MILLMERRAN, QLD
TUESDAY 10
NINDIGULLY, QLD
WEDNESDAY 11
AUGUST 2021

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

GRDC 2021 Grains Research Update Welcome

Welcome.

We at the GRDC understand how challenging the past year has been for all Australians, but we also appreciate how well positioned agriculture has been to respond to and work through the restrictions that have come with this global pandemic.

Across many areas of Queensland and New South Wales, an improvement in seasonal conditions has also provided a much-needed reprieve for growers, advisers, agronomists, researchers and those associated with the grains industry.

With that positive change in circumstances comes a thirst for the latest information and advice from grains research and development – we trust that these GRDC Grains Research Updates will help guide your on-farm decisions this season and into the future.

While COVID-19 has forced temporary changes to our traditional Update locations and audience numbers, these events still offer the high quality, seasonally relevant research, development and extension information you have come to depend on.

We would like to take this opportunity to thank our many research partners, who, like growers and advisers, have gone over and above to continue to work in situations constricted by COVID-19 regulations.

Challenging times reinforce the importance of rigorous, innovative research that delivers genuine gains on-farm. For more than a quarter of a century the GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of the industry.

Sharing the results from this research is a key role of the annual Updates, which are the premier event on the northern grains industry calendar and bring together some of Australia's leading grains research scientists and expert consultants.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers.

For the past five years we have been doing that from regional offices across the country. Through the northern region offices in Wagga Wagga and Toowoomba and a team of staff committed to connecting with industry, we are now more closely linked to industry than ever.

This year we have less people on the ground – as a result of COVID-19 restrictions – but more than ever we are available to listen and engage with you. So if you have concerns, questions or feedback please contact our team directly (details on the back of these proceedings) or email northern@grdc.com.au.

Regards,
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GRAINS RESEARCH & DEVELOPMENT CORPORATION ABN 55 611 223 291

GRDC Grains Research Update
MILLMERRAN

Tuesday 10 August 2021

Millmerran Community & Cultural Centre, 45 Walpole St, Millmerran

Registration: 8:30am for a 9am start, finish 2:50pm

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	
9:10 AM	**Managing mice** • Management and baiting strategies • Population ecology - how long can plagues last and why?	Steve Henry (CSIRO) – via zoom
9:45 AM	**Fall armyworm** • What can we learn from international experience managing FAW • Crop damage and economics • Decision making on insecticides • Using natural enemies • Overwintering - will they survive on the Downs • Resistance update & overlap with *H. armigera* • Specific crop management guidelines.	Melina Miles (DAF Qld) & Phil Armytage (AgBiTech)
10:15 AM	**Discussion session on mice and FAW management**	Graham Boulton (Black Earth Cotton Co) & Angus Dalgliesh (Nutrien Ag Solutions)
10:45 AM	**Morning tea**	
11:15 AM	**High competition sorghum** - how narrow rows and high populations affect crop productivity, water and nutrient use legacies in the farming system	Lindsay Bell (CSIRO)
11:45 AM	**Grain storage** - what's new?	Philip Burrill (DAF Qld)
12:25 PM	**Lunch**	
1:15 PM	**Weed recognition technologies, developments and opportunities for Australian grain production systems**	Craig Baillie (USQ)
1:45 PM	**Optical sprayers** - management optimisation and field experience with their use on robotic platforms	Jeremy Jones (Dalby Rural)
2:15 PM	**Pushing the tech boundary -** Grower experience with optical sprayers on robotic platforms	Elton Petersen ("Traighli")
2:35 PM	**Spray application panel discussion**	
2:50 PM	**Close**	

GRDC Grains Research Update
NINDIGULLY

Wednesday 11 August 2021

Nindigully Hall, Sternes St, Nindigully

Registration: 8:30am for a 9am start, finish 2:35pm

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	
9:10 AM	**Managing mice** • Management and baiting strategies • Population ecology - how long can plagues last and why?	Steve Henry (CSIRO)
9:50 AM	**Fall armyworm management** • Crop damage and economics • Decision making around insecticides • Using natural enemies • Overwintering - will they survive? • Resistance update & overlap with *H. armigera* • Specific crop management guidelines.	Melina Miles (DAF Qld)
10:20 AM	**Cereal diseases** • Step changes in managing crown rot - including a new seed treatment • Seasonal disease update.	Lislé Snyman (DAF Qld)
11:00 AM	**Morning tea**	
11:30 AM	**Sorghum production in western zones** • Row configuration, plant populations and water use efficiency • Pros and cons of early sowing • Establishment in cold soil conditions.	Joe Eyre (UQ)
12:00 PM	**Managing chickpea harvest losses**	Richard Daniel (Northern Grower Alliance)
12:30 PM	**Grower experiences managing chickpea harvest losses**	Luke Walker (South Bunarba Ag)
12:50 PM	**Lunch**	
1:40 PM	**Weed recognition technologies, developments and opportunities for Australian grain production systems**	Craig Baillie (USQ)
2:10 PM	**Pushing the tech boundary -** Grower experience with optical sprayers on robotic platforms	Elton Petersen ("Traighli")
2:35 PM	**Close**	

Contents

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Reducing the impact of mice at critical times of the year

Steve Henry, CSIRO

Key words

mouse plague, monitor stubbles, baiting, residual food

GRDC code

CSP1806-017RTX - Improved surveillance and management options for mice in crops
CSP1804-012RTX - Determining the effectiveness of zinc phosphide rodenticide bait

Take home message

- There is 3 weeks difference between a few mice and a big problem
- Reduce background or residual food to give mice the best chance of finding the bait
- Understand what is happening in your paddocks at critical times of the year for mice and be prepared to bait
- Monitor the effectiveness of your baiting activities.

Mice have been in high numbers in cropping and grazing systems since the start of spring 2020. Northern NSW and parts of southern Queensland have been particularly heavily impacted by the outbreak. Damage has been high in some areas with total losses of some summer crops reported, and loss and contamination of grain and fodder storages.

Mouse numbers are currently highly variable with reports of high numbers through some parts of the northern cropping zone. However, mouse activity has diminished in some areas with the onset of winter and the associated cessation of breeding. This is not cause for complacency, with the likelihood of an average or better than average winter crop, conditions will be favourable for mouse breeding in early spring.

Understanding the level of overwinter survival is critical to reduce mouse damage in the spring of 2021 and ongoing impacts in the summer and autumn of 2022.

Monitoring crops through winter will be critically important to understand mouse numbers. This knowledge will inform baiting activities to minimise damage in winter crops as they ripen in the spring and in the preparation for sowing summer crops in the northern part of the cropping zone and irrigated summer crops in the south.

Stubbles have potential to hide the signs of mouse activity. Walking multiple, 100 metre long by 1 metre wide transects to count active burrows is the best way to get an average estimate of active burrows per 100 square metres. Burrows per 100 square metres can then be multiplied to give burrows per hectare. Rules of thumb can then be applied to estimate of the number of mice per hectare.

Understanding the number of mice per hectare in combination with the rate of reproduction is important to understand the potential for population increase. Many grain producers would assume that they don't have a significant problem if they had 200 mice per hectare but if 100 of those mice give birth to six offspring every 3 weeks, 200 mice become a big problem very quickly.

These dramatic rates of increase, mean that understanding the number of mice in paddocks at the start of the breeding season in early spring as winter crops mature, and in the lead up to sowing, is vital to reducing the potential for damage at these critical times of the year.

In the lead up to sowing, management of residual food is important to improve the chance of effective bait application. Zinc phosphide bait (ZnP) is spread at 1 kilogram per hectare or 22,000 grains per hectare, which equates to three grains per square metre. Pre- and post-harvest grain losses result in significant supply of food for mice. Anecdotal reports of one tonne per hectare loss are not uncommon, resulting in 2,200 grains per square metre. If this residual food is present when bait is spread, it can be difficult for mice to find the bait, and the overall uptake of the bait could be reduced.

Through the stubble phase it is important to reduce the amount of residual food to enhance bait detection and uptake. Spraying out germinations reduces food and conserves soil moisture. If livestock are part of the farming system, use sheep to graze stubbles.

The results of recent laboratory studies undertaken by CSIRO in response to farmers concerns about the effectiveness of ZnP have led to the approval of an emergency permit for the manufacture, supply and use of ZnP bait with a mixing rate of 50 g ZnP/kg of bait. Field trials of this new formulation of bait undertaken in cropping systems near Parkes in central NSW have resulted in promising outcomes of the efficacy of the new bait formulation.

