## Agenda

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<td>GRDC</td>
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<td>9:10 AM</td>
<td><strong>Killing storage pests without mercy:</strong> fumigation strategies that work.</td>
<td>Andrew Ridley (DAF Qld)</td>
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<td>9:30 AM</td>
<td><strong>Using insect traps to find and control storage pests early:</strong> help build a reputation with grain buyers as a reliable supplier.</td>
<td>Greg Daglish (DAF Qld)</td>
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<td>9:45 AM</td>
<td><strong>Super cool results: achieving great aeration results.</strong> Simple maintenance/changes to greatly improve aeration airflow. Results from on-farm trials in 2016.</td>
<td>Philip Burrill (DAF Qld)</td>
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<td>Discussion Q&amp;A on grain storage</td>
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<td>Long-term economics, risk, water-use-efficiency, nutrient use efficiency &amp; impacts on soil sustainability.</td>
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<td><strong>Practical applications for digital imaging.</strong></td>
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<td><strong>Managing the major mungbean diseases:</strong> halo blight, fusarium wilt, tan spot and powdery mildew.</td>
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<td><strong>Minimising nitrogen losses to improve use efficiency in summer crops:</strong></td>
<td>Mike Bell (QAAFI)</td>
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Killing storage pests without mercy – fumigation strategies that work

Andrew Ridley, Philip Burrill and Pat Collins, 
Queensland Department of Agriculture and Fisheries

Key words
Fumigation, grain storage, phosphine, recirculation, pressure tests

PBCRC code
PBCRC3150

Take home message
Results of trial fumigations conducted in 1,400 t silos to test the capability of these large storages have led the following conclusions:

- Recirculation greatly facilitates the distribution of gas in large silos
- Fumigation in large silos without recirculation results in much lower concentration in the base of the silo.
- Peak concentration of phosphine typically occur between day 4 and 6 and decline for the rest of the fumigation.
- The current pressure half-life standard (AS2628) of 5 minutes is appropriate for large silos and is vital for effective fumigation.
- Fumigations are likely to fail where there are points of gas / fresh air leaks in a silo. Pressure testing prior to fumigation is a vital step in identifying and locating gas leaks.
- Strongly phosphine resistant rusty grain beetle can only be controlled by extending fumigation time beyond the minimum label recommendation (of 20 d for blankets) or by implementing active recirculation.

There are very few options available to growers to control storage pests when an infestation has been detected. Phosphine, sold in solid formulation of aluminium phosphide (AIP) under the trade names such as phostoxin® or fumitoxin® is by far the most common disinfection treatment for stored grain.

The label was first written in the 1970’s for relatively small silos and other storages. A significant number of growers are now investing in large capacity (e.g. 1,500 t), flat bottom silos for storing grain on farm. We do not know whether the label directions are appropriate for these larger storages.

Coupled with this uncertainty is the development of strong phosphine resistance in the rusty grain beetle. The resistant populations of the rusty grain beetle, found at a number of sites in eastern Australia, are significantly harder to control than other pests and label rates may need to be updated.

Fan forced recirculation of gas in large silos helps to distribute phosphine and has been advised for some time. Recirculation is not a requirement on the current label but may be a cost effective way to perform better fumigations.

The aim of this trial was to answer the following questions:

- Can strongly resistant rusty grain beetle be controlled in large farm silos?
- Is the current Australian Standard (AS2628 – 5 min pressure half-life) for silo gas-tightness appropriate for large silos?
- What concentrations of phosphine are achieved under passive gas distribution and to what extent does that lengthen the fumigation?
- Do large silos need recirculation for effective fumigation?
- What is an acceptable recirculation air flow rate and system design for large silos?

Two silos, labelled A and B, were fumigated at label rates. The phosphine in silo A was dispersed by natural means (passive fumigation). The gas in silo B was recirculated (active fumigation) for the first five days of the fumigation. Phosphine concentrations were monitored at four centre sampling points (headspace and at 9, 5, and 1 m above the floor) and at three points around the base wall (North, 120° and 240°) of each silo. Silo A had a Pressure Half Life (PHL) of 7 minutes and 35 seconds and silo B had a PHL of 2 minutes and 10 seconds. Both silos were leaking air at the silo base entry door during the pressure tests indicating a location for potential gas loss and dilution of gas with fresh air from outside.

Figure 1. Phosphine concentrations measured in silo A (passive fumigation). The silo had a pressure half-life of 7 minutes and 30 seconds. The dosage (concentration x time) required to control phosphine-resistant lesser grain borer is indicted by the blue box and for phosphine-resistant rusty grain beetle by the red box.
Figure 2. Phosphine concentrations measured in silo B (active fumigation). A recirculation system with an air-flow rate of 0.013 L/s/t was fitted to the silo and was run for the first five days of the fumigation. The silo had a below standard pressure half-life of 2 minutes 10 seconds. The dosage (concentration x time) required to control phosphine-resistant lesser grain borer is indicted by the blue box and for phosphine-resistant rusty grain beetle by the red boxes. Two alternative strategies to meet the required dose to control phosphine-resistant rusty grain beetle are shown. That is, a higher concentration, shorter exposure period and a lower concentration, longer exposure period.

Conclusions

- For phosphine fumigations, strongly phosphine resistant rusty grain beetle can only be controlled by extending fumigation time beyond the minimum label recommendation (of 20 d for blankets) or by implementing active recirculation in gas-tight, sealable silo (AS2628)
- The current pressure half-life standard (AS2628) of 5 minutes is suitable for large silos
- Fumigation without recirculation requires a fumigation period of over 30 days
- Recirculation significantly shortened the fumigation period required to 14 days
- The label recommendations for solid formulations of phosphine must be updated to allow effective control of strongly resistant rusty grain beetle
- Should label rate fumigations with phosphine fail, and rusty grain beetle is identified, consider an alternative treatments such as sulfuryl fluoride (Profume®)

Based on these conclusions, options for updating the label to ensure control of phosphine resistant rusty grain beetle include:

1. Increase application rate to maintain current fumigation period of 20 days for passive fumigations
2. Keep current application rate but extend the passive fumigation period possibly past 30 days
3. Keep the current application rate but mandate active recirculation, and maintain or possibly reduce the fumigation period
4. Increase the application rate, mandate active recirculation and reduce the fumigation period

Increasing the application rate (option 1) may be possible but would require APVMA approval and may require significant industry input to undertake residue testing etc. Increasing fumigation period (option 2) is viable but fumigations may become too long to be practical. This option is heavily reliant on silos being sealed to the Australian standard of a 5 min pressure half-life. Mandating recirculation (option 3) would require a small capital cost to retrofit silos. Increasing the application rate in conjunction with active fumigation (option 4) could reduce fumigation times to a week or less.

A number of issues would need to be resolved if any changes are to be made to the label:

Increase application rate
- Residue testing
- WHS provisions
Increase fumigation time
- Fumigating partially filled silos
- Fumigating highly sorptive commodities such as canola

Active recirculation
- Minimum flow rates
- Fan run times

Measuring the level of silo gas-tightness

Pressure tests were carried out on silos A and B before the fumigation and at the end of the fumigation before venting to measure silo gas-tightness. Silos were sealed and pressurised using a cordless leaf blower. Internal pressure was measured using a digital manometer (Exotech HD755) connected to the plumbing of the pressure relief valve which comes from the headspace down the side of the silo.
Figure 3. Pressure loss from silo A demonstrates that pressure is lost at a fast rate at higher pressures compared to lower pressures. The rate of pressure loss slows down as the pressure gets closer to atmospheric. This is why it is important to conduct pressure half-life tests using the industry AS2628 standard test method, 250 to 125 Pa.

Recirculation system fitted to silo B

A tube was connected to the pressure relief downpipe to 0.37Kw power fan (F370 Downfield, Toowoomba) positioned between the two aeration ducting trenches of the silo (Figure 4). A two way splitter was fitted to the end of a PVC pipe and two 50 mm tubes of equal length was connected to the silo aeration ducting using standard plumbing fittings. Valves (50mm) made it possible to seal the silo at the aeration ducting and isolate the fan for removal. (The short length of white PCV pipe (ID 0.15 m) was fitted to the output side of the fan for the purpose of measuring air flows during the trial.)

Figure 4. Philip Burrill (DAF Qld) measuring air-flow in the recirculation system. For easy to follow details on how to measure air-flow in silos see http://storedgrain.com.au/testing-aeration/
Acknowledgements
The research was part of the project PBCRC3150 “An integrated approach to manage and resistance to phosphine in stored grain” supported by the PBCRC of which the GRDC is a partner. Trial fumigations were conducted at Balarang Lands (Weemelah) owned and operated by Jason and Lisa Orchin. We thank them for their support. The authors wish to thanks of Peter Hobday from AgriStorage and Logistics for assistance conducting the trial.

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Finding storage pests early

Greg Daglish, Queensland Department of Agriculture and Fisheries

Key words
Stored grain, insect pests, sampling, trapping

Take home message
- A pilot study in southern Queensland demonstrated that combining the use of probe traps in the top of a silo with sieving a grain sample from the bottom was an effective insect detection method.
- Probe traps inserted into the grain surface tended to catch more beetles than traps inserted deeper.
- Probe traps inserted into the grain peak via the silo centre top hatch tended to catch more beetles than traps inserted via the roof side hatch.
- Check traps after 1 day initially to avoid clogging if there is a heavy infestation, and less frequently thereafter (e.g. monthly) if few or no beetles are detected.
- Further research is needed examining the relative effectiveness of sieving and trapping for detecting different species, and how serious the situation is when beetles are first detected.

Background
Options for farmers to detect insects in stored grain were explored in a pilot study in 2016 on two farms in southern Queensland. Increasing on-farm storage comes with an increasing risk of insect infestation. There is an urgent need for appropriate sampling methods to help farmers manage this risk and minimize marketing delays. Simple, safe, cost effective and easy to interpret sampling options will enable growers to make informed decisions about pest management.

Silos containing wheat or barley were sampled for stored grain beetles using two methods (Figure 1):
- Sieving of grain samples taken from the top and bottom of the silo
- Captured in probe traps inserted into the grain via the side and top hatches

The bottom grain (2 L) sample was collected by dropping grain from the bottom of the silo. The top grain sample (4 L) was a composite of two samples scooped from the grain surface, i.e. one sample (2 L) scooped from the top hatch and a second sample (2 L) scooped from the side hatch.

Probe traps were inserted into the grain via the top and side hatches. In each case, one trap was inserted to trap beetles 0-28 cm from the grain surface (shallow trap) and the second trap was inserted so that it trapped beetles 28-56 cm from the grain surface (deep trap).

Research results
In this pilot study, stored grain beetles were detected in grain samples and probe traps.

In silos in which beetles were detected in sieved grain samples, the bottom and top grain samples yielded on average 78 and 20% of the beetles respectively (Figure 2). This was despite the top sample having twice as much grain as the bottom sample.

In silos in which beetles were detected in the probe traps, the shallow and deep traps captured on average 82 and 18% of the beetles respectively (Figure 3).

In silos in which beetles were detected in the probe traps, the traps inserted via the side and top hatches captured on average 24 and 76% of the beetles respectively (Figure 4).
It is possible that the usefulness of sampling and trapping may vary between pest species, but it is not possible to confirm this at this stage.

