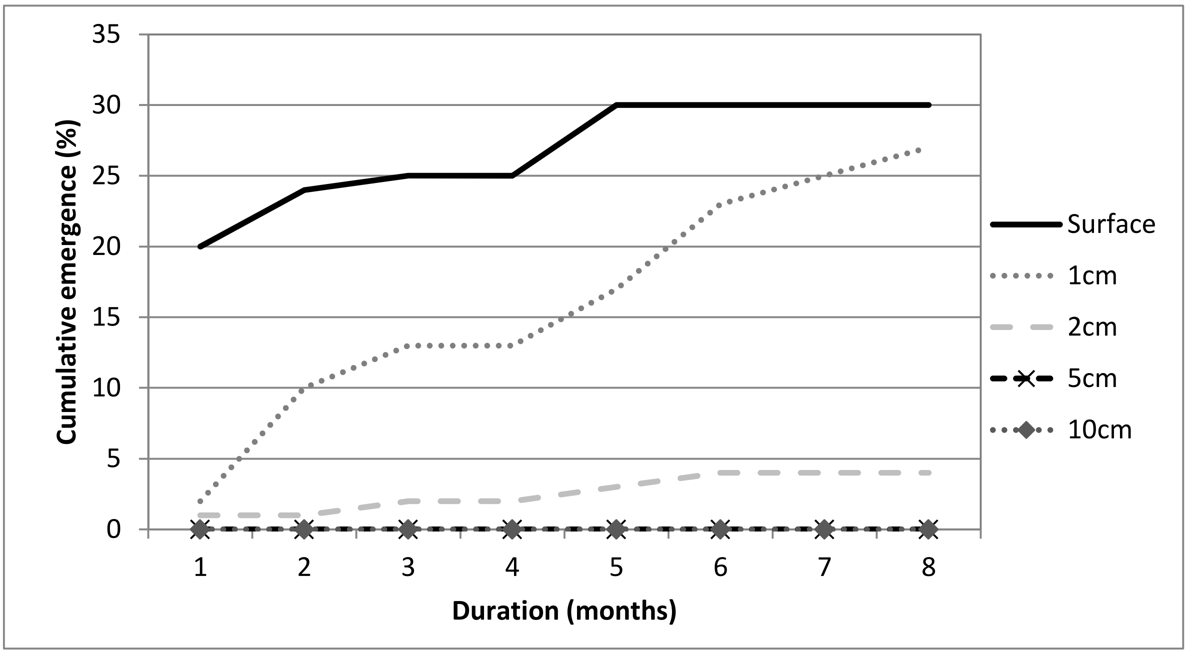

Figure 1. Cumulative emergence of common sowthistle as % of viable seed buried on the soil surface and at different depths (cm)

Persistence

Weed seeds left on or near the soil surface generally have a short life as fluctuating temperature and moisture reduces viability quickly. Generally, seed burial, for example via tillage, will promote persistence of seeds, and generally speaking, the deeper the seed is buried, the longer it will persist.

A clear example of this is barnyard grass and liverseed grass (Figure 2). For both species, seeds only remain viable for a short time in the soil surface layers, but persistence increases with depth of seed burial. Only 1 – 2% of seed remains viable after two years buried at a soil depth of 0 to 2cm, in contrast with approximately 20% remaining after two years buried at the depth of 10cm.

Depth and duration of seed burial also affect the persistence of feathertop Rhodes grass and windmill grass (Figure 2). A recent pot experiment on the eastern Darling Downs showed that after three months of burial, a large number (>70%) of FTR seed persisted at 10cm burial depth (Figure 2). There were a significantly lower number of viable seeds persisting at the 0cm depth. Burial depth had less impact on the persistence of WMG with both depth treatments having <20% viable seed remaining.

There were no further emergences of feathertop Rhodes grass from soil exhumed at 12 and 18 months showing this weed to be short lived in our southern Queensland environment. No emergences were recorded for windmill grass in soil exhumed at 18 months.

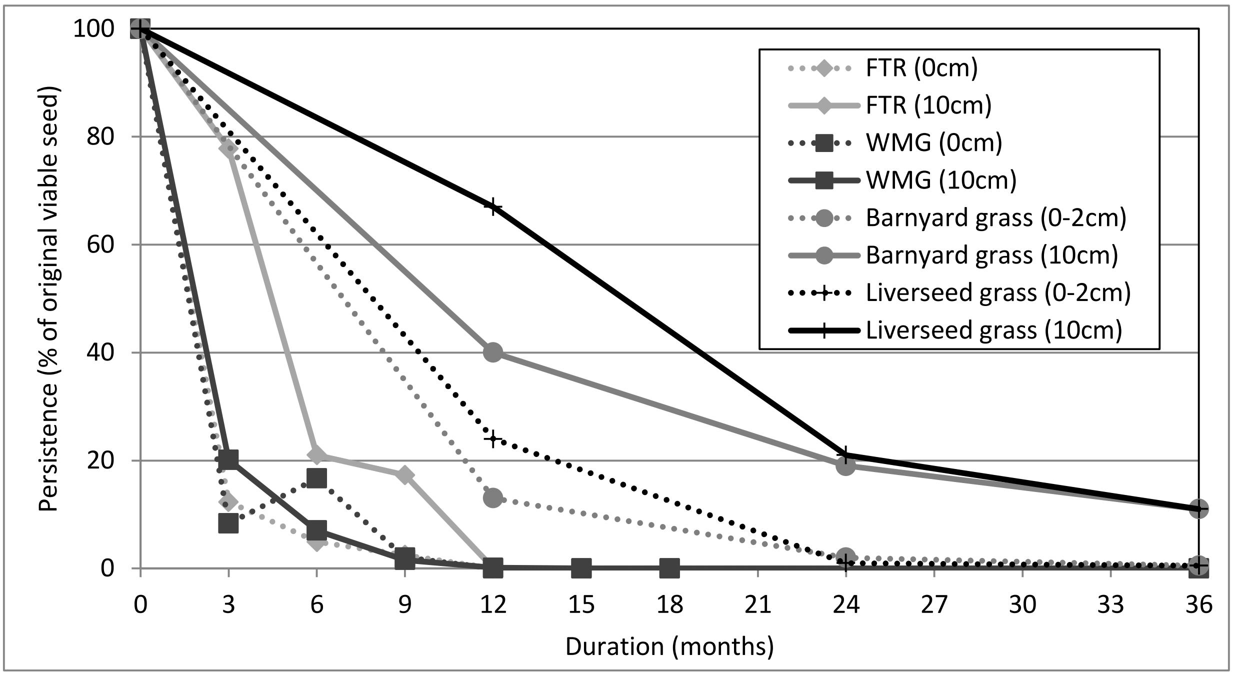

Figure 2. Persistence as assessed through emergence of seed from exhumed soil (% of viable seeds) of feathertop Rhodes grass (FTR), windmill grass (WMG), awnless barnyard grass and liverseed grass in response to different burial depths (cm) and durations of burial (months).