Monitoring stubbles and crops to understand mouse populations and timely action to control mice at critical stages of the stubble and the developing crop are critical to minimising the impact of mice.

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 thanks them for their continued support.

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Fall armyworm

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Notes

Practical management of fall armyworm

Graham Boulton, Black Earth Agronomy

Key words

fall armyworm, management, 2020, *Spodoptera frugiperda*

Take home message

Chemical control alone will not be enough to manage this pest in the long term

Introduction

This presentation is based on the practical experiences of the staff of the Black Earth Agronomy group in managing fall armyworm (*Spodoptera frugiperda*) in the Burdekin region of North Queensland and on the Darling Downs since March 2020.

The 2020 experiences

In January 2020, the Director General of DAF advised that fall armyworm (FAW) had arrived in Queensland across the Torres Strait.

In late April 2020, one of our clients planted a small block (10ha) of maize corn at Mona Park near Clare in the Burdekin Region. This field proved to be where my company started its education in dealing with fall armyworm.

At the time, no-one could tell us what strain of fall armyworm we were dealing with, or what insecticide resistance genes the FAW population was carrying.

In the beginning, we couldn't understand where all the fall armyworm larvae were coming from. We could find low numbers of egg rafts generating 2-3 larvae per plant distributed across a field. Then we discovered that the fall armyworm larvae were hatching in the egg rafts and then 'ballooning' or 'parachuting' in the breeze to colonize other plants. You only need one egg raft in 10 metres of row to produce a significant infestation of fall armyworm larvae per plant.

An application with deltamethrin to the Mona Park block at the 3-4 leaf stage killed the cluster caterpillars (*Spodoptera litura*) present in the crop but left the fall armyworm in the whorl behind. We realised that the plant stand of the crop was at risk and applied Altacor (PER89366). Acceptable levels of control were achieved to preserve the plant stand.

Critical early stage of development in maize

Based on regular and thorough scouting, we gained confidence in what was working and what was not in the Mona Park block and other early planted corn fields in the district.

In maize crops in the Burdekin in 2020, we settled on a strategy which included the following spray program to get the crop through to the 6 true leaf stage:-

1) Steward® (PER89530) The indoxacarb application was often mixed with a post-emergent herbicide for broadleaf weed control at the 2.5 to 3 true leaf stage. By trial and error, we found that indoxacarb was not effective in controlling FAW larvae if rain or irrigation fell 1-2 days after application. My current recommendation is to avoid using indoxacarb if rain is forecast in the 5 days following the spray.
2) Altacor (PER89366) (if deemed necessary by crop monitoring).

In some maize crops, we applied only one insecticide spray during the early stage of crop development because the FAW moths did not 'find' the corn field until it was already at the 4-5 true leaf stage. If crop monitoring indicated that two insecticide applications were required, they often occurred 7-10 days apart during the 2 to 5 true leaf growth stage.

On some farms, we were able to achieve acceptable levels of control with *Bacillus thuringiensis* (Bt) sprays until the third week of May 2020. By this time, the FAW population in the Burdekin and Bowen Regions was increasing exponentially. It reached the point where we were not confident that we would obtain acceptable levels of control using Bt. Consequently, we switched to conventional chemistry.

Cost savings can be made by applying the insecticide in a 50% band over the row, particularly when the crop is 2-4 true leaves.

Once the maize crop had reached 6-7 true leaves, we felt that the plant stand was not at risk. We decided to stop spraying and monitor the FAW larval population and the leaf damage that ensued. The leaf damage caused by large FAW grubs in the whorl from 6 true leaves up to tassel emergence can make the crop appear very 'mauled' but I don't believe that significant yield reductions resulted from this vegetative damage in 2020.

Critical late stage of corn development

By the time that 'most' maize fields had tasselled, all the FAW larvae had gone to ground to pupate.

I was relieved that I did not have to recommend another spray to control FAW and Helicoverpa larvae moving down from the tassels to attack the developing cobs.

When the kernels had coloured and were midway through the soft dough stage, I thought that my job was done with FAW. Little did I know! There were large FAW and Helicoverpa in the tips of a high percentage of the cobs.

It is commonplace to find Helicoverpa going through their life cycle from eggs laid in the silks to large larvae in the tips before going to ground to pupate.

What wasn't expected was the behaviour of very small and small FAW larvae crawling beneath several layers of husk from the tips to midway down the cobs in most of the corn paddocks.

Several test strips were initiated using Altacor (PER89366) and Steward (PER89530) applied by air. The crops were too tall for most ground rigs. As you would expect, control of FAW larvae under the husk was not effective.

The FAW larvae proceeded to grow through to their final instar, feeding on the kernels midway down the cob length. At this late instar stage, they chewed exit holes through the husks to go to ground to pupate. This left many cobs with 2-3 large 'bullet holes' or damage that I describe as body grub damage. The risk of crop failure from aflatoxins and cob rots was very real and some growers prepared to harvest at high moisture rather than allow the crop to experience a rainfall event. Fortunately, it was a very dry finish and all crops were harvested successfully.

One interesting observation was that on three farms (6% of the total maize area under our supervision in 2020), the incidence of body grub damage was minimal. These farms were aerially sprayed with Altacor (PER89366) at tasselling/early silking because the crops were uneven and medium to large FAW larvae were still present when the tassel emerged.

This tassel spray is now standard practice for Black Earth Agronomy **whether or not** there are FAW larvae present at tasselling until research or experience proves otherwise.

Subterranean behaviour

In some corn and soybean plantings, we found that FAW can behave like cutworm.

Case 1

Once volunteers from a previous crop of soybeans had been sprayed out, we discovered that large FAW can quite happily survive under the soybean trash layer for some time before attacking corn plants at the 1-2 true leaf stage. In this case, chlorpyrifos was applied in the late afternoon to control ’cutworm’ and the crop damage subsided.

Case 2

This subterranean ’cutworm’ behaviour was replicated in an August planted crop of soybeans. The grower had a few scattered grass weeds (feathertop Rhodes, crowsfoot and summer grass) in the field where he intended to plant winter soybeans. The grower worked the ground with discs before hilling up and pre-watering.

After a week, small weeds which had germinated were sprayed with glyphosate prior to planting. Before the crop emerged, the field was sprayed with paraquat and metolachlor before flushing the field again to ensure an even crop emergence and survival of the inoculant for successful nodulation. The crop emerged very well.

At the one trifoliate leaf stage, we noted that the soybean seedlings were being attacked above and below ground level. We could find no larvae on the leaves and stems so we proceeded to dig underneath the crop row. There we found large FAW larvae down to 5cm deep in the soil profile.

These larvae were chewing through the base of the seedings below ground level. In the evening, the larvae were feeding on the leaves and stems above ground. We applied deltamethrin because chlorpyrifos is not registered for ’cutworm’ in soybeans. Either the deltamethrin was effective OR the large FAW pupated soon after application, but crop damage subsided quickly and an acceptable plant stand was achieved.

Case 3

In 2021, we have seen a repeat of this behaviour where FAW larvae have infested grass seedlings in the fallow prior to sowing corn. The grasses were sprayed out prior to planting but the larvae seem to be able to survive in the soil until the crop emerges.

Other potential host crops

For those sorghum crops planted in the Burdekin in January-March 2020, we found very few FAW larvae infesting the crops grown on our client’s properties.

Similarly for Panorama Millet planted in July or Shirohie Millet planted in August 2020.

We have anecdotal evidence that FAW have caused significant leaf damage in forage sorghum around Gumlu.

FAW larvae have also penetrated capsicum bells without leaving obvious points of entry. It is disconcerting when ‘unblemished’ fruit reach the markets containing FAW larvae!

Negligible numbers of FAW larvae have been found in green beans, mungbeans or soybeans in the Burdekin.

The 2021 experiences

Corn

Due to the price of corn falling to $280 per tonne in the Burdekin, most growers have decided not to grow corn this winter, especially when the cost of production has increased significantly due to fall armyworm. An increased level of crop monitoring by the grower or his consultant is also required to manage the pest.

In 2021, we have chosen not to recommend Altacor (PER89366) in the early growth stages of corn to reduce our reliance on this valuable insecticide group.