In several heavily infested silos some probe traps captured many thousands of Tribolium castaneum (red flour beetle) beetles resulting in traps becoming congested.

Automatic loggers were used to monitor temperature and humidity in some silos (e.g. Figures 5 and 6). Temperature and humidity varied widely in the headspace reaching potentially lethal levels in the middle of the day. In contrast, temperature and humidity was much more stable in the grain bulk. Beetles are likely to avoid the grain surface during this time of extreme high temperature and low humidity, potentially impacting on the usefulness of visual inspection for beetles on the grain surface.

Preliminary recommendations

There are many beetle species that can infest stored grain and at least five pest species were detected in this study. From a scientific perspective, knowing the identity and exact numbers of beetles in grain samples or probe traps is valuable. From a grower perspective, however, the presence of any beetles in stored grain is a problem.

This pilot study focussed on two simple methods that could be used by growers to detect pests in stored grain, and the following recommendations are based on the results.

- Sieving of grain samples and using probe traps in the top of the grain bulk is useful.
- If sieving grain is to be limited to one location, then a sample from the bottom of the silo is preferable to one from the top of the silo.
- Probe traps should be inserted into the grain bulk so that the top of the trap is level with the grain surface.
- If trapping is to be limited to one location then inserting the probe trap into the grain through the top hatch is preferable to inserting it through the upper side hatch.
- Initially, probe traps should be inspected after 1 day in case there is a heavy infestation, with the risk of large numbers of beetles clogging the traps. If no or few beetles are trapped in the first instance longer trapping period can be used.
- Extremely high temperature and low humidity is possible during the middle of the day, so early morning may be the best time for visual inspection of the grain surface for beetles.

Unanswered questions

- Are the results of this pilot study applicable more broadly?
- What does it mean if I get one beetle or many beetles in my sieved sample or my probe trap? And is the answer the same soon after harvest or later during storage?
- Do different pest species tend to be in different parts of the grain bulk, and how does this affect detection through sampling or trapping?

Acknowledgements

This pilot study was made possible through an Agri-Science Queensland Innovation Opportunity award from DAF entitled ‘Sampling options for farmers to detect insects in stored grain’. I am very grateful to two grain growers and their families for allowing me access to their properties and my DAF colleagues Philip Burring and Valerie Byrne.
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Figure 1. Grain sieve and probe trap used for detecting insect pests in farm silos.

Figure 2. When grain beetles were detected in grain samples then more beetles tended to be detected in the bottom sample than the top sample.
Figure 3. When beetles were detected in probe traps then traps inserted near the grain surface tended to catch more beetles than traps inserted deeper.

Figure 4. When beetles were detected in probe traps then traps inserted via the top hatch tended to catch more beetles than traps inserted via the side hatch.
Figure 5. Temperature measured half-hourly in the headspace and grain bulk in a silo containing barley.

Figure 6. Relative humidity measured half-hourly in the headspace and grain bulk in a silo containing barley.
Super cool results – achieving great aeration results

Philip Burrill, DAF Qld.

Key words
Grain aeration, stored grain temperature, grain quality, storage pests, aeration fans

GRDC code
PRB00001

Take home message
- Seek advice to ensure the right size aeration fans and associated equipment are fitted – ducting, roof vents and fan controller. Not all silo suppliers get it right.
- Recommended aeration cooling airflow rates are 2 to 4 litres of air per second, per tonne (L/s/t). Do your aeration fans achieve this when your silos are full of wheat, barley, chickpeas, sorghum, canola?
- Are you achieving the target ‘grain temperatures’ of 18° to 23°C during summer storage and less than 15°C during the winter period?
- Aeration maintenance: farm case studies show that aeration equipment checks and maintenance can lead to a significant improvement to aeration performance and grain storage results

Storage best practice – four key steps
Aeration cooling is just one of four key best practice strategies that provide good results for on farm storage. When combined, they form the foundation for successful storage and importantly, a grower can build a reputation as a reliable supplier of quality grain.

1. Aeration: correctly designed and managed, will provide cool grain temperatures and uniform grain moisture conditions. The result is reduced problems with grain moulds and insect pests in storage, plus the ability to maintain grain quality attributes such as germination, pulse seed colour, oil quality and flour quality.

2. Hygiene: a good standard of storage facility hygiene is crucial in keeping storage pest numbers to a minimum and reducing the risk of grain contamination.

3. Monitoring: monthly checking of grain in storage for insect pests (sieving / trapping) and at the same time inspect grain quality and temperature. Keep a monthly storage record to record these details, including any grain treatments you applied.

4. Fumigation: in Australia we now only have gases (fumigation) to deal with insect pest infestations in stored grain. To achieve effective fumigations the storage/silo must be sealable – gas-tight (AS2628) to hold the gas concentration for the required time.

Effective aeration – what does it look like?
For the summer storage period November to April we aim to achieve grain temperatures of 18° to 23°C with well managed aeration cooling. For the winter period May to September the target is grain temperatures of less than 15°C.
Push a robust thermometer attached securely to a broom handle, or better, a purpose built grain temperature probe one meter into grain. Leave for a few minutes in grain before reading to see what grain temperature your aeration system has achieved.

**Figure 1.** Two silos - wheat. Non-aerated silo had grain temperature sit above 30°C for 3 months, ideal for insect breeding. Well managed aeration in summer brings temperatures down towards 20°C.

**Aeration - achieving good results**

There are three areas to focus on for good aeration results:

a. Aeration equipment for the job
b. Operating aeration system effectively
c. Maintaining / checking the equipment is doing the job

a. **Aeration equipment for the job**

The three main components are fans, ducting inside the storage and the roof vents.

**Fan selection:** Fan size, number per silo and type of fan are common areas for confusion. It usually requires an “experienced grain aeration specialist” to provide advice to either the silo manufacturer / supplier, or directly to the grower. There are a number of important considerations to consider before fitting fans to a silo or storage.

Silo size - height & width, electricity supply available at site, grain types stored, typical harvest grain moisture contents, and what is the intended purpose of fans? Is it only for aeration cooling (2 - 4 L/s/t), or do you want to set up one or two silos with much larger airflows (15 - 25 L/s/t) for the purpose of aeration drying?

These details can be quickly sorted out with one or two phone calls, when you are dealing with an experienced aeration specialist. It is vital that the right questions are asked. The result, the fan selection, ducting and venting design suits the intended purpose for your grain storage situation.
Figure 2. Note the large variation in aeration fan outputs for four typical fans fitted to grain storages

Farm case study 1: A 130 tonne capacity cone based silo, nearly full with 105 tonnes of barley, fitted with one 0.37 kW aeration fan was tested for airflow output. Using the ‘A-Flow’ testing device (GRDC fact sheet, “Performance testing aeration systems”) the single aeration fan was only able to generate 166 litres of air per second, or 1.6 L/s/t airflow against the 105 tonnes barley. Result: grower decided to fit a second fan (same size) on the opposite side, aiming for 3.0 L/s/t

Farm case study 2: Two Grainmaster™ 150 tonne capacity cone based silos, both fitted with a pair of 0.37 kW Agrdry F100 aeration fans. One silo was full with 140 tonnes of Soybeans and the other silo full with 150 tonnes of White French millet. With identical fans running on identical silos the total airflow output through the soybeans was 397 L/s, providing a useful 2.8 L/s/t. However airflow going into the White French millet silo was only a total of 141 L/s, providing a much lower 0.9 L/s/t. The extra back pressure on fans created by the small seed millet was reducing aeration airflow to well below the recommended cooling range of 2 – 4 L/s/t.

Ducting inside silo: There are two common types, the round tube ducting that can be made to lift up for cleaning, or the house shaped ducting that is fixed down to the cone base. Ducting length, strength, location in silo and size of perforation holes / slots, all involved in achieving optimum airflows through grain. Ability to clean and remove grain residues from ducting for silo hygiene is important for both cone base or flat bottom silos.

Roof vents: Vents can be as simple as a “Chinaman hat style” used on the centre fill top hatch, or the many variations of “goose neck” roof vents. Unfortunately it is not uncommon to see venting design problems on range of silo brands.

The vent size / area needs to be appropriate to suit the fan output. A fan’s airflow should not be used at start up to lift heavy vent lids, or constantly work against lid springs. This ensures fan airflow is not restricted. For all sealable silos, vents require simple, effective systems for creating a gas tight seal during fumigation. Do you also have easy access to vents for maintenance on rubber seal?

Farm case study 3: Three new 150 tonne capacity, sealable, aerated silos, each fitted with two 0.37 kW Downfield F370 aeration fans (smallest curve on Fig. 2 is the F370 fan). The storage facility manager was concerned about fan output after he tested fans shortly after the silos construction
was completed. He was comparing the operating sound of fans running using the four vents fitted to the roof, with the fan’s sound when he also manually opened the centre top fill hatch as well. The fan performance sounded like it improved with the extra vent space provided.

When fan output was tested (A-Flow device) on the ‘empty’ (no grain back pressure) new silo, the pair of F370 fans could only achieve a total of 209 L/s airflow with the four vents used as designed. When the centre top fill lid was also opened, output immediately increased to 517 L/s.

On closer inspection the 4 sealable vents on the roof had no system to hold them open during aeration. There was only a long flexible cable to pull them closed / sealed for silo fumigations. Fans were losing more than half their unloaded performance, just by forcing them to lift four steel plate vent lids. Result: when the silo manufacturer was made aware of the design problem they arranged to fit a simple vent lid lifter.

Access to four vents around the roof edge to maintain rubber seals, is the next design challenge.

b. Operating aeration system effectively

Running the fan at the right times will achieve cool grain temperatures and uniform moistures. Aeration cooling aims to push through a series of ‘cooling fronts’ starting from the base of the silo.

![Figure 3. Cooling / drying fronts in the aeration process (C. Newman Agric. WA)](image)

While there are a number of producers still manually operating aeration fans, for most storage facilities we recommend using a good quality automatic aeration controller with a sensor measuring both ambient air temperature and humidity to automatically turn on fans at optimum times.

**Manual operation of fans**

There are three stages when operating aeration cooling fans from the start of harvest:

1. As soon as enough grain covers the ducting, turn on aeration fans while filling silo. Run continuously (24hrs / day) until the first cooling front comes through the full grain depth. This usually takes 3 - 5 days. If safe, go to the top of the silo and see if the air coming out has
changed from a warm, humid smell to a fresh, cool smell. The first cooling front is through. See Figure 3.
2. Once this has occurred, run the fans for approximately 12 hours per day for the next 5 – 7 days.
Select the cooler night air, but avoid extended periods of high humidity air which may wet grain. Avoid fog, misty or showery conditions.
3. Check the grain temperature and condition. Grain temperature in summer should now be close to 20°C. The longer term “protect” phase now begins. Operate fan for approx. 100 hours per month, selecting cool, mostly dry air from 3 - 5 days per week to maintain cool grain conditions. An automatic controller will usually be much more reliable at this task.

Automatic controller operation of fans

Today there are automatic aeration controllers available that automatically step through the three stages outlined above.

Seek independent advice as to what are the better quality controllers to consider, as there are poor quality units that may put your stored grain at risk. Ensure the supplier has a good reputation for providing after sales support and parts if required.