Even though small-seeded, both fleabane and sowthistle seed can persist at depth for more than three years. A pot study on the Darling Downs showed that after 3 years of burial 1, 10 and 8% of viable fleabane seed remained at depths of 0-2, 5 and 10cm respectively (Figure 3). For sowthistle, after 30 months of burial, over 10% of seed remained viable when buried at 5 or 10cm compared with only 1% at 1cm burial depth (Figure 4).

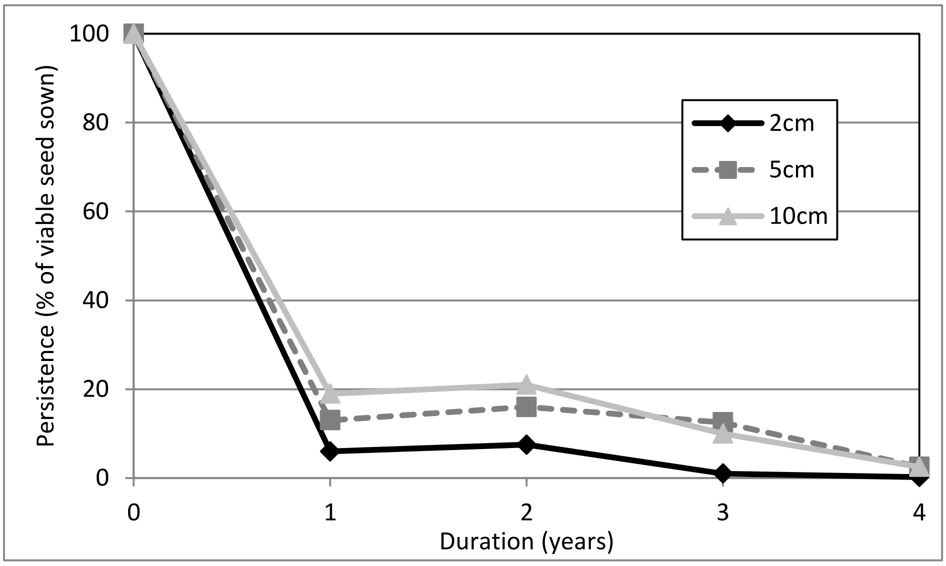

Figure 3. Persistence of flaxleaf fleabane buried at different depths and for different times (years).

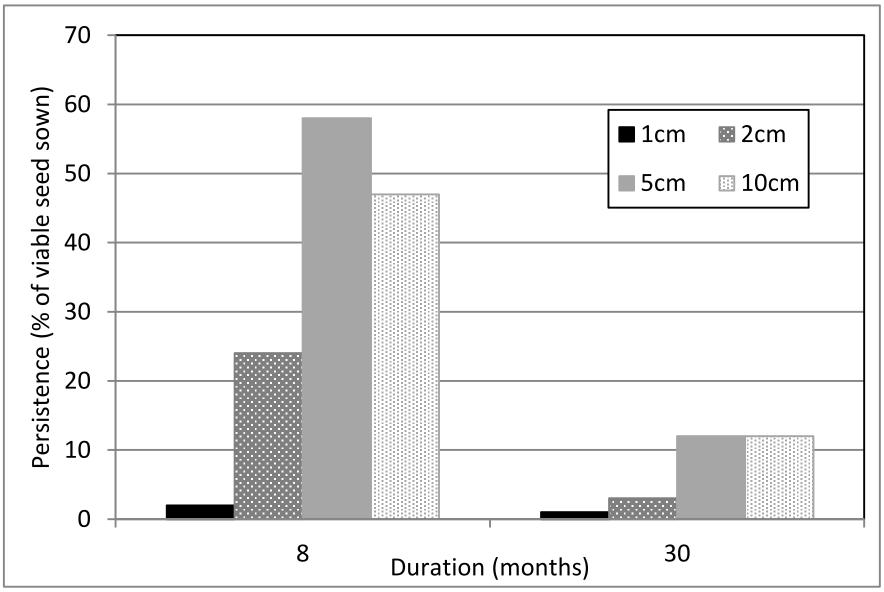

Figure 4. Persistence of common sowthistle seed buried at different depths for either 8 or 30 months.

Tillage effects

The Queensland Department of Agriculture and Fisheries (DAF) have conducted a series of four field experiments since 2011 to investigate the effect of tillage on seed burial and emergence of key weed species.

The first three experiments were established at the DAF Hermitage Research Facility, and the fourth was established at the DAF Wellcamp Research Station. At field experiments one to three, five tillage treatments were imposed with different levels of soil disturbance and inversion;

- Zero tillage (ZT)
- Harrows
- Gyral
- Offset discs

- One-way discs.

At the fourth field experiment, we explored the impact of a second tillage pass with a gyral after one-way disc and offset disc treatment, on the subsequent emergence of weeds.

Seeds of awnless barnyard grass, feathertop Rhodes grass, windmill grass, liverseed grass, common sowthistle and flaxleaf fleabane were sown on the soil surface prior to tillage application. Also, small coloured beads, to represent weed seeds, were included so we could track soil inversion via soil coring and bead recovery.

Weed emergence was counted in each treatment for up to 18 months. We were unable to get emergence of every species in each experiment therefore some of the data presented here excludes certain species.

Glass bead (seed) burial

The burial of glass beads was quite consistent across experiments. As such we are only presenting the data from the fourth experiment (Figure 5) as it also explores the impact of the second pass with the gyral.