We now suggest that our clients use emamectin benzoate (PER89371) instead.

This season, we only have 3 blocks of popcorn (Var. R502 Butterfly) which were planted in early April. To date, we have sprayed the crop 3 times for FAW, twice with emamectin benzoate (PER89371) at the 2-5 true leaf stage and once with Altacor (PER89366) at tasselling. Emamectin benzoate (PER89371) was chosen at the early stages because the weather was rainy and unpredictable. The grower also used QM FAW/methomyl (PER89279) to attract and kill the FAW moths.

Sorghum

One of the neighbouring farms in the Burdekin planted large areas of grain sorghum during the wet season (January-March 2021). The neighbour said that he did not treat any of his sorghum for fall armyworm.

In some blocks, he estimates that crop losses of 50% have occurred in both dryland and irrigated sorghum blocks due to FAW damage. In these cases, high numbers of FAW larvae were present during the late vegetative phase which led to significant damage by large FAW larvae to the developing head in the boot.

In a telephone hook-up last year, I was advised that this type of damage had been observed in grain sorghum crops grown in Texas in the USA (Anthony Hawes *pers.com*). The USA experience suggested that the FAW larvae hidden by the leaves surrounding the developing head in the boot cannot be killed by insecticide sprays. Consequently, you would have to recognise that you had a developing problem with FAW numbers **before** the crop reached the boot stage.

What larval sizes and numbers constitute a spray threshold in vegetative sorghum?

We did not observe this type of head damage in the mid-January planted sorghum on our clients' properties on the Central Darling Downs this season. The FAW larval population remained low throughout the crop's growth and development.

A similar circumstance exists in corn. We have found that you cannot kill FAW larvae feeding on the developing tassel in the whorl until the tassel emerges from the surrounding sheath of leaves. The timing of a spray can be very difficult to determine if a crop is uneven in tassel emergence.

Area wide management

Without doing a statistical analysis of our scouting records, it was apparent to the staff of Black Earth Agronomy that if you fail to control a significant population of FAW larvae in a crop on your farm or on a neighbouring block in your local district, you can generate your own FAW plague or pandemic.

It becomes a numbers game.

In a highly susceptible crop such as corn, you are in big strife if you start to find 2 egg rafts per metre of row in a crop at the 2 true leaf stage. This equates to 200-400 eggs per metre.

This situation requires repeated sprays to reach the 6 true leaf stage. Even then, you may finish up with one large FAW larva buried deep down in the whorl of every plant, which you cannot control with insecticide. Without disease or parasitism, this has the potential to produce 13,333 moths per ha which begin another cycle in the later stages of the crop or migrate to your neighbour's susceptible crop.

Trichogramma

We have tried releasing *Trichogramma pretiosum* which you can buy commercially. We can definitely 'see' a high number of parasitised Helicoverpa eggs in the field but we haven't seen FAW egg rafts which have been significantly parasitised. The staff of Black Earth Agronomy have also caged FAW egg rafts together with commercially reared *T. pretiosum* but have ended up with a cage full of FAW hatchlings! We have not counted the number of eggs in the FAW egg rafts or the number of larvae that actually hatched so we do not have an accurate measurement of the level of parasitism. Melina Miles, DAF Entomologist in Toowoomba, and Siva Subramaniam, the DAF Entomologist in Bowen, might have more accurate numbers from their research in controlled, laboratory environments.

Other pests and diseases of fall armyworm

High levels of parasitism by a parasitic wasp called *Cotesia ruficrus* were recorded in maize crops monitored by Steve and Anna Madden, agricultural consultants in Northern NSW, in the spring of 2020. It is uncertain whether this parasitic wasp species would be a suitable candidate for mass rearing in a commercial insectary. This could be a research project for an aspiring entomologist or entrepreneur?

Fawligen (Permit No. PER90820) is a virus preparation which infects and kills small FAW larvae. To date, Black Earth agronomists have not trialled Fawligen as a 'stand-alone' product against FAW in corn in the Burdekin. It has been used as a mixing partner with conventional insecticides to lower the potential for the development of insecticide resistance. We have felt that the FAW pressure in the corn has been too high and the prevailing minimum temperatures too low to risk a stand-alone application of Fawligen.

Metarhizium (formerly known as Nomuraea) is a fungi genus that has shown that it can kill FAW in NQ. Occasionally, we have come across FAW larvae which have been infected by a local species of Metarhizium in maize crops but the incidence is very low. In the Giru district in the Burdekin, Metarhizium was responsible for the death of a significant number of cluster caterpillars (*Spodoptera litura*) in soybean crops at the end of summer in 2021. I understand that commercial preparations of Metarhizium could become available in Australia in the next few years.

Attract and kill technologies

This technology offers a lot of potential to reduce the FAW moth population on a farm and would be the core of an area wide management plan where susceptible crops are grown.

Magnet® was developed 18-19 years ago as a feeding attractant for Helicoverpa moths which were killed by an insecticide added to the mix. The Magnet/insecticide mix is applied in a very coarse spray to the crop row at a pre-determined interval (36 or 72 metres).

In the winter of 2020, all the Magnet supplies in Australia were sent to the Ord river irrigation area to aid in protecting the seed corn and sorghum production areas.

AgBitech were able to import the active ingredients to make and distribute another batch of Magnet by the end of August 2020.

Magnet (PER89398) was applied commercially to sweetcorn crops in the Bowen and Burdekin regions in the spring and early summer of 2020. Dead Helicoverpa and FAW moths could be found at the base of the corn rows the day after application. The overall effect of applying Magnet to reduce the incidence and distribution of FAW across the farming enterprise was inconclusive in 2020.

In an experiment, Black Earth staff discovered that a large number of moths of various species including FAW could be caught in pheromone bucket traps where the pheromone lure was replaced with a Magnet lure. This experiment was conducted adjacent to a field where poor control of FAW larvae had been achieved. The aim of the experiment was to determine how attractive Magnet was to FAW moths rather than as a tool to reduce the moth population in a particular area of the field.

New attractant products are being developed to target fall armyworm moths. These include Smartgreen Biosciences QM FAW and Organic Crop Protectants ACTTRA FAW.

More trial work needs to be conducted to determine which attractant works best on FAW moths and to quantify the benefits of suppressing moth numbers across a farming district. Quantifying the effect of attract and kill technology is a difficult task.

Different attractant products applied to different fields in a district might be more beneficial than relying on one attractant?

More research needs to be conducted on insecticides to mix with the moth attractants.

The moth attractants do attract a whole range of insect species including beneficials such as lady beetles. Having broad spectrum insecticides such as methomyl as the mixing partner may be useful in the short term. In the future, we need more specific adulticides which target the pest species and conserve the majority of the beneficial insects.

The development of Bt cotton technology and nuclear polyhedrosis virus (NPV) for controlling Helicoverpa in grain sorghum was fundamental to the Area Wide Management of Helicoverpa in the mixed cropping systems on the Darling Downs.

It will take a mixture of different technologies to manage FAW in the future.

Ultimately, developing an Area Wide Management Plan for FAW and assessing its success or failure might be the best course of action. Over time, the diseases, predators and parasites in the local environment might adapt to the availability of the new food resource and assist us in managing the pest.

One thing I am sure of is that we can’t rely on chemical control to manage this pest in the long term.

Acknowledgements

I would like to acknowledge the support and advice from the following people who were instrumental in formulating strategies to target fall armyworm in the field.
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Andrew Sippel, Black Earth Agronomy, Bowen
Tuo Deng, formerly Black Earth Agronomy, Bowen

A very big thank you to the five participating growers for providing your paddocks, time and effort, and financial resources to find practical ways of implementing a range of control strategies.
Barry Breadsell, Mona Park, Clare
Will Lucas, Osborne, Home Hill
Rob Stockham & Sons, Giru
Mark Vass, Home Hill
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High competition sorghum – impacts on crop productivity, water and nutrient use legacies in the farming system

Lindsay Bell[1], Brook Anderson[1], Darren Aisthorpe[2], Jon Baird[3], Andrew Erbacher[2], Jayne Gentry[2] and David Lawrence[2]

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Key words

sorghum, agronomy, population, row spacing, WUE

GRDC code

CSA00050, DAQ00192, DAQ2007-002RTX

Take home message

- Narrow row spacing and higher plant populations in sorghum crops can offer potential for higher weed competition, with higher early crop biomass and early ground cover
- While crop biomass and yield potential can be increased with high-competition sorghum crops, this can increase yield in better seasons but increase risks of yield penalties in drier conditions
- Higher density sorghum crops often extract more soil mineral N and may immobilise some mineral N during the subsequent fallow – a function to growing more biomass
- High competition crops did not extract more soil water and the extra, and more even, crop residue was not sufficient to enhance fallow efficiency
- High-competition sorghum crops will require more starting soil water and available N to meet the demands of growing more biomass.