For a new unit fitted to a storage facility, there is simple start up process to follow. See manual, or consult supplier. As a general rule, leave the auto controller itself powered up. It is recording a history of current weather conditions so it is able to turn fans on at the optimum times.

c. Maintaining and checking aeration equipment

There are a few basic checks and maintenance steps to ensure your system is doing the job.

- Check grain temperatures to see if you are achieving the target temperatures of 18° to 23°C during summer storage and less than 15°C during the winter period.
- See Figure. 4 where an OPI® cable was used in the aerated barley silo (“Farm case study 1”) to record grain temperatures at various depths. This helped identify the low airflow problem.
- When checking silos each month for insects, also look at the hour meter on the aeration auto controller to see if fans are averaging approx. 100 hours per month (+/- 20 hrs).
- At least once per year use a good quality thermometer and relative humidity reader to check the aeration auto controller’s sensor has not been damaged and is readings correctly.
- Manually test-run fans on silos to check they are all operating. Clean fans if required.

Farm case study 4: A ten minute fan cleaning job can produce large improvements. A single 0.37 kW aeration fan was tested for airflow output on a 128 tonne capacity coned based silo holding 105 tonnes of barley. It was observed that the fan impeller had a significant build-up of dust on the blades prior to testing. Using the ‘A-Flow’ testing device, the aeration fan output was recorded as 86 L/s, or 0.8 L/s/t airflow against the 105 tonnes barley. After cleaning the dust from the blades the fan was retested and produced an output of 152 L/s, or 1.5 L/s/t. Result: grower cleaned remaining fans.
Figure 4. Temperatures in a silo of barley in headspace and at three grain depths. The warmer than expected grain temperatures indicated possible aeration problem. See Farm Case study 1.

Further reading

- GRDG Factsheet – “Performance testing aeration systems”
- GRDC Fact Sheet – “Safe storage of Sunflower seed – aeration drying and cooling”
- GRDC Update – “How Aeration Works”
- GRDC booklet – Aeration stored Grain – cooling or drying for quality control

Acknowledgements

The research undertaken is made possible by the significant contributions of growers through both trial cooperation and support of GRDC, DAF Postharvest research team and GRDC’s national grain storage extension team, the author would like to thank them for their continued support.

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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

Kevin Moore, Leigh Jenkins, Paul Nash, Gail Chiplin and Sean Bithell, Department of Primary Industries, NSW

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 HatTrick®.
- 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

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

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

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

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

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

**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 °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**


**Acknowledgements**

This research is made possible by the significant contributions of growers through both trial cooperation, paddocks access and the support of the GRDC, the authors would like to thank them for their continued support.
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Chickpeas – new Ascochyta and Botrytis grey mould advice for 2016

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¹ Department of Primary Industries, NSW
² Department of Economic Development, Jobs, Transport and Resources, VIC

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⁽¹⁾ and PBA Boundary⁽¹⁾) 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**

This research is made possible by the significant contributions of growers through both trial cooperation, paddocks access and the support of the GRDC, the authors would like to thank them for their continued support.

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

Kevin Moore, Kristy Hobson, Steve Harden, Paul Nash, Gail Chiplin and Sean Bithell, Department of Primary Industries, Tamworth, NSW

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 (S, susceptible) and Jimbour (R).
• However, Ascochyta management is easier and more cost effective on varieties with improved resistance eg 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).

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 (R) 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 (R) 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 (S) was applied before inoculation. The first Group MS VMP spray for Genesis Kalkee™, PBA Monarch (R), CICA1302 and CICA1303 was applied after three
infection events (6 rain days, 67 mm rain since inoculation), for Group MR VMP spray (PBA HatTrick\(^1\) and PBA Boundary\(^1\); CICA1007) and R (CICA0912, Genesis 425\(\text{TM}\)) 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\(^1\) yielded 1862 kg/ha with a GM of $954/ha
- Under extreme disease pressure, unsprayed PBA HatTrick\(^1\) 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\(^1\) in VMP15 was both a surprise and a disappointment. In all previous VMP trials at Tamworth, unsprayed (Nil treatment) PBA HatTrick\(^1\) 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 38 cm row spacing in plots 4 m wide by 10 m 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 430 mm rain in 67 rain days (46 days >1.0 mm) i.e. 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\(^1\) yielded nearly 3 t/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\(^1\) performed exceptionally well, yielding over 2 t/ha without any foliar fungicide, a minimal yield loss (4%), compared with 53 % in 2015.
- Under extreme disease pressure in 2010 unsprayed HatTrick\(^1\) still gave a profitable yield, but unsprayed HatTrick\(^1\) 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.

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

*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 aggressiveness 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

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

<table>
<thead>
<tr>
<th>Variety</th>
<th>Rate of chlorothalonil</th>
<th>No. Sprays</th>
<th>Cost $/ha</th>
<th>Yield kg/ha</th>
<th>GM $/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jimbour</td>
<td>1.0L</td>
<td>14</td>
<td>294</td>
<td>2988</td>
<td>750</td>
</tr>
<tr>
<td>Kyabra(^1)</td>
<td>1.0L</td>
<td>14</td>
<td>294</td>
<td>2549</td>
<td>553</td>
</tr>
<tr>
<td>PBA HatTrick(^1)</td>
<td>1.0L</td>
<td>14</td>
<td>294</td>
<td>2604</td>
<td>578</td>
</tr>
<tr>
<td>PBA Boundary(^1)</td>
<td>1.0L</td>
<td>14</td>
<td>294</td>
<td>2410</td>
<td>491</td>
</tr>
<tr>
<td>Jimbour</td>
<td>Nil</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-300</td>
</tr>
<tr>
<td>Kyabra(^1)</td>
<td>Nil</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-300</td>
</tr>
<tr>
<td>PBA HatTrick(^1)</td>
<td>Nil</td>
<td>0</td>
<td>0</td>
<td>1707</td>
<td>468</td>
</tr>
<tr>
<td>PBA Boundary(^1)</td>
<td>Nil</td>
<td>0</td>
<td>0</td>
<td>2320</td>
<td>744</td>
</tr>
</tbody>
</table>

\(^1\)Kyabra\(^1\) 1.0L one of the four reps was severely affected by water logging which (i) compromised Ascochyta control and (ii) impacted on yield.

Acknowledgements

This research is made possible by the significant contributions of growers through both trial cooperation, field access and the support of the GRDC; the authors most gratefully thank them and the GRDC. Thanks to Woods Grains, Goondiwindi, Glen Coughran, “Beefwood”, Moree and Joe Fleming, “Parraweena”, Blackville for providing seed for the trials. We also thank agronomists for help with the crop inspections and submitting specimens, Gordon Cumming, Pulse Australia for industry liaison and chemical companies who provide products for research purposes and trial management.

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**Chickpea on chickpea – is it worth it?**

*Kevin Moore, Kristy Hobson and Sean Bithell, Department of Industry, NSW, Tamworth*

**Key words**
chickpea, Ascochyta, Phytophthora, Sclerotinia, management

**GRDC codes**
DAN00176, DAN00151

<table>
<thead>
<tr>
<th>Take home message:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planting your 2016 chickpea crop into paddocks that had chickpeas in 2015, or earlier, is risky and you could lose money.</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>Growers are urged to follow recommendations for current best practice especially with regard to crop rotation.</td>
</tr>
</tbody>
</table>

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

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

The risks of Botrytis grey mould (*BGM, Botrytis cinerea*), Botrytis seedling disease (*BSD, B. cinerea*) and viruses (several species) are unlikely to increase with chickpea on chickpea UNLESS some consequence of back to back chickpea favours these diseases eg patchy, uneven stands caused by Ascochyta, Sclerotinia or Phytophthora will increase the risk of virus.
If I did not find any disease in my 2015 crop, is it safe to plant chickpea on chickpea in 2016?

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

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

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

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

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

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

There are three:

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


and in the NSW DPI 2016 Winter Crop Variety Sowing Guide

**Acknowledgements**

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Chickpea Ascochyta – latest research on variability and implications for management

Kevin Moore1, Kristy Hobson1, Nicole Dron1, Prabhakaran Sambasivam2, Rebecca Ford3, Steve Harden1, Yasir Mehmoodd, Jenny Davidson4, Shimna Sudheesh5, Sukhiwan Kaur5 and Sean Bithell1

1Department of Primary Industries NSW, 2University of Melbourne VIC, 3Griffith University, QLD, 4SARDI, SA, 5Agribio DEDJTR, VIC

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 HatTrick1 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 HatTrick1 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<sup>1</sup>. 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<sup>1</sup> at Yallaroo, 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<sup>1</sup> (rated MR, coded HAT), 4) Kyabra<sup>1</sup> (rated S, coded KYB).

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

These experiments complement the pathogenicity work and confirm variability does exist in the pathogen population.
**Figure 1.** Latent period results for experiment ABLAT04 grouped by genotype (ICC3996 (ICC), Genesis 090 (GEN), PBA HatTrick (HAT), Kyabra (KYB)) for inoculation with six isolates listed by isolate no, source and variety: TR6359 2014 North Star NSW, Flipper; TR7165 2014 Horsham VIC; Genesis425, TR7163 2014 Donald VIC; Slasher; TR6415 2014 Yallaroi NSW, HatTrick; TR7164 2014 Donald VIC, Slasher; TR7166 2014 Salter Springs SA, Monarch.

**Histopathology experiments**

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

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

These differential fungal responses may be indicative of host recognition and defence strategies, which are being further investigated.
Figure 2. Significant differences were observed among the physiological traits of a highly pathogenic isolate FT13092-1 from Kingsford, SA when inoculated onto chickpea genotypes that are resistant (ICC3996 and Genesis090), moderately resistant (PBA HatTrick) 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>
<thead>
<tr>
<th>Name</th>
<th>Field rating</th>
<th>Isolate FT13092-1</th>
<th>Isolate TR5919</th>
<th>Marker genotype</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kyabra</td>
<td>S</td>
<td>100</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>PBA HatTrick</td>
<td>MR</td>
<td>0</td>
<td>20</td>
<td>+, desi</td>
</tr>
<tr>
<td>PBA Boundary</td>
<td>MR</td>
<td>35</td>
<td>75</td>
<td>+, desi</td>
</tr>
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<td>MS</td>
<td>8</td>
<td>28</td>
<td>Not conclusive</td>
</tr>
<tr>
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<td>R*</td>
<td>0</td>
<td>42</td>
<td>+, desi</td>
</tr>
<tr>
<td>CICA1007</td>
<td>MR*</td>
<td>0</td>
<td>50</td>
<td>+, desi</td>
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<td>CICA1521</td>
<td>R*</td>
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<td>8</td>
<td>+, desi</td>
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<tr>
<td>Almaz</td>
<td>MS</td>
<td>8</td>
<td>8</td>
<td>-, suggests other genes</td>
</tr>
<tr>
<td>Genesis 090</td>
<td>R</td>
<td>0</td>
<td>8</td>
<td>+, kabuli</td>
</tr>
<tr>
<td>Genesis 425</td>
<td>R</td>
<td>8</td>
<td>17</td>
<td>+, kabuli</td>
</tr>
<tr>
<td>Genesis Kalkee</td>
<td>MS</td>
<td>50</td>
<td>20</td>
<td>--, suggests other genes</td>
</tr>
<tr>
<td>PBA Monarch</td>
<td>MS</td>
<td>3</td>
<td>42</td>
<td>+, kabuli plus others</td>
</tr>
<tr>
<td>CICA1156</td>
<td>R*</td>
<td>0</td>
<td>0</td>
<td>+, kabuli</td>
</tr>
</tbody>
</table>

*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**


**Acknowledgements**

This research would not be possible without the considerable and ongoing support from growers and the GRDC for which we are most grateful. Thanks to Paul Nash and Gail Chiplin for technical support. Thanks also to agronomists for help with the crop inspections and submitting specimens.
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Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.
Phytophthora in chickpea varieties HER15 trial –resistance and yield loss

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1 NSW DPI Tamworth; 2 DAFQ Toowoomba; 3 DAFQ Warwick

Key words
Phytophthora root rot, variety, risk management

GRDC code
DAN00176, DAN00151, DAFQ00186, DAS00137

Take home message
- In a wet season, substantial (94%) yield losses from PRR occur in susceptible varieties such as PBA Boundary1. Do not grow PBA Boundary1 if you suspect a PRR risk
- Varieties with improved resistance to PRR (PBA HatTrick1 and Yorker1) 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, medic 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 medic 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.