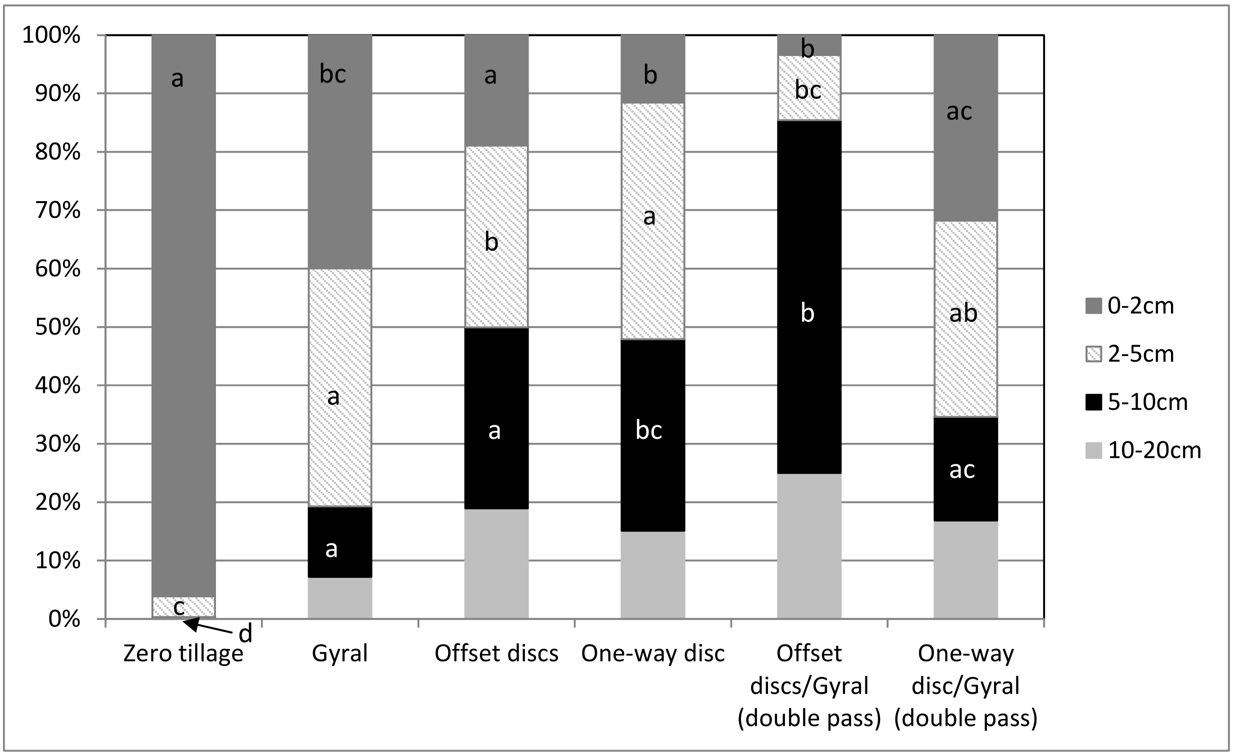

Figure 5. Burial of glass beads (cm) under different types of tillage as assessed through bead recovery from soil cores. Lettering is based upon LSD's of the transformed means. Means with the same letter within each burial depth are not significantly different at the 5% significance level.

The application of different tillage treatments affected the burial of glass beads (Figure 6). Generally, the zero tillage treatment had a larger proportion of glass beads in the top 2cm of soil and as tillage intensity increased, this proportion decreased.

Analysis showed there was a significant difference between tillage type for seed burial ($P<0.001$) at 0-2, 2-5 and 5-10cm soil depths but not for the 10-20cm depth.

For the 0-2cm depth, the offset disc treatment with and without the second gyral pass and the one-way disc treatment all significantly reduced the number of glass beads at this depth compared to zero tillage. Of note, the one-way disc double pass treatment had significantly more beads at this depth than the single one-way disc treatment showing that the second pass of the gyral returned more beads back into this layer.

For the 2-5cm depth, the zero tillage treatment had significantly fewer glass beads than all other treatments except for the offset/gyral double pass treatment. There was no significant difference between the single and double pass treatments for the offset and one-way disc treatments, showing that the second pass did not significantly alter the number of glass beads at this depth.

For the 5-10cm depth the zero tillage treatment had significantly fewer beads than all other treatments. For this depth there was a significant difference between the offset disc and the offset disc/gyral double pass treatments with a significantly greater bead count for the double pass treatment. This result shows that the double pass moved more beads into this layer.

Weed emergence

Given the difference in glass bead burial under the different tillage treatments and the impact of seed burial on emergence, it is not unexpected that we found tillage to have a significant impact on weed emergence. However, the effect of tillage on weed emergence was different across field experiments.

In this paper, we firstly report on the first field experiment to show the potential, favourable impact of tillage on reducing weed emergence (Figure 6). We will then provide an example, using sowthistle, to demonstrate how season can impact on weed emergence under different tillage treatments.

In the first experiment, cumulative weed emergence density in zero tillage treatments was 233 (fleabane), 149 (feathertop Rhodes grass), 433 (windmill grass), 267 (barnyard grass), 380 (sowthistle) and 72 (liverseed grass) plants/m^2 across a $3m^2$ assessment area (to account for horizontal seed movement).

Most forms of tillage greatly reduced the emergence of all weed species (Figure 6) with the greatest reduction evident in the small-seeded species fleabane. Generally, as the intensity of tillage increased, the emergence of weeds decreased. The greatest reduction in emergence was generally under a one-way disc, which caused large amounts of soil to be inverted and seed burial.

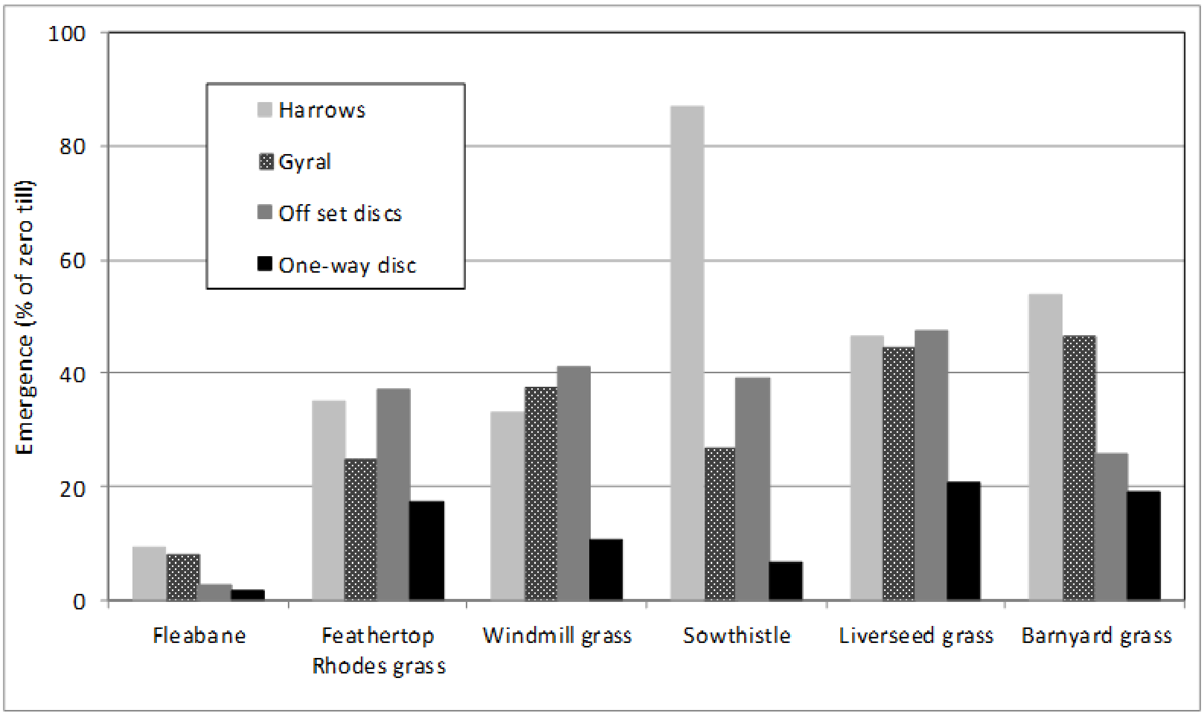

Figure 6. Emergence of key northern region weed species, as a % of emergence in zero tillage treatment, under different types of tillage

The effect of tillage on weed emergence was not consistent across experiments. For example, for sowthistle, off set discs and one-way discs reduced emergence compared with zero tillage in all four field experiments (Figure 7). However, in field experiment 2 both the harrow and gyral treatments increased seedling emergence and in experiment 3 the gyral treatment increased emergence.