Introduction

Grain sorghum is often grown on wide row spacings (1m or more) with moderate to low plant populations (<60 K plants/ha) to help manage water use through the season and maintain yield stability under dry conditions. While this can have benefits in some seasons, this presents challenges for weed control, particularly grasses, due to low competition from the crop meaning that the limited suite of residual herbicides are critical. However, there are very limited options for pre-emergent control of grass weeds in grain sorghum and these herbicides can sometimes limit future crop choices, place pressure on limited herbicide options for the development of resistance, and in some circumstances, allow sufficient weed escapes to enable weed seedbank replenishment, or at worst a weed seed blowout. Wide rows can also leave low and unevenly distributed crop residues with implications for fallow water accumulation, resulting in uneven sowing moisture for subsequent crop establishment.

In our farming systems research, we are implementing an 'Integrated Weed Management' system which aims to compliment herbicides by increasing in-crop competition for weeds through growing crops on narrower row spacings at higher densities. In our experiments, we are not testing the capacity of the high competition crops to suppress weeds (we are maintaining a system with low weed populations) but this allows us to compare the impacts of this practice on diverse aspects of the farming system (e.g. soil water and nitrogen extraction and accumulation, subsequent crop performance) compared with conventional practice. In this paper we report on 5 seasonal comparisons where sorghum crops were grown to produce high competition via narrow rows (0.5 m compared with 1 m) and higher seeding densities (25-70% higher) compared to conventional practice. These involved crops grown in 2017/18 at our farming systems sites in Emerald (Central Qld), and Pampas (Eastern Darling Downs) and three subsequent crop comparisons at Pampas in 2018/19, and 2020/21.

Crop performance

Tables 1 to 4 show each of the seasonal comparisons of the high-competition and conventional sorghum crops in terms of the crop densities and seasonal conditions, crop performance, i.e. grain yield, biomass, water-use-efficiencies, soil water and nitrogen extraction and legacy impacts on subsequent fallow water and nitrogen accumulation (this data isn't available for 2020/21 crops as yet). In all cases crops were sown with very similar or equivalent plant-available soil water (PAW) at the opening of the sowing window and in all cases PAW had exceeded 150 mm prior to sowing.

Crop yield and biomass

Across the 5 seasonal comparisons we have seen yields of the high-density sorghum crops range from an 18% increase (Emerald 17/18) to a 45% decrease (Pampas 2020/21). The high-competition crops have resulted in a higher yield in one of the 5 seasons (Table 1), two seasons produced the same grain yields (Tables 2 & 3) and a yield penalty occurred in the final comparisons in the same year (Table 4). These results occurred for seasons that produced crop yields in our conventional crops ranging from 3.4 t/ha to 5.4 t/ha.

While grain yields have not been significantly increased, the biomass of crops have increased by 10-30% in 4 of 5 seasons. This is a result of the higher plant populations allowing earlier growth and resource capture. However, despite the higher biomass this did not translate into higher yields, meaning that these crops have resulted in lower harvest index (i.e. ratio of grain to biomass). This often indicates that high competition crops may have encountered more moisture stress during grain filling which reduced their capacity to fill grain and realise higher yield potentials. We would expect this to occur more in seasons with lower grain yields. Our data does support this, with a significant yield penalty occurring in the high competition crops at Pampas in 2020/21 which had the lowest yields, despite the high in-crop rainfall (much of which occurred very late in the season).

Table 1. Performance and legacy impacts of high competition sorghum crops compared to conventional practice at Emerald in 2017/18. Cultivar MR Buster sown on 22 Jan 2018.

CROP CONDITIONS	High comp.	Conven.	Difference
Row spacing (m)	0.5	1.0	
Target density ('000 plants/ha)	60	40	
Pre-sow plant-available soil water (mm)	145	145	-
In-crop rainfall (mm)	224		
CROP PERFORMANCE			
Grain yield (t/ha)	5.9	5.0	+0.9
Crop biomass (t/ha)	15.6	11.6	+4.0
Grain WUE (kg grain DW/mm)	18.9	16.0	+3.0
Biomass WUE (kg DM/mm)	48.6	36.5	+12.1
Soil water extraction (mm)	97	97	-
Change in soil mineral N (kg/ha in 0-90 cm)	-100	-110	-10
LEGACY IMPACTS (11-month fallow, 417 mm rain)			
Fallow soil water accumulation (mm)	72	96	-24
Mineral N accumulation (kg/ha)	75	89	-14

Water, N use and WUE

We have not measured any large differences in terms of final soil water extraction between the high competition and conventional crops, meaning that both crops have ultimately used a similar amount of water from the system. However, the timing of this water use may have differed (as mentioned above). This means that the grain WUE and biomass WUE of the crops closely reflect the relative grain yields and biomass achieved. The higher biomass WUE observed in all crops indicates that the higher densities are transpiring a larger proportion of the available water, and less is lost to evaporation. However, as discussed above, this has not always translated into a higher grain yield.

In all these comparisons all crops had very similar starting levels of soil mineral nitrogen and received the same fertiliser applications. However, the data does show that on average the high-competition crops have y extracted more soil mineral N than the conventional crops by about 20 kg N/ha. This extra N use is associated with the greater biomass growth.

Table 2. Performance and legacy impacts of high competition sorghum crops compared to conventional practice at Pampas in 2017/18. Cultivar Taurus sown on 3 Nov 2017

CROP CONDITIONS	**High comp.**	**Conven.**	**Difference**
Row spacing (m)	0.5	1.0	
Sowing rate (kg/ha)	4.7	3.5	
Established density ('000 plants/ha)	90	68	
Pre-sow plant-available soil water (mm)	125	160	
In-crop rainfall (mm)	195		
CROP PERFORMANCE			
Grain yield (t/ha)	5.4	5.4	-
Crop biomass (t/ha)	16.0	14.1	+1.9
Screenings (%)	0.2	0.1	-
Grain WUE (kg grain DW/mm)	11.3	11.2	+1.0
Biomass WUE (kg DM/mm)	33.8	29.3	+4.5
Soil water extraction (mm)	105	110	-
Change in soil mineral N (kg/ha in 0-90 cm)	-130	-107	+23
LEGACY IMPACTS (20-month fallow, 559 mm rain)			
Fallow soil water accumulation (mm)	96	63	-33
Mineral N accumulation (kg/ha)	113	126	-13

Table 3. Performance and legacy impacts of high competition sorghum crops compared to conventional practice Pampas 2018/19. Cultivar Taurus sown on 26 Oct 2018.

CROP CONDITIONS	**High comp.**	**Conven.**	**Difference**
Row spacing (m)	0.5	1.0	
Sowing rate (kg/ha)	3.7	3.0	
Established density ('000 plants/ha)	85	66	
Pre-sow plant-available soil water (mm)	130	130	
In-crop rainfall (mm)	153		
CROP PERFORMANCE			
Grain yield (t/ha)	4.4	4.5	-0.3
Crop biomass (t/ha)	10.1	9.1	+1.0
Screenings (%)	0.3	0.3	-
Grain WUE (kg grain/mm)	11.5	11.3	-
Biomass WUE (kg DM/mm)	25.7	23.0	+2.7
Soil water extraction (mm)	116	117	-
Change in soil mineral N (kg/ha in 0-90 cm)	-39	-20	+19
LEGACY IMPACTS (17-month fallow, 440 mm rain)			
Fallow soil water accumulation (mm)	119	133	-14
Mineral N accumulation (kg/ha)	79	85	-6

Legacy impacts

We had expected that the higher crop biomass achieved by the high-competition crops could result in higher levels of residue ground cover and potentially enhance the accumulation of soil water in the subsequent fallow. However, our results do not support this. Following all 3 crop comparisons we have followed so far, we have seen very little difference in soil water accumulation over long fallows (11-20 months) following the high-competition crops, and no clear benefit for subsequent fallow efficiency. Two sites saw slightly lower fallow water accumulation within measurement error (Tables 1 & 3), while the other comparison the higher density crop accumulated 33 mm more soil water over a long fallow (Table 2). It could be that the differences in crop biomass (about 10% extra) are not sufficient to dramatically influence ground cover and hence rainfall infiltration enough. Further, most of these crops will have left 6-10 t DM/ha of residue after harvest and ground cover of >50% meaning that the benefits of additional biomass are likely to be low. Under conditions with lower ground cover and/or wetter fallow periods, perhaps differences might be more evident and favourable following the high-competition crops.