Current commercial varieties differ in their resistance to P. medicaginis, with Yorker1 and PBA HatTrick1 having the best resistance and are rated MR (historically Yorker1 has been slightly better than PBA HatTrick1), while Jimbour is MS - MR, Flipper2 and Kyabra2 are MS and PBA Boundary1 has the lowest resistance (S). PBA Boundary1 should not be grown in paddocks with a history of PRR, lucerne, medic or other known hosts such as sullal.

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\(^{a}\) and PBA HatTrick\(^{b}\) 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\(^{b}\) were 94% in 2015 and 74% in 2014. However, the 2015 trial again confirmed that Yorker\(^{b}\) and PBA HatTrick\(^{b}\) had better resistance than PBA Boundary\(^{b}\) (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\(^{b}\) 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\(^{b}\).

### 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)

<table>
<thead>
<tr>
<th>Variety/line(^{a})</th>
<th>Yield (t/ha) in absence of Phytophthora infection</th>
<th>Yield (t/ha) in presence of Phytophthora infection</th>
<th>% yield loss due to Phytophthora infection</th>
</tr>
</thead>
<tbody>
<tr>
<td>CICA1328(^{a})</td>
<td>2.64</td>
<td>1.54</td>
<td>41.7</td>
</tr>
<tr>
<td>D06344&gt;F3BREE2AB027(^{a})</td>
<td>2.52</td>
<td>1.05</td>
<td>58.4</td>
</tr>
<tr>
<td>PBA HatTrick(^{b})</td>
<td>2.50</td>
<td>0.81</td>
<td>67.7</td>
</tr>
<tr>
<td>Yorker(^{b})</td>
<td>2.61</td>
<td>0.57</td>
<td>78.7</td>
</tr>
<tr>
<td>CICA1007</td>
<td>2.93</td>
<td>0.71</td>
<td>75.9</td>
</tr>
<tr>
<td>CICA0912</td>
<td>2.76</td>
<td>0.37</td>
<td>86.6</td>
</tr>
<tr>
<td>PBA Boundary(^{b})</td>
<td>2.88</td>
<td>0.17</td>
<td>94.0</td>
</tr>
</tbody>
</table>

\(^{a}\)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)

<table>
<thead>
<tr>
<th>Variety/line(^{a})</th>
<th>Yield (t/ha) in absence of Phytophthora infection</th>
<th>Yield (t/ha) in presence of Phytophthora infection</th>
<th>% yield loss due to Phytophthora infection</th>
</tr>
</thead>
<tbody>
<tr>
<td>CICA1328(^{a})</td>
<td>2.76</td>
<td>2.71</td>
<td>1.8</td>
</tr>
<tr>
<td>Yorker(^{b})</td>
<td>3.01</td>
<td>2.69</td>
<td>10.4</td>
</tr>
<tr>
<td>CICA1211</td>
<td>3.01</td>
<td>2.66</td>
<td>11.6</td>
</tr>
<tr>
<td>D06344&gt;F3BREE2AB027(^{a})</td>
<td>2.93</td>
<td>2.13</td>
<td>27.4</td>
</tr>
<tr>
<td>PBA HatTrick(^{b})</td>
<td>2.94</td>
<td>1.98</td>
<td>32.8</td>
</tr>
<tr>
<td>CICA0912</td>
<td>3.23</td>
<td>1.79</td>
<td>44.6</td>
</tr>
<tr>
<td>PBA Boundary(^{b})</td>
<td>2.79</td>
<td>0.73</td>
<td>73.8</td>
</tr>
</tbody>
</table>

\(^{a}\)These lines are crosses between chickpea (C. arietinum) and a wild Cicer species
Acknowledgements

Thanks to growers and agronomists for help with crop inspections and submitting specimens, to Woods Grains, Goondiwindi for planting material for trials and to chemical companies who provided products for research purposes and trial management.

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Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.
High performance crop sequences for Southern Queensland – long-term economics, risk, water-use-efficiency, nutrient-use-efficiency and impacts on soil sustainability

*Lindsay Bell*¹, *Jeremy Whish*¹, *Andrew Zull*², *Peter DeVoil*³, *David Thornby*⁴

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²Department of Agriculture and Fisheries, Queensland  
³University of Queensland  
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**Key words**  
Crop systems, water, nematodes, herbicide resistance, gross margin, risk

**GRDC code**  
CSA00050

**Take home message**

- Optimising crop sequence is critical to maximising system efficiency and sustainability.
- No crop sequence is universally optimal against all system attributes, but sequences with higher water capture and use were also better for soil carbon, and sequences performed similarly for risk of weed herbicide resistance and propagating *Pratylenchus thornei*.
- Crop sequence affected evaporative losses little, but higher crop intensity reduced runoff and drainage losses, increased fallow efficiency and increased proportion of rain transpired by crops.
- Average sequence gross margin was highest in sequences with less time in fallow and a greater proportion of rainfall transpired by crops, but this increased risk in further west environments (e.g. Mungindi). While average gross margin was more linked to crop intensity, different crop sequences managed risk better than others.
- Sequences using a double crop of chickpea or mungbean had higher variability in gross margin and a higher frequency of crop failures, particularly at lower rainfall environments. Short-fallow sorghum crops were also much riskier than long-fallow crops at Goondiwindi and Mungindi.
- Sequences with low risk of developing *P. thornei* required a 2.5-3 year phase of resistant crops (e.g. sorghum) or fallow. Risks of developing herbicide resistant weeds were low when a phase of summer and winter crops were rotated, but high when summer fallows were frequent.

**Introduction**

Many cropping systems in the northern grains region are facing significant sustainability and profitability challenges. Analysis of paddocks in southern southern Qld and northern NSW have shown that while many individual crops are highly water-use-efficient, in many cases crop sequences are performing less well. Current cropping systems are being challenged by declining soil resilience, build-up of soil-borne pathogens such as root lesion nematodes, and increasing reliance on external inputs. Furthermore most systems continue to deplete soil nutrients which would cost an additional $75-200/ha to be replaced. Hence, there is a need to pay closer attention to crop sequences in order to enhance the capture and conversion of rainfall into production and profit and to maintain long-term productivity.

The analysis reported in this paper uses simulation models to compare the long-term performance of a range of common crop sequences against multiple elements of the farming system. That is, how
do the various crop sequences compare in terms their relative profitability, riskiness, productivity, water-use-efficiency, fertiliser input use and efficiency and risks for multiplication of nematodes, herbicide resistance and soil carbon depletion. This comparison is done at 3 locations in southern Queensland (Cecil Plains, Goondiwindi and Mungindi) to capture environmental differences from east to west. Through this analysis we aim to identify opportunities to improve the efficiency of crop sequences, and quantify some future threats for the range of crop sequences currently used. It is important to note that there is no ‘best’ crop sequence, this will be affected by current prices, soil constraints, and other farm resources; here we hope to identify the relative benefits and costs of some of these.

Methods

Simulations

Using historical climate data for Condamine Plains, Goondiwindi and Mungindi long-term simulations (110 years) of 18 common cropping sequences were conducted in APSIM. APSIM is a farming systems model which predicts the production of crops and captures the dynamics of water and nutrients in the farming system. The sequences simulated vary in their cropping intensity (from 0.5 to 1.3 crops per year), mix of crops, and summer/winter dominance (Table 1). The simulated sequences were set, and were defined by rules which ensured each crop in the sequence was sown if a sowing opportunity occurred in their sowing window or at the end of the recommended sowing window, even when moisture levels were marginal. All cereal crops were fertilised to ensure 200 kg of N was available at sowing and legumes were not fertilised. All sequences simulated are based on a no-till system with full stubble retention using a common good cropping soil in each district (i.e. plant-available water-holding capacity (PAWC) for wheat at Condamine Plains = 290 mm, Goondiwindi = 190 mm, and Mungindi = 186 mm). Simulations generated long-term information on crop yields, dynamics of soil water and nitrogen accumulation and use during fallows and under crops, and changes in soil carbon over the 110 year record of climate.
Table 1. Summary of simulated crop sequences. The growing windows for each crop are indicated by the various colours (below), otherwise land is fallow.

<table>
<thead>
<tr>
<th>Crop sequence</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
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<tbody>
<tr>
<td>SChxWMgx</td>
<td></td>
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<td>SChxWxx</td>
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<td></td>
</tr>
<tr>
<td>SxMgWxCh</td>
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</tr>
<tr>
<td>SxSChxWxx</td>
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</tr>
<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>SxSxSChxx</td>
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</tbody>
</table>

Sequence annual gross margin ($/ha/yr) was calculated using simulated outputs of grain yield, N requirements and number of germination events during fallows, using the equation below. These assumed long-term average grain prices and current variable input prices for each crop (Table 2).

Downside risk for each sequence was calculated from the average gross margin in the worst 20% of simulated years.

\[
GM_{20\%} = \sum\left( (\text{Grain yield} \times \text{price}) - (\text{kg N} \times 1.3) - (\text{sprays} \times 17) - \text{variable costs} \right) / \text{no. of years}
\]

Table 2. Assumptions of crop prices and variable costs used in gross margin calculations for crop sequences

<table>
<thead>
<tr>
<th>Crop</th>
<th>Average Price ($/t) (after transport)</th>
<th>Variable costs excl N fertiliser &amp; fallow sprays ($/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheat</td>
<td>240</td>
<td>175</td>
</tr>
<tr>
<td>Sorghum</td>
<td>205</td>
<td>218</td>
</tr>
<tr>
<td>Chickpea</td>
<td>400</td>
<td>284</td>
</tr>
<tr>
<td>Fababean</td>
<td>380</td>
<td>341</td>
</tr>
<tr>
<td>Mungbean</td>
<td>550</td>
<td>276</td>
</tr>
</tbody>
</table>

Nematodes multiplication factor was calculated for *Pratylenchus thornei* based on the proportion of time in a sequence that a susceptible crop versus a fallow or resistant crop was present. The proportion of days over the simulation that a susceptible crop was growing increased was multiplied.
by 2.5 times, and the proportion of days that a resistant crop or fallow periods was multiplied by -0.4. The changes are based on the rates of increase and decline in populations observed during susceptible and resistant crops or fallow periods.