This difference can be explained by considering the season (temperature and rainfall) and depth of seed burial. At the start of experiments 2 and 3, there was hot and dry weather, resulting in minimal emergence from zero tillage treatments and a rapid depletion of seed on the soil surface. In these experiments, seed buried by the harrow and gyral treatments were preserved at a depth from which they could later emerge once a favourable environment was present (sufficient moisture and suitable temperature). The emergence from the offset disc and one-way disc treatments was always less than in zero tillage treatments as the seed was buried too deep for emergence.

In experiments 1 and 4, there was a wet start to the experiment, resulting in a large flush of sowthistle emergence from zero tilled treatments. In these experiments, a portion of seed was buried below the depth of emergence in all tilled treatments and therefore a reduction in emergence was measured.

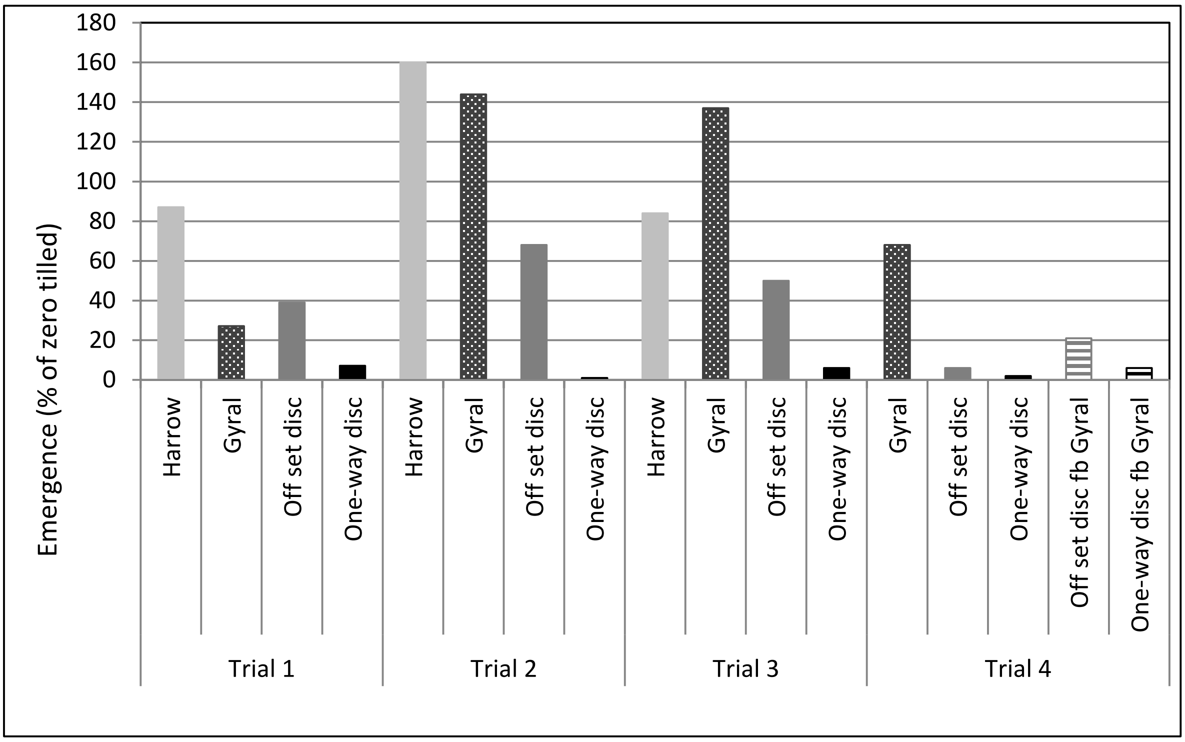

Figure 7. Impact of different forms of tillage on the emergence of common sowthistle as % of emergence in zero tilled plots

Impact of second pass

The second pass with the gyral altered the distribution of glass beads in the soil profile (Figure 5). This in turn resulted in further emergences of all species, but not in all treatments (Figure 8). The emergence of barnyard grass was greatest of all species and while there was an increase in emergence following the gyral double pass after the one-way disc, the same effect was not evident for the gyral double pass after the offset disc. For sowthistle, feathertop Rhodes grass and windmill grass there was a small increase in emergence following the application of the gyral double pass.

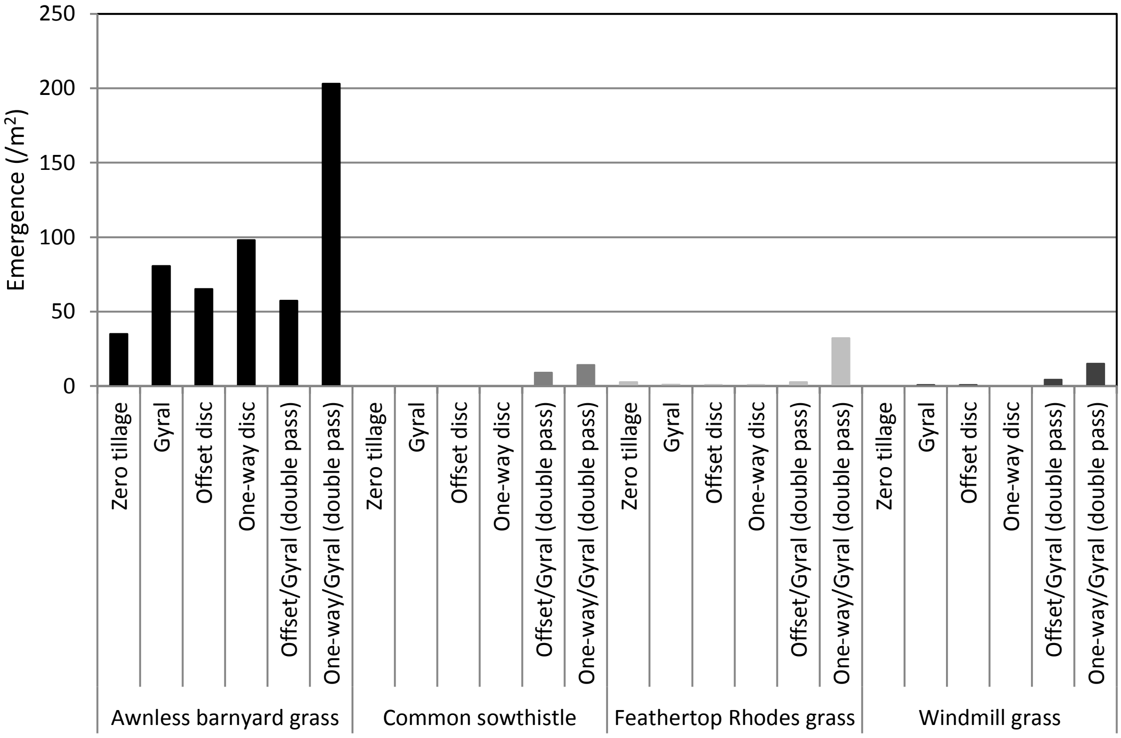

Figure 8. Emergence (/m^2) of key weed northern region weed species after the second pass gyral treatment had been applied following different forms of tillage