Despite the higher biomass and N uptake by the high-competition crops, this additional N did not mineralise during the subsequent fallow and result in higher N accumulation following the high-competition crops. In fact, the high-competition crops often results in slightly lower N accumulation during the subsequent fallow (6-15 kg N/ha). These differences could be the result of the higher amounts of residue biomass, with sorghum stubble often having a high C:N ratio this can immobilise more mineral N from the soil. These differences are small and not likely to influence subsequent management.

Table 4. Performance of high competition sorghum crops compared to conventional practice at Pampas 2020/21. These crops had different cropping histories, either following a long-fallow (left) or a short fallow (right). Cultivar Taurus sown on 5 Nov 2020.

	Sown following long fallow			Sown following short fallow		
CROP CONDITIONS	**High comp.**	**Conv.**	**Diff.**	**High comp.**	**Conv**	**Diff.**
Row spacing (m)	0.5	1.0		0.5	1.0	
Sowing rate (kg/ha)	5.0	3.2		5.0	3.2	
Est. density (‘000 plants/ha)	91	53		86	53	
Pre-sow PAW (mm)	135	145		100	105	
In-crop rainfall (mm)	377			377		
CROP PERFORMANCE						
Grain yield (t/ha)	2.1	4.1	-2.0	2.7	3.4	-0.7
Crop biomass (t/ha)	8.6	9.3	-0.7	7.5	7.1	+0.4
Screenings (%)	6.5	5.1	+1.4	4.0	4.0	-
Soil water extraction (mm)				+20	+15	-
Grain WUE (kg grain/mm)				7.6	9.4	-1.8
Biomass WUE (kg DM/mm)				21.0	19.6	+1.4

Concluding remarks

We have found mixed results from growing sorghum to induce higher crop competition, with upsides for yields in some seasons and clearly some downsides in others. It does seem that the potential downside risks increase from around 60 K plants/ha to higher populations (For example over 90 K plants/ha) while a benefit was seen when populations increased from 40 to 60 K plants. Hence, there could be a case for increasing plant populations from low levels or with very wide row spacings. However, further understandings of the limits for plant population may be needed for particular environments.

While we had hoped to see some system benefits of the higher density crops for subsequent water accumulation, we have yet to show any of these experimentally. Hence, it seems that management to increase crop competition for weeds is probably best targeted in situations where weed control is problematic, and this approach has not yet revealed any other clear system or carry over benefits for subsequent crops.

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Grain storage, what's new: managing large flat-bottom silos; grain protectants; storing pulses; resistance update

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Key words

monitoring stored grain, large grain silos, grain protectant insecticides, storing pulses, phosphine insect resistance, grain pest control

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Take home message

- Regular monthly monitoring of stored grain and keeping records for both small and large capacity silos is critical for successful grain quality results and storage pest control
- Carefully check the design and build quality of any monitoring equipment before purchase and instalment in silos. Grain temperature and equilibrium relative humidity (ERH) information is valuable but requires robust sensors, carefully placed
- Monitoring of fumigation gas levels in large silos and storages such as grain bunkers and sheds helps to check if grain pests have had the required dose over time to achieve effective control.
- Talk with potential grain buyers and seek advice prior to applying grain protectant treatments. Each year restrictions change with respect to acceptance of insecticide residues in both domestic and export markets
- Storage pests can develop resistance to fumigants and grain protectants. Growers should be alert to this threat and ensure that phosphine fumigations are conducted to the highest standard and choose effective grain protectant combinations
- Effective management of insect pests of stored pulses is possible using an integrated approach: pest monitoring, aeration cooling and phosphine fumigation.

Managing large flat-bottom silos – grain quality & pests

- There has been widespread investment in large flat-bottom silos by many grain growers as part of on-farm storage facilities. While large capacity (600 – 2000 tonnes), flat-bottom silos are a cost-effective on-farm storage method, they currently have a significant downside. The silo design makes it difficult to carry out effective checks for storage pests and storage conditions, such as grain temperature and moisture content.
- Regular monitoring is critical to ensure grain quality is maintained and pests are controlled in a timely manner. In addition, an efficient method for monitoring gas levels at a number of locations in a large silo during a fumigation would also be beneficial.
- While there are grain storage monitoring systems available from the USA and Canada, most have design issues that currently make them unsuitable for the majority of silos / storages in Australia.

Figure 1. A farm storage facility with ten large flat-bottom silos, each with 1500 tonnes capacity (photo DAF Qld)

Figure 2. Cable or canister monitoring systems can be located inside a silo to monitor grain temperature, humidity or gases

Things to consider when assessing storage monitoring systems

- Measuring both grain temperature and equilibrium relative humidity (ERH) is valuable as it provides information on storage conditions, grain moisture content and providing insight as to how active insect pests are, if present
- Tests following phosphine fumigation have shown that sensors inside a silo designed to measure humidity in grain can be permanently damaged by phosphine gas during a standard fumigation
- Sensor location inside a silo is critical. If sensors are too close to silo walls, readings may be influenced by excessive grain trash or external temperatures i.e. sun or shade on walls
- Some sensors may be difficult to install in silos and to access later if they require maintenance
- Grain storage sensors and cables are in a hostile environment with dust, heat, moisture and significant physical stresses when the silo is filled, emptied and as grain settles during storage
- Sensor's build quality, lifespan and long-term accuracy will be important for each parameter i.e. grain temperature, humidity and in some cases gas concentration measurements

- Reliable communication of data between the internal storage sensors and external reading / recording devices will be required.