**Herbicide resistance risk** - The pyRAT model, which predicts the risk of weeds developing herbicide resistance to Group M, I and A herbicides was used to predict risk scores for each rotation. The maximum risk, either for summer or winter grasses or broadleaf weeds, was used for each crop sequence. Risks for development of Group A and Group I herbicides were low to negligible in the sequences simulated here and hence results presented are for Group M (glyphosate) resistance.

**Limitations of the analysis**

When interpreting the results of this analysis it is important to be aware of some of the limitations. First the current crop models in APSIM used here don’t capture the effect of extreme heat stress, frost events, or sub-optimal supply of nutrients other than nitrogen. Hence, they may over-predict the likely yield due to losses from heat events at flowering in sorghum or mungbeans at Mungindi and Goondiwindi. Secondly, the yields in the crop sequences here are not reduced by losses due to weed competition or from soil-borne pathogens such as crown rot or nematodes; these capabilities are still under development and aim to be included in future analyses. Thirdly, the soils used here had no constraints for crop growth, for example, chickpea which might perform more poorly where subsoil constraints occur. Finally, we have used long-term average prices for each of the crops simulated; risk associated with price fluctuations amongst these are not considered here and the shifts in the relative prices of these crops is likely to shift the relative profitability of sequences.

**Relative performance of common crop sequences**

None of the 18 crop sequences simulated here performed best against all systems attributes. There were important trade-offs between crop sequence profitability, production risk, water capture and utilisation and long-term risks amongst the various crop sequences. Figure 1 illustrated the relative performance against 11 different attributes of the farming system for 6 common crop sequences at the 3 locations, Cecil Plains, Goondiwindi and Mungindi. From this there are some evident correlations between key attributes:

- Sequences which transpired a higher % of rainfall also performed better in terms of fallow efficiency and had fewer losses to drainage and runoff. They also performed better in terms of maintaining soil carbon reserves. Conversely sequences with less rainfall used by crops had lower fallow efficiencies, more losses to drainage and run-off and depleted soil carbon more rapidly.

- Systems performing poorly in terms of risk for propagating *P. thornei*, were also low ranked in terms of risks of developing herbicide resistant weed populations, and vice versa.
Figure 1. Relative performance of 7 common crop sequences at (a) Cecil Plains, (b) Goondiwindi, (c) Mungindi against several systems attributes. The point where the line for each sequence listed crosses each axis indicates the relative performances compared to all 20 simulated crop sequences. If the line is the closest to the centre, the crop sequence performed the worst for that attribute; if the line is on the outside it performed the best for that attribute.
The relative performance of crop sequences shifts with the environment. A benchmark of a wheat-wheat-chickpea sequence is included at each location for comparison. It is clear that this sequence performs well against many attributes at Mungindi, but has high future risks for developing soil-borne pathogen and weed problems. Other crop sequences clearly outperformed the WxWxCh sequence at Cecil Plains and alternatives involving summer crops were available at Goondiwindi which had similar profitability.

Below we explore in more detail many of these performance attributes amongst the 18 simulated crop sequences at the 3 locations.

**Sequence water-use efficiency**

Across all locations, crop sequence had little if any effect on the amount of rain lost to evaporation – this was typically about 50-60 % of rain that falls; it is constant and difficult to change (Figure 2). The rain not lost as evaporation was either transpired (i.e. used by the crop) or was lost as runoff or drainage; the balance of these two was significantly influenced by the crop sequence. Crop sequences with high crop intensity had the highest percentage of transpiration and hence had the lowest losses, while sequences with lower crop intensity had lower % of rainfall transpired with the rest of the water being lost as runoff or drainage.

The amount of rainfall transpired by crops, or conversely the proportion to time in fallow, were found to be critical drivers of water-use-efficiency and average sequence gross margin (i.e. the average annual GM over the full crop sequence). Figure 3 shows the different relationships at each location between average sequence gross margin (GM) and rainfall transpired (bottom) or proportion of time in fallow (top) for the full set of crop sequences.

- At Cecil plains (Fig 3a), crop sequences with less time in fallow had higher average gross margins and as fallow increases the average sequence GM decreases. Despite the potential for higher crop intensity to increase risk, at Cecil Plains the GM in the worst 20% of sequences also declined as the time in fallow increased – that is, there was no substantial benefits for avoiding downside risks from longer fallow periods. The mix of crops in the sequence had little impact on the average sequence GM (this was most affected by proportion fallow), but did have some effect on managing risk in poor years.

- At Goondiwindi (Fig 3b), there was also a clearly higher average sequence GM in sequences with increasing crop transpiration and hence average GM declines as time in fallow increased. However, this relationship was less steep than at Cecil Plains. The GM in the worst 20% of years was not closely related to the time in fallow, with some sequences having lower downside risk compared to others with similar crop intensity. Like Cecil Plains for average GM the mix of crops in the sequence was less important than crop intensity, but large differences were evident between sequences for managing risk in poor years.

- At Mungindi the relationship between crop transpiration, or proportion of time in fallow, with average sequence GM was weak. That is, there was only a slight effect of time in fallow and crop transpiration on average GM of the sequences, the sequence of crops grown was more critical. At the same time the gross margin in the worst 20% of years was better in sequences that had more fallow. This means that sequences with higher crop intensity do not necessarily result in higher average GM and comes with greater risk.
Figure 2. Proportion of rainfall that is transpired by crops (green), lost as runoff or drainage (blue) and evaporated (orange) in 18 crop sequences at 3 locations in southern Queensland.
Figure 3a. Cecil Plains: Relationships between time in fallow (top) and average sequence gross margin (GM) ($/ha/yr; top) or downside risk ($/ha/yr in worst 20% of years; middle) and crop transpiration (mm/yr) with average sequence GM (bottom) across 18 simulated crop sequences.
Figure 3b. Goondiwindi: Relationships between time in fallow (top) and average sequence gross margin (GM) ($/ha/yr; top) or downside risk ($/ha/yr in worst 20% of years; middle) and crop transpiration (mm/yr) with average sequence GM (bottom) across 18 simulated crop sequences.
Figure 3c. Mungindi: Relationships between time in fallow (top) and average sequence gross margin (GM) ($/ha/yr; top) or downside risk ($/ha/yr in worst 20% of years; middle) and crop transpiration (mm/yr) with average sequence GM (bottom) across 18 simulated crop sequences.
Evaluating the water-use-efficiency of the whole crop sequence is important as it does not just consider the conversion of this available soil water and in-crop rainfall into grain product (crop water-use-efficiency) but also integrates the accumulation of soil water from rainfall during fallows (fallow-use-efficiency). Because of the range of crops grown and their different value, gross crop returns (i.e. sum of yield x price) or gross margin per hectare are used to calculate WUEprofit. Below we provide some indicative benchmarks for sequence water-use-efficiency for the crop sequences at the 3 locations in southern Queensland (Table 3). This shows a significant difference in maximum and typical range for water-use-efficiency of the crop sequences between locations.

Table 3. Average water use efficiency benchmarks for crop sequences ($/ha/mm rain) at 3 locations in southern Queensland

<table>
<thead>
<tr>
<th>WUEprofit</th>
<th>Cecil Plains</th>
<th>Goondiwindi</th>
<th>Mungindi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross returns ($/ha/mm)</td>
<td>Max: 2.0</td>
<td>1.4</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td>Typical range: 1.4 - 1.7</td>
<td>1.0 - 1.2</td>
<td>1.0 - 1.2</td>
</tr>
<tr>
<td>Gross margin ($/ha/mm)</td>
<td>Max: 1.20</td>
<td>0.60</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>Typical range: 0.85 - 1.0</td>
<td>0.45 - 0.50</td>
<td>0.35 - 0.40</td>
</tr>
</tbody>
</table>

Variability in gross margin and risk of failed crops

Figure 4 shows the variation in sequence gross margin for the different crop sequences at each of the 3 locations. Note this variability is less than would be observed when considering individual crops, because the sequences includes several years which include both good and bad years that offset each other, and a diversity of crops that are grown across these years. Hence, longer crop sequences and those with a greater diversity of crops, particularly growing a mix of summer and winter crop had lower variability in gross margin.

Crop sequences with higher variability were those that had a high probability of unprofitable or failed crops (i.e. a negative GM), shown in Figure 5. At all locations, sequences with regular long-fallows had a much lower frequency of failed crops, though at Cecil Plains this reduction was only small. The frequency of failed crops was much lower at Cecil Plains, but at Goondiwindi and Mungindi more aggressive crop sequences with higher crop intensity had higher frequencies of failed crops. Sequences with a particularly high frequency of failed crops were those involving a chickpea double crop (e.g. SChxW, SChxWMgx); at Goondiwindi and Mungindi around 40% and 60% of chickpeas grown as double crops in the sequence did not produce a positive gross margin. Crop sequences involving double crops of mungbean, were also risky with about 30% and 40% of these crops failing at Goondiwindi and Mungindi, respectively. At all locations sequences where the sorghum crops were grown after a short fallow had a higher frequency of failure than those proceeded by a long-fallow (from a previous winter crop), though this was much lower at Cecil plains than at Goondiwindi or Mungindi.
Figure 4. Variability in sequence gross margins ($/ha/yr) for 18 crop sequences at 3 locations in southern Queensland. Light shaded boxes indicate 25th - 50th percentile, dark shaded boxes indicate 50th – 75th percentile and bars the 95th and 5th percentile years. Table 1 provides price and cost assumptions used.
Figure 5. Frequency of crop failure, that is a crop with a negative gross margin, for 18 crop sequences at 3 locations in southern Queensland. Critical crop yields for each crop used are provided in the legend.
Crop sequence consequences for root-lesion nematodes and herbicide resistance risk

Table 4 categorizes the various crop sequences according to their predicted risk for propagating root lesion nematodes. The key results are:

- Sequences with low or negligible risk of propagating *P. thornei* are those that have 2.5 – 3 years phase without a host plant, including crops of sorghum and/or fallow.
- A single sorghum crop in a system dominated by wheat and chickpeas will slow the rate of build-up but does not prevent build-up of nematodes.
- Resistant winter crops (e.g. canola) are required to reduce risks in winter-dominated sequences. Data not shown here.
- Several crop sequences in the lower risk categories that have only a small opportunity cost compared to the crop sequence with the highest average GM. If losses of around $100/ha or 0.5 t/ha from nematodes then alternative ‘low-risk’ rotations could provide alternatives.

Table 4. Estimated shadow costs (i.e. difference in average GM from highest returning sequence) for crop sequences that have differing levels of risk of propagating *P. thornei*.