New tillage approaches

In a desire to find the balance between retaining the benefits of zero tillage and using tillage to improve weed control, current research is investigating and evaluating the use of robotics and targeted tillage in combination with weed detector technology. Both of these innovative approaches are being investigated to target low density weed populations. Thereby, stopping weed seed set and spread of herbicide resistance, whilst causing minimal soil disturbance.

There are several research groups investigating the role of robotics in the management of weeds. Whilst all are still in the development stages, there has been some very positive progress made. The robots are able to detect weeds, with some systems able to distinguish between weed types (grass vs broad leaf). One research group are developing a system that can apply different weed management tactics, depending upon the weed type present. For example, if it detects a grass weed, it may apply tillage. If the robot detects a broad leaf weed, it may apply herbicide.

Targeted tillage research is developing a hydraulically driven, rapid response tine system for the conduct of spot tillage operations. This approach relies upon a tractor operator but will use technologies already on the market (weed detection, tines).

Management implications

Effective weed management is reliant on an integrated approach. As with any other weed management tactic, the positives and negatives of tillage need to be considered. There have been many positive gains through the adoption of zero till and reduced tillage systems. However, the negative result of herbicide resistance cannot be ignored. We have demonstrated that tillage can have a positive impact in improving weed control. However, tillage across the whole paddock on a regular basis is likely to undo the positive gains achieved through zero tillage. Targeted tillage aimed at disturbing less of the soil and thereby reducing weed seed burial is the optimal approach if tillage is reintroduced in our current farming systems.

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

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Grower experience with new planter technology

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Chickpeas – what we learnt in 2015 and recommendations for 2016

Note: Recommendations for Ascochyta were revised in May 2016 – please see related article in these proceedings

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Key words

chickpea, Ascochyta, Phytophthora, management

GRDC code

DAN00176 Northern NSW Integrated Disease Management

Take home message

- Plant seed of known identity and purity and of high quality that has been properly treated with a registered seed dressing.
- Localities where Ascochyta was found on any variety in 2015 are considered high risk for 2016 crops and growers are advised to apply a preventative fungicide before the first post-emergent rain event to all varieties including PBA HatTrick⑰.
- Mild temperatures, long cloudy periods and frequent rainfall events during Jun/Jul across the Northern region as occurred in 2015, are ideal for early season outbreaks of Ascochyta blight in chickpea crops.
- In wet seasons the management of Ascochyta can be hindered by getting ground rigs into wet paddocks and shortage of fungicides.
- Follow the disease management recommendations in this article and associated links – they will maximise your chance of a profitable chickpea crop in 2016.

The 2015 northern NSW/southern QLD chickpea season

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

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

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

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

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

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

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

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

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

Chickpea diseases in 2015

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

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

The mild wet winter also favoured Sclerotinia (24 cases) especially in paddocks with a canola history, with both basal and aerial infections detected. Where canola was involved, the species was always *S. sclerotiorum*. One crop in the wetter areas east of Narrabri had aerial infection from ascospores of *S. minor* instead of the typical infection of roots and stem base by mycelia from sclerotia. This was the first record in this region for infection from windborne ascospores from sclerotia (due to carpogenic germination of sclerotia) leading to infection of chickpea by of *S. minor*. If such windborne infection is common, greater *S. minor* infection may result.

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

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

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

Disease management recommendations for 2016

Seed treatment and seed purity

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

Table 3. Chickpea seed treatments

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

Ascochyta blight

Recommendations for Ascochyta were revised in May 2016 – please see related article in these proceedings

The following strategy should reduce losses from Ascochyta in 2016:

- In areas where AB was detected in 2015, spray all varieties, including PBA HatTrick⒫ and PBA Boundary⒫ with a registered Ascochyta fungicide prior to the first rain event after crop emergence, three weeks after emergence, or at the 3 branch stage of crop development, whichever occurs first.

- In areas where AB was NOT detected in 2015, spray all varieties with AB resistance lower than PBA HatTrick⒫ with a registered Ascochyta fungicide prior to the first rain event after crop emergence, three weeks after emergence, or at the 3 branch stage of crop development, whichever occurs first.

- 2-3 weeks after each rain event, monitor all crops irrespective of variety and spray if Ascochyta is detected in the crop or is found in the district on any variety.
- Ground application of fungicides is preferred. Select a nozzle such as a DG TwinJet or Turbo TwinJet that will produce no smaller than medium droplets (ASAE) and deliver the equivalent of 80–100 litres water/hectare at the desired speed.
- Where aerial application is the only option (e.g. wet weather delays) ensure the aircraft is set up properly and that contractors have had their spray patterns tested.

Botrytis grey mould, BGM

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

Phytophthora root rot

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

Further information

http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management and in the NSW DPI 2016 Winter Crop Variety Sowing Guide.

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Chickpeas – new Ascochyta and Botrytis grey mould advice for 2016

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Key words

chickpea, Ascochyta, Botrytis, management

GRDC code

DAN00176 Northern NSW Integrated Disease Management

Take home message

- Guidelines for managing Ascochyta and Botrytis in 2016 have been revised as a result of changes to predicted winter and spring rainfall.
- Growers are advised to take a conservative approach to Ascochyta management and use an integrated management strategy of agronomy and fungicide application in Northern Region chickpea crops (with the exception of Central Queensland).
- Have at least 2-3 Ascochyta and 1-2 Botrytis fungicides on farm.
- In most situations, apply an Ascochyta fungicide to ALL varieties (including PBA HatTrick⏀ and PBA Boundary⏀) BEFORE the first post-emergent rain event.
- Be prepared to apply a BGM fungicide in early-mid September

Changes to the 2016 winter crop weather forecast

For the Northern Region the long term seasonal forecast has moved from predicted average early winter rainfall, and a probable El Niño, to above average winter rainfall combined with La Niña conditions in spring. This forecast, combined with evidence that the Ascochyta blight (AB) fungus is changing and concerns about varietal purity in the northern region, means chickpea growers will need to take a conservative approach to Ascochyta management. Mild, wet winter conditions will also produce high biomass crops and, combined with a wet spring, will favour Botrytis Grey Mould (BGM).