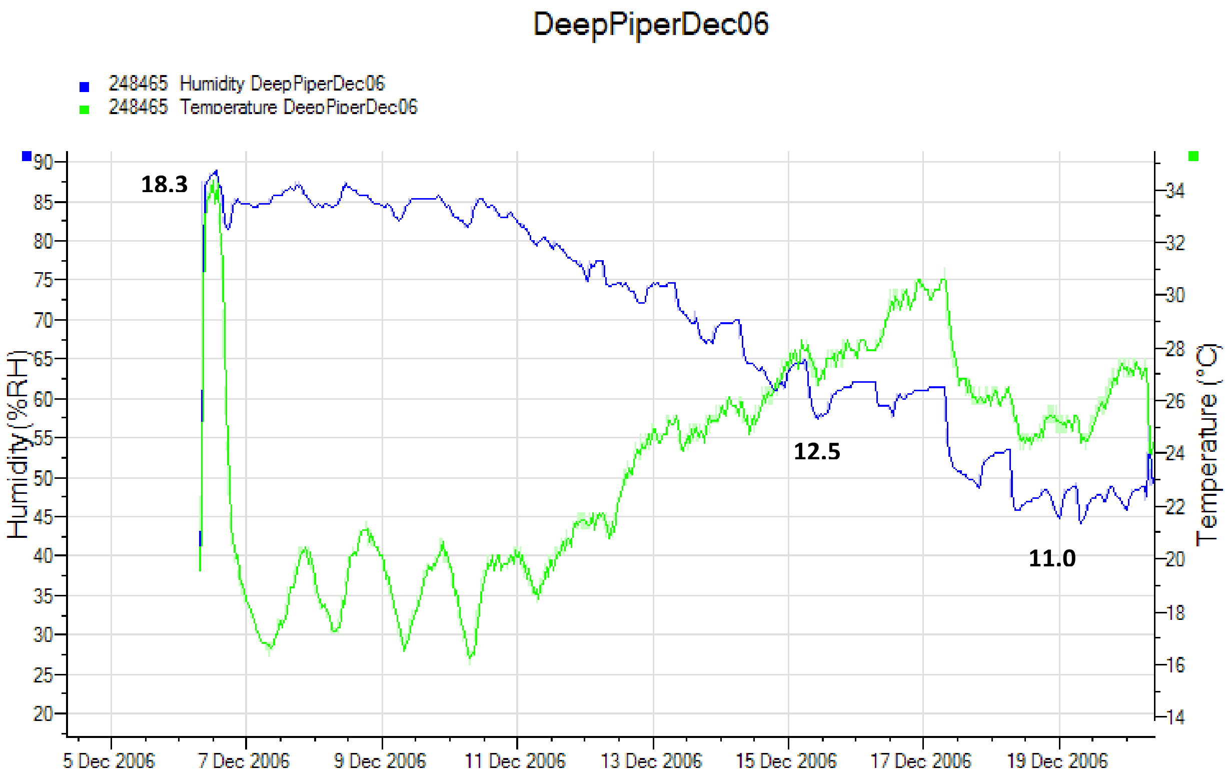

Figure 3. Sensors in the lower half of a 60 tonne aeration drying silo measured both wheat temperature and equilibrium relative humidity (ERH). Using this information wheat moisture contents (18.3%, 12,5%, 11.0%) can be determined using a wheat ERH chart. The silo was fitted with a 7.5 kW fan delivering an airflow rate of 27 L/s/t for 238 hours to reduce moisture content from 18.3% to 11.0%

Pest detection and fumigation

Timely pest detection in stored grain is critical to ensure grain is ready for sale, meeting the 'nil live stored grain insects' delivery standard. Early detection of pests is also important to ensure significant grain losses and grain quality damage does not occur.

While it is relatively easy to sample grain and check for pests in small cone-based silos, it is difficult to check for storage pests in large flat-bottom silos with limited access to sample grain at the base and top of silos. Currently there appears to be very few commercial products offered to resolve this pest detection issue for large silos.

Unfortunately, this can lead to the practice of 'calendar based' regular fumigations of large silos. Silos are fumigated with no knowledge of either pest numbers or pest species present. Any grain stored for 12 – 18 months plus, may then receive multiple fumigations, some of which may not have been required. This is when the risk of development of insect pest resistance to fumigation products like phosphine increases substantially.

Measuring gas concentrations during fumigation at a number of locations inside large silos or other large capacity storage types like grain bunkers or sheds is important. For any fumigation to be effective at controlling storage pests, the insects need to be exposed to a given gas concentration ('C'), for a specified length of time '(T)'.

If this ‘C x T’ exposure requirement is not met throughout all parts of the storage during the fumigation, survival of various insect life cycle stages (eggs, larvae, pupae, adults) is likely. Live adult insect pests will quickly reappear in the grain within days or weeks.

Along with not killing the pests, poor fumigation can also lead to selection and development of resistant insect populations.

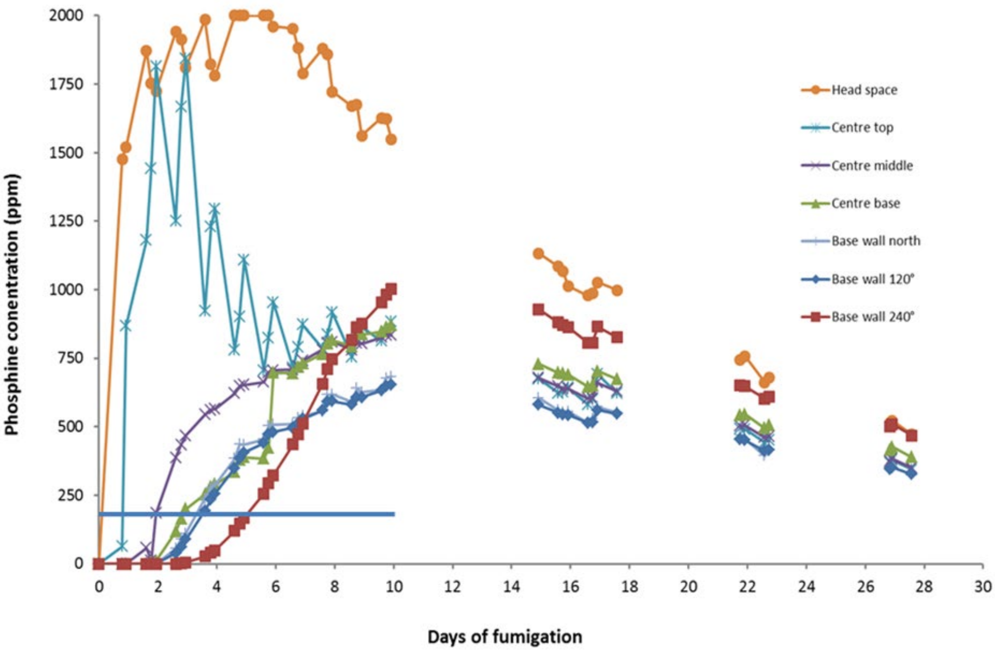

Figure 4. Phosphine gas concentrations at 7 locations in a silo fumigating 1420 t of wheat. Phosphine blankets were placed in the silo headspace with no gas recirculation. It took 5 days before all grain at the silo base reached at least 200 ppm gas concentration.

Potential future ideas for grain & pest monitoring equipment

- Development of grain storage humidity sensors that are not damaged by phosphine fumigations would add significant value to the current commercial grain moisture cables or canisters (e.g. OPI® moisture cable)
- Developing a new storage cable designed to included both temperature sensors plus 3 or 4 air sample lines to sample air at various heights within the storage could provide multiple measurement functions e.g., equilibrium relative humidity (ERH), fumigation gas levels and detection of insect pest pheromones
- Fitting small ports through the silo wall next to silo ladder landings provides access for 1.0 to 1.5 meter-long grain probes. These 6 mm diameter stainless steel probes are currently available (Graintec Scientific™) to measure grain temperature and to take air samples for a range of functions.

Grain protectant treatments update

Warning: Grain protectant notes below do not apply to the grains industry in Western Australia where their use is restricted. In all cases, product labels are to be used to determine correct use patterns.

Grain protectant sprays – a useful tool for storage management

Strategic use of grain protectant insecticides is only one of five key strategies to maintain grain quality and achieve reliable pest control results. Combined, they form the foundation of successful grain storage. Good results with on-farm grain storage is crucial in the long term for a producer to build a reputation as a reliable supplier of quality grain with no pest problems. Key aspects of successful grain storage are:

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

Use of grain protectants on cereal grains for both domestic and export markets is becoming increasingly difficult. Acceptance of insecticide chemical residues on grain, even at extremely low levels, has changed significantly in the last few years. It is important that growers always check with potential grain buyers before using grain protectants.

The Manildra Group™ is a recent example of a large tonnage, Australian wheat buyer who has been required to move to pesticide residue free (PRF) grain due to a number of European and Asian countries banning residues of commonly used grain protectant chemicals such as chlorpyrifos-methyl.

When to use grain protectants

- Typically, protectant sprays are applied to clean cereal grain at harvest time as grain is augered into storages, providing storage pest protection for 3 to 9 months. Protectants are effective at controlling insects as they invade or emerge from eggs within grain during storage
- Grain protectant sprays are not to be used to disinfest grain. When live storage pest insects are detected, fumigation in a sealable silo is required for effective control
- With many domestic and export markets seeking grain supplies which are 'pesticide residue free' (PRF), always talk to potential grain buyers / traders prior to applying grain protectant sprays
- The general rule is that NO protectant sprays can be applied to pulses and oilseeds. Always check labels.

Common 'on-farm' uses for grain protectants (always read and follow directions for use on the registered label before using)

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

Grain protectant choices

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

1. **Conserve® Plus Grain Protector** – active ingredient: 100 g/L spinosad, 100 g/L s-methoprene. Used in combination with a compatible organophosphate (OP) product such as chlorpyrifos-methyl (e.g. Diplomat 500 EC), or fenitrothion

   For label and details on product use, see: Conserve® Plus Grain Protectant | Corteva Agriscience (https://www.corteva.com.au/products-and-solutions/crop-protection/conserve-plus.html)

Key recommendations

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

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

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

Key recommendations

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

Insecticide resistance management

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

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

Application of grain protectants

Grain protectant application requires care to achieve the correct dose and uniform grain coverage. This leads to effective pest control results and ensures MRL's are not exceeded. See Figure 5 below.