<table>
<thead>
<tr>
<th>Nematode propagation risk</th>
<th>Sequence</th>
<th>Cecil Plains</th>
<th>Goondiwindi</th>
<th>Mungindi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negligible (&lt;1.1)</td>
<td>SxSxSChxx</td>
<td>-101</td>
<td>-76</td>
<td>-53</td>
</tr>
<tr>
<td></td>
<td>SxSxSMgx</td>
<td>-189</td>
<td>-59</td>
<td>-54</td>
</tr>
<tr>
<td></td>
<td>SxSxSChxxWxx</td>
<td>-260</td>
<td>-83</td>
<td>-62</td>
</tr>
<tr>
<td></td>
<td>SxSxMgWxx</td>
<td>-188</td>
<td>-3</td>
<td>-27</td>
</tr>
<tr>
<td></td>
<td>SxSxSChxxWxx</td>
<td>-144</td>
<td>-68</td>
<td>-68</td>
</tr>
<tr>
<td>Low (1.1-1.25)</td>
<td>SxxWxWxx</td>
<td>-332</td>
<td>-130</td>
<td>-106</td>
</tr>
<tr>
<td></td>
<td>SxSChxWxx</td>
<td>-139</td>
<td>-82</td>
<td>-80</td>
</tr>
<tr>
<td></td>
<td>SxxChxWxx</td>
<td>-277</td>
<td>-97</td>
<td>-62</td>
</tr>
<tr>
<td></td>
<td>WxxxChxxx</td>
<td>-436</td>
<td>-149</td>
<td>-75</td>
</tr>
<tr>
<td></td>
<td>SxxSfSbxWxChxWxx</td>
<td>-66</td>
<td>-40</td>
<td>0</td>
</tr>
<tr>
<td>Moderate (1.25-1.5)</td>
<td>SxxWxCChxWxx</td>
<td>-218</td>
<td>-80</td>
<td>-50</td>
</tr>
<tr>
<td></td>
<td>SChxWxx</td>
<td>-130</td>
<td>-84</td>
<td>-65</td>
</tr>
<tr>
<td></td>
<td>SxxChxWxCChxWxx</td>
<td>-221</td>
<td>-78</td>
<td>-46</td>
</tr>
<tr>
<td></td>
<td>SxxChxWxFbxWxx</td>
<td>-240</td>
<td>-94</td>
<td>-61</td>
</tr>
<tr>
<td></td>
<td>SxxWxCChxWMgx</td>
<td>-118</td>
<td>-46</td>
<td>-33</td>
</tr>
<tr>
<td>High (&gt;1.5)</td>
<td>SChxWMgx</td>
<td>-39</td>
<td>-62</td>
<td>-104</td>
</tr>
<tr>
<td></td>
<td>SxMgWxCh</td>
<td>0</td>
<td>0</td>
<td>-28</td>
</tr>
<tr>
<td></td>
<td>xWxCChxWMgx</td>
<td>-182</td>
<td>-66</td>
<td>-49</td>
</tr>
<tr>
<td></td>
<td>xWxCxWCh</td>
<td>-165</td>
<td>-67</td>
<td>-46</td>
</tr>
</tbody>
</table>

Table 5 categorizes the various crop sequences according to their predicted risk for developing glyphosate resistant weed populations. The key results found were:

- Highest risks were for summer weeds and hence the level of risk were lower at Mungindi due to the lower frequency of summer rainfall events.
- Sequences with lowest risk were those that had a mixture of winter and summer crop phases and crop frequencies of around 1 crop per year.
- Highest risk crop sequences were those that were dominated by winter crops, with high requirements for summer fallow herbicides placing high selection pressure on summer weeds.
Again, several crop sequences in the lower risk categories have only a small opportunity cost compared to the crop sequence with the highest average GM. In particular, crop sequences with higher crop intensity performed better in terms of glyphosate resistance risk and had higher long-term average gross margins.

Table 5. Estimated shadow costs (i.e. difference in average GM from highest returning sequence) for crop sequences that have differing levels of developing herbicide resistance in weeds.

<table>
<thead>
<tr>
<th>Herbicide resistance risk</th>
<th>Sequence</th>
<th>Cecil Plains</th>
<th>Goondiwindi</th>
<th>Mungindi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>SxSxMgWxx</td>
<td>-188</td>
<td>-3</td>
<td>-27</td>
</tr>
<tr>
<td></td>
<td>SxSxSChWxx</td>
<td>-144</td>
<td>-68</td>
<td>-68</td>
</tr>
<tr>
<td></td>
<td>SxSChWxx</td>
<td>-139</td>
<td>-82</td>
<td>-80</td>
</tr>
<tr>
<td></td>
<td>SxSxSxxWMgx</td>
<td>-189</td>
<td>-59</td>
<td>-54</td>
</tr>
<tr>
<td></td>
<td>SxSxSxxChxWxx</td>
<td>-260</td>
<td>-83</td>
<td>-62</td>
</tr>
<tr>
<td>Moderate</td>
<td>SxMgWxCh</td>
<td>0</td>
<td>0</td>
<td>-28</td>
</tr>
<tr>
<td></td>
<td>SChxWxx</td>
<td>-130</td>
<td>-84</td>
<td>-65</td>
</tr>
<tr>
<td></td>
<td>SxSxSChxx</td>
<td>-101</td>
<td>-76</td>
<td>-53</td>
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<td>-218</td>
<td>-80</td>
<td>-50</td>
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<tr>
<td></td>
<td>SChxWMgx</td>
<td>-39</td>
<td>-62</td>
<td>-104</td>
</tr>
<tr>
<td></td>
<td>SxSxSFbxWxChxWxx</td>
<td>-66</td>
<td>-40</td>
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<td>-118</td>
<td>-46</td>
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<tr>
<td></td>
<td>SxxChxWxx</td>
<td>-277</td>
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<td></td>
<td>SxxWxWxx</td>
<td>-332</td>
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<tr>
<td>High</td>
<td>SxxChxWxChxWxx</td>
<td>-221</td>
<td>-78</td>
<td>-46</td>
</tr>
<tr>
<td></td>
<td>SxxChxWxFbxWxx</td>
<td>-240</td>
<td>-94</td>
<td>-61</td>
</tr>
<tr>
<td></td>
<td>xWxChxWMgx</td>
<td>-182</td>
<td>-66</td>
<td>-49</td>
</tr>
<tr>
<td></td>
<td>WxxxCxChxxx</td>
<td>-436</td>
<td>-149</td>
<td>-75</td>
</tr>
<tr>
<td></td>
<td>xWxWxCh</td>
<td>-165</td>
<td>-67</td>
<td>-46</td>
</tr>
</tbody>
</table>

Changes in soil carbon

Most of the crop sequences simulated saw soil carbon levels decline over the period of the simulation. Figure 4 compares the long-term simulated changes in soil carbon between 5 differing crop sequences at the 3 locations. The critical result here was that crop sequences with a higher frequency of crops maintained soil carbon at higher levels, and conversely longer periods in fallow reduced soil carbon more rapidly. Winter cereals also appeared to be better at maintaining soil carbon levels that sorghum, but this was a less important effect. The differences between sites were related to the soil characteristics used in the simulations more than their association with climatic conditions – for example the soil used at Goondiwindi had high initial levels of labile soil carbon and hence saw faster and larger losses than the soils used for Dalby and Mungindi which had lower initial labile soil carbon.
Figure 6. Change in labile soil carbon (t/ha) over 110 simulated years for a selection of crop sequences varying in cropping intensity (SChxWMgx = 1.3 crops/yr; xWxWxCh and SxSChxWxx = 1.0 crops/yr; SxxWxChxWxx = 0.8 crops/yr; and SxxChxWxx = 0.75 crops/yr) at 3 locations in southern Queensland.
Acknowledgements

The research undertaken as part of CSA00050 is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. We would also like to thank the growers and advisors involved in meetings to understand the range of crop sequences being applied across the northern grain zone.

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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, DN 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
www.satamap.com.au
www.pct-ag.com
www.pasource.com
www.geosys.com

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Growing mungbeans successfully: plant population, row spacing, varieties yields and nitrogen fixation

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Mungbeans, soybeans, agronomy, row spacing, population

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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>
<thead>
<tr>
<th>Starting PAW (mm)</th>
<th>Grain Yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Drier 10% years</td>
</tr>
<tr>
<td>170</td>
<td>1298</td>
</tr>
<tr>
<td>110</td>
<td>927</td>
</tr>
<tr>
<td>55</td>
<td>549</td>
</tr>
</tbody>
</table>

*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 nitrate. 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/m², 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 25 plants/m². 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](image)

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 II. There is an effect on Crystal 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)

<table>
<thead>
<tr>
<th>Row space (m)</th>
<th>0.25</th>
<th>0.5</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>WUE</td>
<td>11.1</td>
<td>9.7</td>
<td>8.9</td>
</tr>
</tbody>
</table>

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.
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/m² and a flat yield response in 20, 30 and 40 plants/m². 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/m².

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 Crystal and Jade-AU was different with changes in row spacings, however Satin II 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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Management of the major mungbean diseases in Australia

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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)

<table>
<thead>
<tr>
<th>Genotype</th>
<th>Pt 1</th>
<th>Pt 2</th>
<th>Pt 3</th>
<th>Pt 4</th>
<th>Pt 5</th>
<th>Pt 6</th>
<th>Pt 7</th>
<th>Pt 8</th>
<th>Pt 9</th>
<th>Pt 10</th>
<th>Pt 11</th>
<th>Pt 12</th>
</tr>
</thead>
<tbody>
<tr>
<td>AusTRC 321818</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>M773</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>OAEM58-62</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>ATF2074</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>AusTRC 324872</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Crystal(1)</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
</tbody>
</table>

**Frequency isolated (%)**

| (n=81)       | 9.9  | 40.7 | 2.5  | 23.5 | 6.2  | 4.9  | 1.2  | 4.9  | 2.5  | 1.2   | 1.2   | 1.2   |

Tan spot

Tan spot (also known as bacterial scorch and wilt) is caused by the bacterium, *Curtobacterium flaccumfaciens pv. flaccumfaciens*. Symptoms in seedlings, often resulting from seed borne inoculum, can be seen on the 1<sup>st</sup> or 2<sup>nd</sup> 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 through 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 (>30<sup>°</sup>) 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.

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\textsuperscript{b} 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\textsuperscript{b} and Crystal\textsuperscript{b} 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

<table>
<thead>
<tr>
<th><em>Fusarium</em> species</th>
<th>Frequency isolated (%) (n=61)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>F. solani</em></td>
<td>39.3a</td>
</tr>
<tr>
<td><em>F. oxysporum</em></td>
<td>39.3a</td>
</tr>
<tr>
<td><em>F. moniliforme</em> species complex</td>
<td></td>
</tr>
<tr>
<td><em>F. incarnatum-equisetti</em> species complex</td>
<td>9.8b</td>
</tr>
<tr>
<td><em>F. proliferatum</em></td>
<td>3.3b</td>
</tr>
</tbody>
</table>

*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

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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Fungicide management of mungbean powdery mildew

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Key words
Mungbean, powdery mildew, management, fungicide

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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(1) has the highest level of resistance to P. fusca (moderately susceptible; MS), with all other Australian varieties apart from cv. Green Diamond(1) 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). Sprayer 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](image_url)

**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(1) under different fungicide spray regimes in 2015 and 2016 trials at different localities

<table>
<thead>
<tr>
<th>Treatment (total no. of sprays)</th>
<th>2015</th>
<th>2016</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HRF</td>
<td>HRF</td>
</tr>
<tr>
<td>4/5 weeks +1 spray 14 days later (2)</td>
<td>-</td>
<td>30.4*</td>
</tr>
<tr>
<td>1/3 up plant + 1 spray 14 days later (2)</td>
<td>3.3</td>
<td>28.8*</td>
</tr>
<tr>
<td>First sign + 1 spray 14 days later (2)</td>
<td>6.6</td>
<td>28.7*</td>
</tr>
<tr>
<td>4/5 weeks + 2 sprays 14 days apart (3)</td>
<td>9.5</td>
<td>27.6*</td>
</tr>
<tr>
<td>First spray 4/5 weeks after emergence (1)</td>
<td>-</td>
<td>22.6</td>
</tr>
<tr>
<td>First spray at first sign of PM (1)</td>
<td>-3.3</td>
<td>17.9</td>
</tr>
<tr>
<td>First spray when PM is 1/3 up plant</td>
<td>0.9</td>
<td>-</td>
</tr>
</tbody>
</table>

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 days after emergence.
treatment being applied earlier (35 dae) and the 1/3 canopy treatment later (57 dae). By contrast, in the 2016 trial at HRF, powdery mildew appeared early, with the first spray for the first sign of powdery mildew being applied at 24 dae and the first sprays for the other two treatments both being applied at 34 dae.