Reducing foliar disease risk through agronomy

Delaying planting will reduce the number of disease cycles to which the crop is exposed, however this increases the risk that it may start raining and remain too wet to plant. In this situation, planting on wider rows (75cm or greater) will provide better aeration, delayed canopy closure and improved penetration and coverage by foliar fungicides. Planting deeper will prolong emergence and achieve a similar result to delaying planting.

Be prepared – have fungicides on farm

There is a high possibility of a global shortage of chlorothalonil and mancozeb fungicides in 2016. If possible, stocking 3-4 Ascochyta sprays in high Ascochyta risk areas and 2-3 sprays in lower risk areas on farm would protect growers from such a shortage. There will also be strong demand for BGM fungicides from the lentil industry and growers are advised to have 1-2 BGM sprays available on farm. In addition, Pulse Australia has already obtained Minor Use Permits for alternative Ascochyta fungicides.

Be proactive with Ascochyta fungicide application

In the 2016 season, growers will face a few different scenarios with regard to Ascochyta management.

Irrespective of whether Ascochyta was detected in 2014 or 2015 in your district, all varieties rated Susceptible (S) (e.g. Kyabra⟳) or Moderately Susceptible (MS) (e.g. PBA Monarch⟳) should be treated with a registered Ascochyta fungicide before the first post emergent rain event. Central Queensland growers should consult with their agronomist.

In the following situations, it is recommended that growers spray with a registered Ascochyta fungicide BEFORE the first post emergent rain event:

- If Ascochyta was found in your district in 2014 or 2015;
- If Ascochyta was found on volunteers over the 2015/16 summer;
- If you are uncertain of purity of your variety - purity of your variety is best determined by asking yourself: How confident am I that every plant in my crop of PBA HatTrick⟳ is a HatTrick⟳ plant?
- If Ascochyta was not detected in your district in 2014 or 2015 and was not found on volunteers over 2015/16 summer, but you want to minimize your risk of Ascochyta.

If none of the above scenarios apply to your situation and you are prepared to accept some risk of Ascochyta, wait until Ascochyta is detected before activating a fungicide program. It should be noted that a lack of detection of Ascochyta in your crop or district does not mean it is not present. There have been several cases where Ascochyta was not detected in a previous crop, as was the case in 2014 and 2015, but became widespread on a subsequent crop or on volunteers.

Botrytis Grey Mould (BGM)

Unlike Ascochyta, if conditions favour BGM in 2016 it will occur irrespective of what has happened earlier in the season, including the use of Ascochyta fungicides. If the canopy is likely to close by mid to late September, apply a registered BGM fungicide. Consult your agronomist as to whether to apply a second BGM spray.

Acknowledgements

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Effect of chickpea ascochyta on yield of current varieties and advanced breeding lines – the 2015 Tamworth trial VMP15

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Key words

Ascochyta, variety, management

GRDC code

DAN00176, DAN00151

Take home message

- Under extreme disease pressure, Ascochyta can be successfully and economically managed on susceptible varieties such as KyabraⓅ and JimbourⓅ.
- However, Ascochyta management is easier and more cost effective on varieties with improved resistance eg PBA HatTrickⓅ and PBA BoundaryⓅ
- The 2015 Ascochyta trial, VMP15, confirmed the next variety planned for release (CICA0912) has excellent resistance to Ascochyta

2015 Tamworth Ascochyta management trial, VMP15

This trial sought to match Ascochyta blight (AB) management to a chickpea genotype's Ascochyta rating using ten varieties/advanced breeding lines with a range of Ascochyta resistance ratings: seven desis KyabraⓅ (S, susceptible), PBA HatTrickⓅ (MR, moderately resistant), PBA BoundaryⓅ (MR), CICA0912 (putatively R, resistant), CICA1007 (putatively MR), CICA1302 (for CQ, putatively MR) and CICA1303 (for CQ, putatively MR) plus the kabulis Genesis Kalkee ™ (rated MS), PBA MonarchⓅ (MS, moderately susceptible) and Genesis 425 ™ (rated R).

There were three treatments: a regular fungicide application with regular applications of 1.0L/ha chlorothalonil (720g/L active), an alternative application variety management package (VMP) treatment with a low and off label rate of chlorothalonil; and a nil application; irrespective of treatment, all fungicides were applied before rain. Data for full rate and nil fungicide treatments only, are reported here (Table 1) because of restrictions on publishing off label results.

The trial was sown into standing cereal stubble on 18-19 May 2015 using tyne openers on 50cm row spacing in plots 4m wide by 10m long. VMP15 was split across two experiments, one on red soil, one on heavy black soil, the later had waterlogging problems which affected AB resistance (data not presented), data presented here are results for the trial on the red soil. We have seen examples of this in commercial crops of PBA HatTrickⓅ eg at Yallaroi in 2014 and Gulargambone in 2015 where waterlogging stress lead to a decline in AB resistance. On 16 Jun, when plants were at the 3 leaf stage, the trial was inoculated during a rainfall event with a cocktail of 20 isolates of Ascochyta collected from commercial chickpea crops (1999-2014) at a rate of 1,066,666 spores per mL in 200L/ha water. This early and heavy rate of inoculation combined with extremely favourable conditions resulted in high levels of Ascochyta disease, so much so that the unprotected susceptible varieties were dead by the end of July and even unprotected PBA HatTrickⓅ had severe damage (stem breakage). From inoculation to desiccation (1 Dec), the trial received 341mm in 46 days (32 days >1.0mm).

The first Group S VMP spray for KyabraⓅ was applied before inoculation. The first Group MS VMP spray for Genesis Kalkee ™, PBA MonarchⓅ, CICA1302 and CICA1303 was applied after three infection events (6 rain days, 67 mm rain since inoculation), for Group MR VMP spray (PBA HatTrickⓟ and PBA Boundaryⓟ, CICA1007) and R (CICA0912, Genesis 425™) the first spray occurred after four infection events (14 rain days, 79 mm rain since inoculation). The number of rain days, rainfall and spray applications are summarised in Table 1.

Key findings of VMP15 (see Table 2) were:

- Under extreme disease pressure, Ascochyta can be successfully managed on susceptible varieties with frequent applications of registered rates of chlorothalonil
- Well managed Kyabraⓟ yielded 1862 kg/ha with a GM of $954/ha
- Under extreme disease pressure, unsprayed PBA HatTrickⓟ yielded only 417 kg/ha (GM -$4/ha)
- The new line CICA0912 performed well, yielding 1568 kg/ha (GM $844/ha) with no foliar fungicide

The performance of PBA HatTrickⓟ in VMP15 was both a surprise and a disappointment. In all previous VMP trials at Tamworth, unsprayed (Nil treatment) PBA HatTrickⓟ has produced substantial and profitable yields. For example in the 2010 trial, VMP10, it produced 1707 kg/ha (Table 3). 2010 also had above average rain in Jun/Jul that persisted throughout the season, so was in fact more conducive to Ascochyta than 2015 (although 2015 had more rain days in Jun/Jul than 2010).