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

Figure 5. Spray application equipment designed for good coverage by applying treatment at two points in the auger

Grain pest resistance update – phosphine and grain protectants

Phosphine resistance

Phosphine fumigation is the most commonly used method used by growers and other grain handlers to disinfest grain. Over recent decades there has been a steady increase in both the prevalence and strength of phosphine resistance in various insect pests of stored grain. Despite these trends, phosphine fumigation remains effective against resistant pests except for one species.

The strongest level of phosphine resistance occurs in the rusty grain beetle (*Cryptolestes ferrugineus*) . This tiny beetle is one of several species of flat grain beetles (*Cryptolestes* species) found on farms (Figure 6). Although not normally the most common pest on farms, the presence of strongly resistant rusty grain beetles will threaten fumigation success, even in well-sealed silos.

GRDC has supported phosphine resistance monitoring for many years, as well as research on managing resistant pests. Our testing procedure allows us to categorise populations as susceptible, weakly resistant or strongly resistant, based on the presence of survivors in laboratory tests. Table 1 shows the results of recent resistance testing of pest populations collected from farms located in the GRDC northern region. The results show that phosphine resistance is common. Concerningly, half of the rusty grain beetle populations were categorised as strongly resistant.

Table 1. Phosphine resistance testing of grain beetle populations collected from farms in the GRDC northern region (2020-2021).

Pests	Number of populations		
	Susceptible	Weak resistance	Strong resistance
Lesser grain borer (*Rhyzopertha dominica*)	0	43	21
Rust-red flour beetle (*Tribolium castaneum*)	12	49	15
Rice weevil (*Sitophilus oryzae*)	1	10	0
Saw-toothed grain beetle (*Oryzaephilus surinamensis*)	0	6	0
Flat grain beetles (*Cryptolestes* species)*	0	12	6

* There are several *Cryptolestes* species, but only rusty grain beetle (*Cryptolestes ferrugineus*) has been shown to develop strong resistance.

Two phosphine fumigation trials conducted at Warwick in February 2017 show how difficult it is to control strongly resistant rusty grain beetles compared with strongly resistant populations of other pests. Silos containing wheat were fumigated according to the registered label for fumigations using aluminium phosphide tablets, with one trial lasting 7 days and the other 10 days. Cages of pests were placed in the silo at three depths (top, middle and bottom) to evaluate fumigation success. The species tested were the rusty grain beetle, the lesser grain borer, the rust-red flour beetle, the rice weevil and the saw-toothed grain beetle. The cages contained all life stages (eggs, larvae, pupae and adults) because phosphine tolerance can vary between life stages.

All species except for the rusty grain beetle were controlled in both the standard 7-day fumigation and the extended 10-day fumigation. The resistant rusty grain beetles were much harder to control (Table 2). As is often observed, the highest average phosphine concentrations were in the upper part of the silo and the lowest in the lower part of the silo. In the 7-day fumigation, there was a high level of population suppression (99.7%) of the rusty grain beetle in the top and middle cages but suppression was negligible (8.6%) in the bottom cages. Efficacy was better in the extended 10-day fumigation with high levels of suppression (99.4-100%) at all three levels of the silo. Similar average phosphine concentrations were achieved in the two fumigations but the extra 3 days made the 10-day fumigation much more effective against the strongly resistant rusty grain beetles.

Table 2. Phosphine efficacy against strongly phosphine resistant infestations of rusty grain beetle (*Cryptolestes ferrugineus*) in sealable silos (46.5 cubic metre volume)

Measurement	Cage location in silo	Fumigation trial	
		7-day	10-day
Average concentration (ppm)	Top	1368	1232
	Middle	936	899
	Bottom	577	628
Infestation suppression (%)	Top	99.7	100
	Middle	99.7	100
	Bottom	8.6	99.4

Figure 6. Flat grain beetles, *Cryptolestes* spp.

Grain protectant resistance

Grain protectant insecticides are used by many growers and other grain handlers where storage structures cannot be sealed well enough for fumigation. There has been a long history of stored grain pests developing resistance to protectants. GRDC has supported protectant resistance monitoring for many years, as well as research on managing resistant pests.

A study is under way testing grain pests to some commonly used protectants. Table 3 shows some preliminary results. As mentioned earlier, no single grain protectant will control all species or all resistant types within a species, so combinations of two or three protectants are needed. This is reenforced by these results.

Chlorpyrifos-methyl is an old organophosphate protectant that targets rust-red flour beetles and rice weevils. There was no evidence of resistance in either species.

S-methoprene is an insect growth regulator that targets lesser grain borers and several other pests. Resistance was first detected in lesser grain borers in the 1990s, so its lack of control of the lesser grain borer populations tested is not surprising. The poor control of rice weevils is expected – not because of resistance but an innate tolerance. S- methoprene controlled about half of the rust-red flour beetle populations and this could be because of resistance or a degree of innate tolerance.

Spinosad was registered for control of lesser grain borers but combined treatments were tested because spinosad is no longer available as a stand-alone treatment. The results for the spinosad combination treatments show how combinations can overcome various protectant resistances to maximise the breadth of pest coverage.

Table 3. Number of populations of lesser grain borer (*Rhyzopertha dominica*; LGB), rust-red flour beetle (*Tribolium castaneum*; RRFB) and rice weevil (*Sitophilus oryzae*; RW) controlled by grain protectant treatments.

Treatment (ppm)	Pest		
Number of populations tested for each pest (n)	LGB (n =7)	RRFB (n = 12)	RW (n = 5)
Chlorpyrifos-methyl (10)	0	12	5
S-methoprene (0.6)	0	5	0
S-methoprene (1) + spinosad (1)	7	12	0
Chlorpyrifos-methyl (10) + s-methoprene (1) + spinosad (1)	7	12	5

Successful storage of pulses

Managing pests of stored pulses

The pulse industry is growing rapidly in the GRDC northern region and the Queensland Government has recently supported a project on effective management practices for pests of stored pulses, especially mungbeans and chickpeas. A lot of research has been done overseas but this has limited relevance to Australia, because of the focus on cowpeas and subsistence agriculture.

Recent farm sampling in the GRDC northern region shows that infested mungbeans and chickpeas can contain pests normally associated with stored cereals, as well as the cowpea weevil (*Callosobruchus maculatus,* also known as bruchids), which is the major pest of stored pulses (Table 4). The cereal pests are probably not causing much damage to pulses, but their presence will negate their insect-free status. Cowpea weevil adults do not feed but the larvae cause major damage as they develop inside individual pulse seeds, and newly developed adults emerge from large exit holes in the pulse seeds (Figure 7).

Cowpea weevils are good fliers. Although the cowpea weevil is a serious pest of stored pulses, overseas studies show that it can infest the cowpea crop before harvest. For cowpeas at least and potentially other pulses, infestation can be caried over from the field and into storages. Pre-harvest infestation is rare in most pests of stored cereals, except for the maize weevil (*Sitophilus zeamais*).

Table 4. Detections of insect pests in infested mungbeans and chickpeas collected from farms in the GRDC northern region.

Pests	Mungbeans (8 samples)	Chickpeas (27 samples)
Cowpea weevil (*Callosobruchus maculatus*)	5	4
Lesser grain borer (*Rhyzopertha dominica*)	5	14
Rust-red flour beetle (*Tribolium castaneum*)	6	26
Rice weevil (*Sitophilus oryzae*)	0	6
Saw-toothed grain beetle (*Oryzaephilus surinamensis*)	0	2
Flat grain beetles (*Cryptolestes* species)	0	4

Figure 7. The distinctive large white eggs and round exit holes of the cowpea weevil (*Callosobruchus maculatus*) on mungbeans. The eggs are white because the larvae have hatched and burrowed into the mungbeans. (Source: QDAF)

Pest monitoring

As with stored cereals, regular monthly inspections and sampling of stored pulses is essential to check both grain quality and for the presence of pests. Sieving of pulse samples from the top and bottom of storages is useful for early detection, as is trapping with probe or pitfall traps placed in the grain surface. Newly laid cowpea weevil eggs are hard to see but are white after the larvae hatch and burrow into the seeds. Adult cowpea weevils are easy to see, as are the large exit holes in the seeds.

Aeration cooling

Population growth of insects is strongly dependent on temperature and aeration cooling has long been promoted as a chemical-free means of reducing infestation levels in stored cereals. Similarly, aeration cooling can be used to reduce infestation levels in cowpea weevils. Figures 8 and 9 show the impact of temperature on generation time and multiplication rate per generation in this pest. The temperature at which population growth was zero was estimated to be 17˚C using these results.