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

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

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

$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
Acknowledgements

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Understanding & managing N loss pathways

Mike Bell (QAAFI), Graeme Schwenke (NSW DPI) and David Lester (DAF Qld)

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

NANORP codes
0120.027; 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, sideways or upwards movement. Downward movement of nitrate [\(\text{NO}_3^-\)] 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. Fillyery 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.

Nitrates 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\(_2\)O, and direct measurement of denitrification losses in the field has so far only been able to quantify losses as N\(_2\)O. There are reports in the literature of the ratio of losses as N\(_2\):N\(_2\)O 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\(_2\)O losses at fertiliser N rates delivering maximum yield of 1-2 kg N\(_2\)O-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 \(^{15}\text{N}\) 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\(_2\)O 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$_2$O can be used to estimate the ratio of N$_2$ to N$_2$O 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$_2$O 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 [\(\text{NH}_4^+\)] to nitrate [\(\text{NO}_3^-\)] 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 [\(\text{N}_2\)]. The greenhouse gas nitrous oxide [\(\text{N}_2\text{O}\)] 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 [\(\text{N}_2\), \(\text{N}_2\text{O}\)] are not retained by soil adsorption, whereas ammonia [\(\text{NH}_3\)] 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 \(\text{N}_2\text{O}\) emissions by an average of 85% (range: 65–97%) compared to uncoated urea. Despite the reductions in \(\text{N}_2\text{O}\) 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 (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 (\(\text{N}_2 + \text{N}_2\text{O}\)) 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
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.

![Diagram showing N rates and losses](image)

**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 (N₂ + N₂O) 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 N₂O-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 N₂O-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 ¹⁵N 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 NO₃-N in the soil profile after crop harvest.

Despite 65-70% reduction in annual N₂O 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 (Irongate). 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 N₂O 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, N₂O emissions and N losses was also consistent with the ley pasture trial in 2012/13 – fertiliser N requirements were less and N₂O emissions intensity was lower (by 25%) in the legume systems compared to back to back sorghum.
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 N₂O emissions during the growing season and the emissions intensity (kg N₂O 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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The impact of various organic amendments on yield and soil properties

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Key words
Organic amendment, compost, manure

Take home message
• Regular, long term use of organic amendments can increase crop yields
• Phosphorus and potassium nutrient levels can be increased over time using organic amendments

Background and Aims
Despite a significant research effort aimed at clarifying the real impact of organic amendment (composts and manures) use, success has been limited. The complexity of the products, access to consistent and uniform products, different use and application methods, difficulty in measuring products and their impacts on crops as well as the length of time required to assess their impacts in terms of change in soil health and fertility, add high levels of variability to trials and reduce the consistency and significance of results. However, the uptake and use of these products by growers has continued to increase based mainly on field observations, practical experience and grower interaction.

Numerous research studies have shown that organic amendments can not only improve the nutrient status of soils but also their physical properties and organic carbon levels. However, these studies have tended to demonstrate soil benefits when application rates are much higher than arelogically and financially sensible to the majority of growers. Benefits associated with low application rates have been much more variable and unreliable. Despite the significant research effort, there are currently few general guidelines available to farmers in regards to their use.

In 2010 a large scale soil amendment farmer trial was established near Cecil Plains to replicate current farmer practice and to explore various compost and manure to determine the longer term effects of these practices.

Trial Method
The trial was established on the property “Pittwater” in Cecil Plains. The randomized strip trial included six treatments with five replications. Each plot was 0.53 hectare in size. The block was surface irrigated on 2 metre beds. Treatments were (1) zero amendment (2) gin trash compost (3) raw poultry manure (4) poultry manure compost (5) feedlot manure and (6) feedlot manure compost.

5 tonne of product was applied prior to each crop rotation and worked in. All other cultural practices were uniformly applied across the trial including nitrogen fertilising and starter fertiliser applications. Five crops (2011-12 Maize, 2012-13 Cotton, 2013-14 Cotton, 2014-15 Cotton, 2015 Wheat) were grown over the trial period, yields recorded and soil samples taken in May of each year.
Results

Yields

No significant difference for yield was identified for the maize crop in 2011-12 or cotton crops in 2012-13 and 2014-15, however a significant result was identified in the 2013-14 cotton crop. This crop was significantly impacted by flooding / waterlogging during the vegetative and early flowering period. It appears that the composted feedlot manure, feedlot manure and composted poultry manure treatments were able to respond more quickly following the waterlogging impacts. A significant 8.2% increase in yield for the composted feedlot manure treatment and a 7.5% yield increase for the raw feedlot manure were recorded from the nil treatment. A 4.3% yield increase for the composted poultry manure treatment was also recorded but this wasn’t significantly different from the nil treatment.

A significant yield difference was also identified in the wheat crop 2015. Composted feedlot manure (7.9% or average 377 kg/ha), feedlot manure (13.6% or average 645 kg/ha) and composted poultry manure (12.2% or average 580 kg/ha) and gin trash grower compost (5.9% or average 282 kg/ha) were significantly higher yielding than the nil treatment.

Table one summarises average yield results for all crops over the trial period and levels of significant differences. Although significant yield differences were not identified across all years and treatments, responses appear to be constantly higher than the nil treatment. Figures 1 and 2 show significant yield differences in cotton in the 2013/14 season, and in wheat in 2015.

Table 1. Average yields for all crops over the 5 year period of the trial. Averages with the same letter are not significantly different at the 5% level. NS = not significant.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Average Maize Yields (t/ha) 2011</th>
<th>Average Cotton Yields (bales/ha) 2012/13</th>
<th>Average Cotton Yields (bales/ha) 2013/14</th>
<th>Average Cotton Yields (bales/ha) 2014/15</th>
<th>Average Wheat Yields (t/ha) 2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Nil Treatment</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Gin Trash Compost rate @ 5t/ha</td>
<td>7.546</td>
<td>9.88</td>
<td>7.38a</td>
<td>11.87</td>
<td>4.747a</td>
</tr>
<tr>
<td>3 Raw Poultry/barn Litter manure @ 5 t/ha</td>
<td>7.723</td>
<td>10.11</td>
<td>7.54a</td>
<td>11.67</td>
<td>5.029ab</td>
</tr>
<tr>
<td>4 Composted poultry/barn litter @ 5 t/ha</td>
<td>7.767</td>
<td>9.87</td>
<td>7.54a</td>
<td>11.98</td>
<td>4.752bc</td>
</tr>
<tr>
<td>5 Raw Feedlot Manure @ 5 t/ha</td>
<td>7.755</td>
<td>10.34</td>
<td>7.69ab</td>
<td>11.91</td>
<td>5.327c</td>
</tr>
<tr>
<td>6 Composted Feedlot Manure @ 5 t/ha</td>
<td>7.794</td>
<td>10.12</td>
<td>7.98b</td>
<td>11.51</td>
<td>5.392c</td>
</tr>
<tr>
<td></td>
<td>7.799</td>
<td>9.85</td>
<td>7.93b</td>
<td>12.4</td>
<td>5.124c</td>
</tr>
</tbody>
</table>

NS = not significant.
Soil Properties

Changes in several different soil properties have been identified over the trial period in both the 0-10cm and 10-30cm soil samples. Phosphorus and potassium (Colwell) levels for the 0-10cm soil depth showed significant increase over the trial period (figure 3 and 4) for all treatments. There were also significant differences between treatments.
Figure 3. Average Phosphorus levels 0-10cm soil depth over the trial period.

Figure 4. Average Potassium levels 0-10cm soil depth over the trial period.

Total organic carbon was trending up in the 0-10cm soil samples but was not significant (Figure 5) within the five year time frame. Soil tests were variable, but the composted feedlot manure and composted gin trash appear to have had the greater response. The increasing trend line for organic carbon appears to be more consistent in the 10-30cm soil samples however there wasn’t a
significant difference between treatments but again the compost treatments appear to be having a greater impact.

![Average Organic Carbon Levels 0-10cm](image)

**Figure 5.** Average organic carbon levels 0-10cm soil layer.

**Discussion**

The regular and continuous addition of organic amendments to a cropping system has shown to increase crop yields as well as improve soil nutrient levels. Yields for all treatments were generally greater than the nil treatment across all crops over the period of the trial. Significant yield responses to composted feedlot manure, composted poultry manure and raw feed lot manure were produced in cotton 2103/14. These responses followed a very significant flooding and waterlogging event. This potentially indicates that the use of these amendments provided the soil with the resilience to be able to recover more quickly and better meet crop nutrient demand after this event. Further research would be required to confirm this outcome. There were also significant increases in 2015 wheat yields for most organic amendment treatments. The result supports the understanding that the benefits of using organic amendments (at commercial levels) are not immediate and regular, long term applications of organic amendments is required to increase yields and have a positive impact on soil nutrient status.

The use of composted feedlot manure and composted poultry manure has significantly increased phosphorus and potassium nutrient levels in the soil, particularly in the 0-10cm layer. However these nutrients increased for all treatments (although at a much lower level) and may be demonstrating nutrient stratification under a minimum tillage system. Further research would be required to confirm this outcome.

The impact of the treatments on organic carbon is inconclusive however there appears to be an increasing trend in both the 0-10 cm and 10-30 cm soil depths. Given that 25 tonne of each product has been applied over the 5 years this is probably understandable. Tracking changes in soil carbon is difficult as has also been found by another GRDC project (DAQ00182) investigating the impact different farming systems have on soil organic matter and carbon levels. The aim of this trial is to determine the impact on soil carbon using feedlot manure when compared to granular fertiliser within a dryland farming system. This trial began in 2013. Although data is not presented in this paper it is interesting to note that manure applied at 5 t/ha every three to four years compared to granular fertiliser (aimed to supply similar level of nutrients as the manure) has had no impact on
carbon to date and crop yields have appeared to be responding to the amount of nutrient rather than whether it was applied as manure or granular fertiliser. This trial will continue to be monitored.

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Fallow Management of Grass Weeds

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Key words
Awnless barnyard grass, feathertop Rhodes grass, liverseed grass, button grass

GRDC code
NGA00004: GRDC Grower Solutions for Northern NSW and Southern Qld

Take home messages

- Effective fallow management of key summer grass weeds - relying on glyphosate alone – is increasingly unsustainable
- Need to incorporate a range of other tactics including double-knocks and residual herbicides to assist management
- Knockdown options can be effective but heavily rely on preplanning and being able to target small growth stages
- Suitable tactics will vary by weed species but in all cases there is a need to utilise as many non-chemical approaches as practical
- Individual paddock rotations may need to change to enable use of effective residual chemistry in fallow or in-crop

The issue

Grass control in the summer fallow has become an increasingly difficult and expensive component of many northern farming systems in recent years. At least part of the reason has been due to the heavy reliance on glyphosate. This has selected weed species that were naturally more glyphosate tolerant or selected for glyphosate resistant populations.