VMP10 was sown 19 May 2010 using disc openers on 38cm row spacing in plots 4m wide by 10m long. There were four replicates (Table 3). On 17 Jun, when plants were at the 3 leaf stage, the trial was inoculated during a rainfall event with a cocktail of nine isolates of Ascochyta collected from commercial chickpea crops in 2008 and 2009 at a rate of 1 million spores per mL in 200L/ha water. From inoculation to desiccation (28 Nov), the trial received 430mm rain in 67 rain days (46 days >1.0mm) ie wetter than VMP15 both in total mm and number of rain days. Both VMP15 and VMP10 were in seasons that had regular rainfall and so supported the Ascochyta development consistently over the season and so provide a strong evaluation of current varieties and advanced breeding lines. A number of the key findings of VMP10 were similar to VMP15:

- Under extreme disease pressure, Ascochyta can be successfully managed on susceptible varieties with registered rates of chlorothalonil
- Well managed Jimbourⓟ yielded nearly 3t/ha with a GM of $750/ha
- The performance of varieties and advanced breeding lines with improved resistance to Ascochyta provided the best gross margins

The findings below contrasted between the two VMP experiments

- In 2010 PBA Boundaryⓟ performed exceptionally well, yielding over 2t/ha without any foliar fungicide, a minimal yield loss (4%), compared with 53 % in 2015.
- Under extreme disease pressure in 2010 unsprayed HatTrickⓟ still gave a profitable yield, but unsprayed HatTrickⓟ yields were lower in 2015 and was not profitable

Table 1. VMP15 2015 dates, number of rain days (>1 mm rain), mm of rain and dates and number of 1 L/ha chlorothalonil applications, trial sown 18-19 May.

Date	No. days	mm Rain	1L spray
28-31 May	4	31	
12 Jun			Ist All genotypes
16*-19 Jun	4	61	
22 Jun	1	1	
30 Jun-01 Jul	2	4	
9 Jul			2nd All genotypes
10-17 Jul	8	12	
21 Jul			3rd All genotypes
24-27 Jul	4	13	
21 Aug			4th All genotypes
23-24 Aug	2	40	
1 Sep			5th All genotypes
3 Sep	1	11	
4 Sep	1	6	
16 Sep	1	4	
11 Oct			6th All genotypes
14 Oct	1	16	
22 Oct	1	18	
23 Oct	1	12	
26 Oct	1	10	7th All genotypes

*trial was inoculated with Ascochyta on 16 June 2015

The following factors in VMP15 may have contributed to the nil PBA HatTrick treatment having a poorer yield (Table 2) than in previous VMP trials (Table 3):

(a) parts of VMP15 were waterlogged during Jun/Jul; we know from past experience and commercial crops that any stress including waterlogging compromises PBA HatTrick's moderate resistance to Ascochyta.

(b) interaction between herbicide damage and Ascochyta resistance – VMP15 sustained minor herbicide injury in August. This may have also compromised PBA HatTrick's moderate resistance to Ascochyta.

(c) change in the pathogen; the isolates used in VMP10 were collected from crops in 2008 and 2009 compared to the isolates used in VMP15 which were collected from 1999 to 2014. Recently collected isolates have shown a higher level of agressiveness on PBA HatTrick. See Ascochyta Variability GRDC Update paper for further information.

Table 2. Number and rate/ha of chlorothalonil sprays, cost of spraying, grain yield, and gross margin for seven desi and three kabuli chickpea varieties on red soil in the Tamworth VMP15 trial. (GMs also take into account other production costs estimated at $300/ha; chickpea price desi $730/t; kabuli $1000/t) Yield P<0.001, LSD 417kg/ha; GM P<0.001, LSD $354/ha

Variety	Rate of chlorothalonil	No. Sprays	Cost $/ha	Yield kg/ha	GM $/ha
CICA0912	1.0L	7	105	1853	984
Genesis425	1.0L	7	105	1875	1470
CICA1007	1.0L	7	105	1846	982
PBA Boundary⍭	1.0L	7	105	1755	876
PBA Monarch⍭	1.0L	7	105	1274	869
PBA HatTrick⍭	1.0L	7	105	1722	852
CICA1302	1.0L	7	105	1864	954
CICA1303	1.0L	7	105	1949	1018
Kyabra⍭	1.0L	7	105	1862	954
Kalkee	1.0L	7	105	1659	1254
CICA0912	Nil	0	0	1568	844
Genesis425	Nil	0	0	1144	844
CICA1007	Nil	0	0	1083	491
PBA Boundary⍭	Nil	0	0	1233	600
PBA Monarch⍭	Nil	0	0	887	587
PBA HatTrick⍭	Nil	0	0	417	4
CICA1302	Nil	0	0	0	-300
CICA1303	Nil	0	0	0	-300
Kyabra⍭	Nil	0	0	0	-300
Kalkee	Nil	0	0	1589	1289

Table 3. Number and rate/ha of chlorothalonil sprays, cost of spraying, grain yield, and gross margin for four desi chickpea varieties in the Tamworth VMP10 trial. (GMs also take into account other production costs estimated at $300/ha; chickpea price $450/t).

Variety	Rate of chlorothalonil	No. Sprays	Cost $/ha	Yield kg/ha	GM $/ha
Jimbour	1.0L	14	294	2988	750
[a]Kyabra⟮D⟯	1.0L	14	294	2549	553
PBA HatTrick⟮D⟯	1.0L	14	294	2604	578
PBA Boundary⟮D⟯	1.0L	14	294	2410	491
Jimbour	Nil	0	0	0	–300
Kyabra⟮D⟯	Nil	0	0	0	–300
PBA HatTrick⟮D⟯	Nil	0	0	1707	468
PBA Boundary⟮D⟯	Nil	0	0	2320	744

[a]Kyabra⟮D⟯ 1.0L one of the four reps was severely affected by water logging which (i) compromised Ascochyta control and (ii) impacted on yield

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Chickpea on chickpea – is it worth it?

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Department of Industry, NSW, Tamworth

Key words

chickpea, Ascochyta, Phytophthora, Sclerotinia, management

GRDC codes

DAN00176, DAN00151

Take home message:

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

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

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

Background

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

What are the risks of back to back chickpea?

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

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

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

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

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

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

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

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

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

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

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

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

There are three:

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

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

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

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

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

http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management and in the NSW DPI 2016 Winter Crop Variety Sowing Guide

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Chickpea Ascochyta – latest research on variability and implications for management

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Key words

chickpea, Ascochyta, pathogenicity, latent period

GRDC code

DAN00176, UM00052, DAN00151, DAV00126, DAN00151, DAV00098

Take home message

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

Ascochyta blight in 2015 chickpea crops

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

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

Latest research on variability in the Ascochyta pathogen

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

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

Latent period

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

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

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

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

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

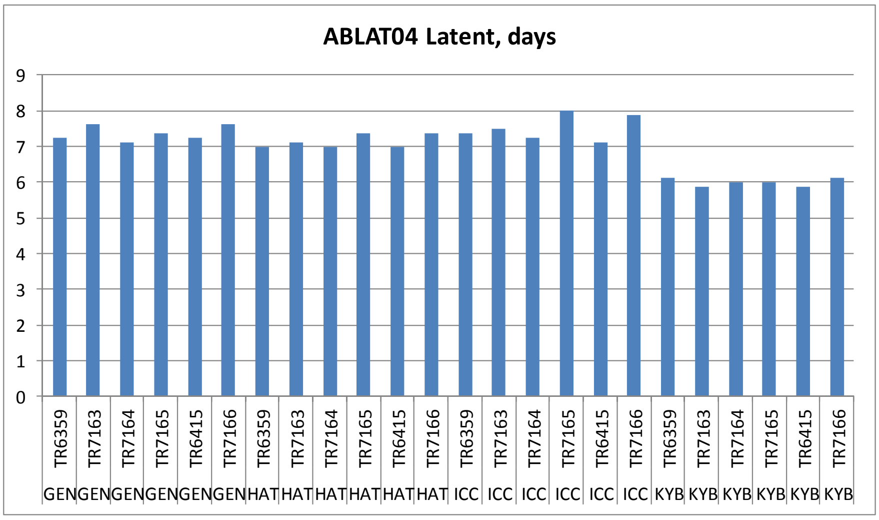

Figure1. Latent period results for experiment ABLAT04 grouped by genotype (ICC3996 (ICC), Genesis 090 (GEN), PBA HatTrickⓓ (HAT), Kyabraⓓ (KYB)) for inoculation with six isolates listed by isolate no, source and variety: TR6359 2014 North Star NSW, Flipperⓓ; TR7165 2014 Horsham VIC; Genesis425, TR7163 2014 Donald VIC; Slasherⓓ; TR6415 2014 Yallaroi NSW, HatTrickⓓ; TR7164 2014 Donald VIC, Slasherⓓ; TR7166 2014 Salter Springs SA, Monarchⓓ.

Histopathology experiments

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

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

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

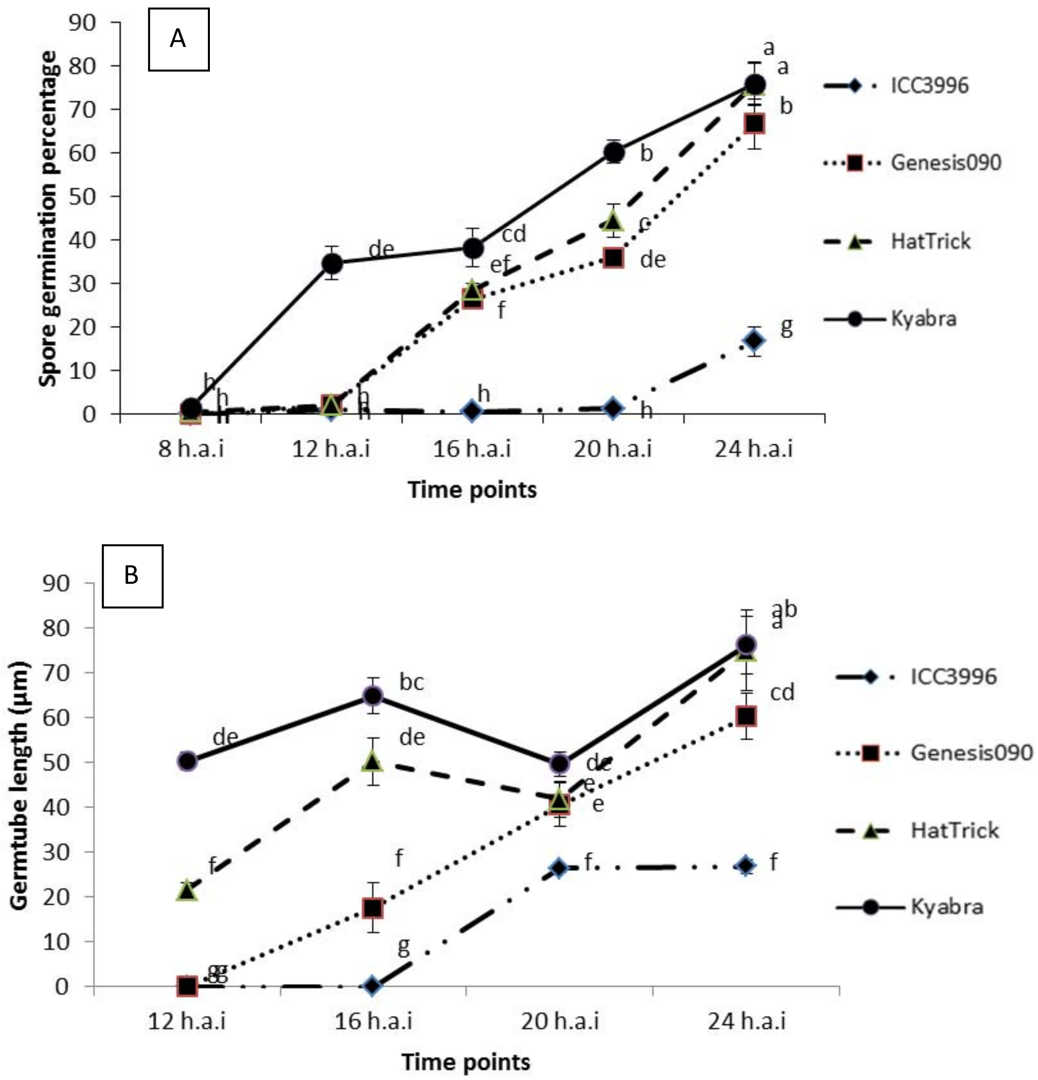

Figure 2. Significant differences were observed among the physiological traits of a highly pathogenic isolate FT13092-1 from Kingsford, SA when inoculated onto chickpea genotypes that are resistant (ICC3996 and Genesis090), moderately resistant (PBA HatTrick) or susceptible (Kyabra). Where A = the percentage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

How is this information used by the PBA Chickpea program?

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

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

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

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

*Advanced breeding lines, putative AB rating

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

Further information

http://www.grdc.com.au/Resources/Factsheets/2013/05/Chickpea-disease-management and in the NSW DPI 2016 Winter Crop Variety Sowing Guide

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Phytophthora in chickpea varieties HER15 trial –resistance and yield loss

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Key words

Phytophthora root rot, variety, risk management

GRDC code

DAN00176, DAN00151, DAQ00186, DAS00137

Take home message

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

Varietal resistance to phytophthora root rot

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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