Although this paper will focus on chemical management of these weeds, it is clear we need to better understand and employ other weed management tactics to successfully and economically control these significant threats to cropping.

1. Awnless barnyard grass (*Echinochloa colona*)

Awnless barnyard grass (ABYG) has been a major summer grass issue for many years. It is a difficult weed to manage for at least three key reasons:

- Multiple emergence flushes (cohorts) each season
- Easily moisture stressed, leading to inconsistent knockdown control
- Glyphosate resistant populations are becoming widespread

Resistance levels

Prior to summer 2011/12, there were 21 cases of glyphosate resistant ABYG. Collaborative survey work was conducted by NSW DPI, DAF Qld and NGA in summer 2011/12 with a targeted follow-up in 2012/13. Agronomists from the Liverpool Plains to the Darling Downs and west to areas including Mungindi collected ABYG samples that were tested at the Tamworth Agricultural Institute.

The key outcome was that the number of ‘confirmed’ glyphosate resistant ABYG populations had nearly trebled. Selected populations were also evaluated in a glyphosate rate response trial. This showed that some of these populations were still only suppressed when sprayed with 12.8 L/ha.
Additionally it has been found recently that the glyphosate ‘resistance’ expression is increased when conditions are warmer i.e. glyphosate resistant populations are even ‘more resistant’ under hotter temperatures.

The days of solely relying on glyphosate for ABYG control are behind us.

Residual herbicides (fallow and in-crop)
There are a range of active ingredients registered in either summer crop e.g. metolachlor (e.g. Dual Gold®) and atrazine or in fallow e.g. imazapic (e.g. Flame®) that provide useful management of ABYG. The new fallow registration of isoxaflutole (e.g. Balance®) can provide useful suppression of ABYG but has stronger activity against other problem weed species. Few, if any, residual applications will provide complete control. However they are important tools that need to be considered to reduce the population size exposed to knockdown herbicides as well as to alternate the herbicide chemistry being employed. Use of residuals together with camera spray technology (for escapes) can be a very effective strategy in fallow.

Double-knock control
This approach uses two different tactics applied sequentially. In reduced tillage situations, it is frequently glyphosate first followed by a paraquat based spray as the second application or ‘knock’. Trials have shown that glyphosate followed by paraquat can give effective control even on glyphosate resistant ABYG but timing and stress are important. Ensure glyphosate rates are robust. Another strategy can be to use paraquat as both ‘knocks’, particularly for populations where glyphosate effectiveness has been poor.

Timing of paraquat application as the second “knock” for ABYG control has generally proven flexible. The most consistent control is obtained from a delay of ~3-5 days, which also can allow for lower rates of paraquat to be used. Longer intervals may be warranted when ABYG is still emerging at the first application timing, shorter intervals are generally required when weed size is larger or moisture stress conditions are expected. High levels of control can still be obtained with larger weeds but paraquat rates will need to be increased to 2.0 or 2.4 L/ha.

Knockdown control
A number of Gp A herbicides eg haloxyfop (e.g. Verdict®) and eg clethodim (e.g. Select®) are effective on ABYG but are only registered in summer crops such as mung beans. NB Gp A herbicides are generally more sensitive to weed moisture stress or size. Application to large or mature weeds can result in poor efficacy.

Key points ABYG
- Glyphosate resistance is widespread. Tactics against this weed must change from glyphosate alone
- Utilise residual chemistry wherever possible and aim to control ‘escapes’ with camera spray technology
- Try to ensure a double-knock of glyphosate followed by paraquat is used on one of the larger early summer ABYG flushes
- Utilise Gp A herbicides in crop and aim for strong crop competition
- Cultivation can be very effective on this weed but multiple emergences are likely each summer season
2. **Feathertop Rhodes grass (Chloris virgata)**

Feathertop Rhodes grass (FTR) started to become an important weed in southern Qld and northern NSW in ~2008. It is a small seeded species that germinates on, or close to, the soil surface. It has rapid early growth rates and easily becomes moisture stressed.

Some likely reasons for the difficulty of managing this weed are:

- It is a species with higher levels of natural tolerance/resistance to glyphosate and has been selected by glyphosate dominated fallow/roadside management strategies
- It is frequently poorly controlled by paraquat alone or even a double-knock of glyphosate followed by paraquat
- QDAF research showed FTR is one of the first weed species to colonise bare areas and can germinate on smaller rainfall events than many other problem species
- Minimum/zero tillage practices are likely to have contributed to the threat posed by this weed as cultivation or seed burial (to depths of 2cm or deeper) can be effective management tools

Three characteristics that can be useful to assist FTR control are that:

1. Seed viability does not appear to be improved by seed burial (in contrast to many other weed species)
2. Seed longevity is short (~12 months). If effective control strategies can be used for a period of ~12-18 months, the seedbank of FTR can be rapidly run-down.
3. New incursions of FTR are often in well-defined patches (in contrast to weeds such as common sowthistle). Aggressively treatment of these patches can prevent whole of paddock blow-outs

**Residual herbicides (fallow)**

Evaluation of a wide range of residual herbicides has shown a number of promising candidates for FTR management. Currently the only registered product for residual control in fallow is Balance®. Additional product registrations for fallow use are being sought.

**Residual herbicide (in-crop)**

Utilising residual herbicides in-crop will allow the use of additional weed management approaches. In-crop use benefits from:

- Crop competition
- Change in crop being grown and available herbicide options
- Herbicide application often under more favourable conditions than in fallow or where a level of mechanical incorporation occurs
- ‘Increased disturbance’ planting may provide benefits for FTR management via weed seed burial or removal of early weed emergence

Currently there are no registrations for residual control of FTR in-crop. Residual herbicide strategies for awnless barnyard grass control (e.g. Dual® Gold, Flame®, trifluralin eg TriflrX® and pendimethalin eg Stomp® Xtra) applied in a range of summer crops have been noted to reduce the emergence of FTR.

FTR is predominantly a summer weed but the first cohort of emergence can occur during the winter crop phase. Screening of herbicides, currently registered for residual control of other weeds, in winter cereal or chickpea production has shown encouraging levels of activity. Residual herbicide
strategies for the control of a range of both grass and broadleaf weeds (e.g. Balance®, Treflan®, Stomp®, Sakura® and terbutylazine eg Terbyne® Xtreme) applied in a range of winter crops have been noted to reduce the emergence of FTR.

Residual herbicides for FTR in non-crop situations

FTR frequently dominates in non-crop areas with a potential for re-infestation of adjacent areas. For non-crop areas, there is a registration for 7L/ha of imazapyr 150g/L (eg Arsenal®).

Knockdown herbicides (in-crop)

The main registrations for knockdown of FTR are from the use of Gp A (grass selective) herbicides in cotton, mungbeans and other broadleaf summer crops.

Double-knock control

Glyphosate followed by paraquat is generally an effective strategy for ABYG management. However the same approach is rarely effective for FTR management. In contrast, a small number of Gp A herbicides (all members of the ‘fop’ class) can be effective against FTR but need to be managed within a number of constraints:

- Although they can provide high levels of efficacy on fresh and seedling FTR, they need to be followed by a paraquat double-knock to get consistent levels of control
- Gp A herbicides have a high risk for resistance selection, again requiring follow up with paraquat
- Many Gp A herbicides have plantback restrictions to cereal crops
- Gp A herbicides generally have narrower growth stage windows for successful use than herbicides such as glyphosate ie Gp A herbicides will generally give unsatisfactory results on flowering and/or moisture stressed FTR
- Gp A herbicides vary in their effectiveness on FTR

A permit (PER12941) is valid until 31/8/2019, in Qld only, for the control of FTR in summer fallow situations prior to planting mungbeans. The permit is for the application of haloxyfop 520 g ai/L formulations (eg Verdict®) at 150-300L/ha followed by paraquat at a minimum of 1.6 L/ha, within 7-14 days after the first application. In addition there has been a recent registration of Shogun® for FTR management in fallow but only when followed by a paraquat double-knock.

Key points

- Glyphosate alone or glyphosate followed by paraquat generally unsatisfactory
- Utilise residual chemistry wherever possible and prepare a plan to control ‘escapes’ e.g. camera spray technology
- Utilise aggressive patch management for new incursions (including manual weeding and chipping) and preferably follow up with residual herbicides over previous patches where weeds may have seeded

Other tactics to consider

- Salvage cultivation is often the most effective and economic tool for mature plants
- Consider (infrequent) strategic cultivations for seed burial (repeated tillage may simply return seeds to the soil surface)
- Burning appears a useful tool where blow outs have occurred in patches or even in larger areas to reduce seed viability
3. Liverseed grass (Urochloa panicoides)

Liverseed grass is another widespread weed in the northern grains region. Unlike ABYG, Liverseed grass is generally noted for a single main emergence flush each season.

Residual herbicides (fallow)

The only product currently registered for residual control in fallow is Flame®. Evaluation of a wide range of residual herbicides has generally shown inconsistent residual control of Liverseed grass (particularly compared to ABYG and FTR).

Residual herbicide (in-crop)

There are a number of residual herbicide options registered for in-crop use eg Dual® Gold, TriflurX®, Stomp® Xtra and imazamox eg Raptor®). A good strategy for paddocks with high seed burdens of liverseed grass seed is to grow crops that allow the use of these residual herbicides. Use of these herbicides in registered winter crops can also assist in liverseed grass management.

Double-knock control

A double knock of glyphosate followed by paraquat is generally an effective option with paraquat followed by paraquat also an option to consider. The paraquat followed by paraquat approach is likely to be more successful particularly on moisture stressed populations.

Knockdown control

A number of Gp A herbicides eg Verdict® and Select® are effective on Liverseed grass but are only registered in summer crops such as mung beans. NB Gp A herbicides are generally more sensitive to weed moisture stress or size. Application to large or mature weeds can result in poor efficacy.

4. Button grass (Doctyloctenium radulans)

Button grass is generally a more localised weed threat than ABYG or liverseed grass. It prefers lighter soils and is often one of the first weeds to emerge after rain events. Button grass often appears as the first weed species to enter moisture stress.

Residual herbicides (fallow or in-crop)

Very restricted range of options. The only product currently registered for residual control in fallow is Flame®. The only product currently registered for residual control in-crop is Stomp® Xtra.

Use of these residuals on small infestations of button grass (eg on sandy ridges) may allow more targeted and timely knockdown applications.

Double-knock control

Trial work in 2015/16 showed a double knock of glyphosate followed by paraquat as an effective option together with paraquat followed by paraquat. Large rate responses were seen to glyphosate alone. It is important to keep the glyphosate rates robust.

There are no currently registered in-crop knockdown options.

Conclusions

Profitability is of course still paramount. The suggestion with these problem weeds is to focus on individual paddocks and adjust rotations to crops that most suit your environmental conditions but also enable the use of effective residual herbicides in the previous fallow or even in crop. Particularly
for FTR, the seed bank appears only short lived and two years of effective management can ensure that paddocks return to full flexibility of rotational choice.

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