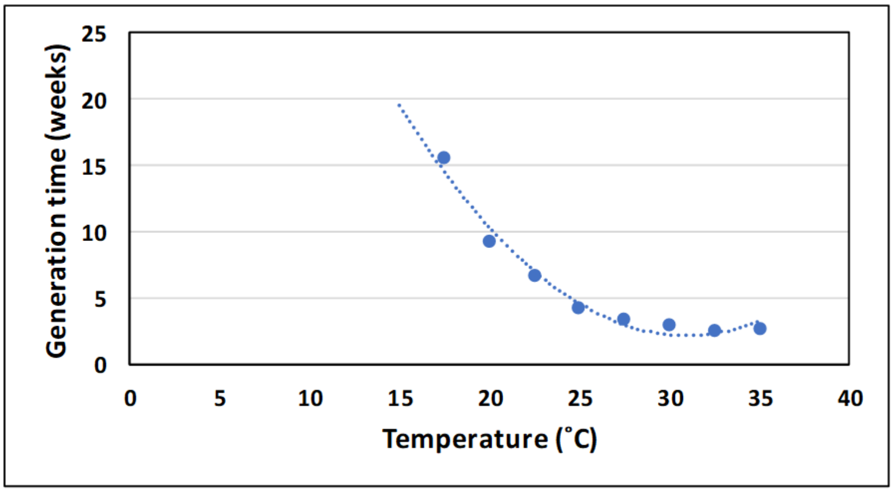

Figure 8. Effect of temperature on generation time of the cowpea weevil (*Callosobruchus maculatus*) in mungbean.

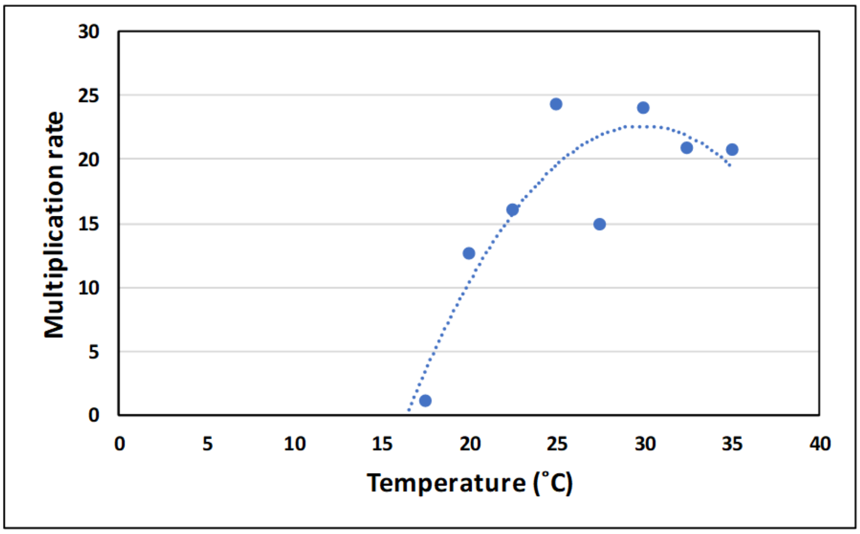

Figure 9. Effect of temperature on multiplication rate of the cowpea weevil (*Callosobruchus maculatus*) in mungbean.

Phosphine fumigation

Phosphine fumigation can be used by growers and other grain handlers to disinfest pulses and there is no evidence to date of resistance in the cowpea weevil. Because of a lack of information on the efficacy of phosphine against cowpea weevils, laboratory fumigations and silo-scale fumigations were conducted.

Phosphine efficacy against other pests is known to be affected by concentration and time. Therefore, this was investigated in the laboratory using fixed concentrations and exposure periods. Cages of pests were placed in the silo at several depths to evaluate fumigation success against cowpea weevil infestations. Mixed-age infestations containing all life stages (eggs, larvae, pupae and adults) were used because phosphine tolerance in other species can vary between life stages.

Table 5 shows that both higher phosphine concentrations and longer exposure periods increase phosphine efficacy against cowpea weevils. Some variation in tolerance to phosphine was evident between different test populations, but concentrations of 360-720 ppm for 7 days would result in high levels of infestation suppression.

Table 5. Phosphine efficacy against infestations of cowpea weevils (*Callosobruchus maculatus*) in laboratory fumigations.

Exposure (days)	Concentration (ppm)	Infestation suppression (%)		
		Mungbeans	Chickpeas (Desi)	Chickpeas (Kabuli)
1	360	54.7-86.8	87.8-99.2	96.8-100
	720	69.0-88.3	98.1-99.0	100
4	360	90.0-99.6	85.5-100	100
	720	99.8-100	99.8-100	97.1-100
7	360	99.8-100	100	100
	720	99.5-99.7	100	100

Two phosphine fumigation trials were conducted at Warwick on mungbeans (March 2019) and chickpeas (March 2021). Silos containing mungbeans or chickpeas were fumigated according to the registered label for fumigations using aluminium phosphide tablets. Cages were placed in the silo at several depths to evaluate fumigation success against cowpea weevil infestations. The cages contained all life stages (eggs, larvae, pupae and adults) because phosphine tolerance in other species can vary between life stages.

The results show that phosphine fumigation conducted according to the registered label resulted in high levels of suppression of cowpea weevil infestations (Table 6).

Table 6. Phosphine efficacy against infestations of cowpea weevils (*Callosobruchus maculatus*) in 7-day fumigations of sealable silos (11.1 cubic metre volume)

Measurement	Cage location in silo	Fumigation trial	
		Mungbeans	Chickpeas
Average concentration (ppm)	Top	1040	1187
	Middle	945	1199
	Bottom	909	1213
Infestation suppression (%)*	Top	99.8-100	100
	Middle	99.9-100	100
	Bottom	100	100

Diatomaceous earth (DE)

Diatomaceous earth (DE) can be used as a structural treatment as part of storage hygiene. Treating empty storages will control cereal pests sheltering in cracks and crevices. Field trials on structural treatments are difficult so DE efficacy against the cowpea weevil was investigated in the laboratory.

Concrete and stainless-steel surfaces were treated with a commercial DE product (Dryacide®) at the rate of 2 g/m^2 and held at either 25˚C and 55% RH or 30˚C and 70% RH. Efficacy was determined after 0 and 3 months by adding adults and monitoring mortality for up to 7 days. High levels of mortality occurred on treated concrete and steel within 7 days of exposure (Table 7).

Table 7. Mortality of cowpea weevils (*Callosobruchus maculatus*) exposed to surfaces treated with diatomaceous earth (DE) at 2 g/m^2.

Surface	Assessment	Storage conditions	
		25˚C and 55% RH	30˚C and 70% RH
Concrete	0 months	100% by 2 days	99.2% by 7 days
	3 months	100% by 2 days	99.2% by 7 days
Steel	0 months	100% by 2 days	100% by 7 days
	3 months	92.9% by 7 days	97.9% by 7 days

A new publication on pulse storage will be released in the second half of 2021. The publication "Best management practices for storage of pulses" will be published by Queensland's Department of Agriculture and Fisheries. It documents further research and management details to add to the pulse storage data included above. It provides the pulse industry in Australia with a valuable pulse storage management reference guide for the future.

Further information

GRDC fact sheet – Vigilant monitoring protects grain assets Vigilant Monitoring Protects Grain Assets | Stored Grain | Information Hub for Grain Storage, Quality Control, Insect & Pest Management

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

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

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

Corteva agriscience - Conserve Plus™ Grain Protector Conserve® Plus Grain Protectant | Corteva Agriscience

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

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Weed recognition technologies: development and opportunity for Australian grain production

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Key words

weed recognition, machine learning, ML, site-specific weed control, SSWC

GRDC Project codes

UOS2002-003, UOS1806-002AWX

Take home messages

- Visual spectrum weed images can be used to develop highly accurate weed recognition algorithms
- The ready availability of low-cost digital camera and processor technologies has created the opportunity for superior weed recognition capability
- Accuracy of recognition algorithms continues to improve, increasing the opportunity for precise weed detection and identification in Australian cropping systems
- Currently there is a lack of suitably collected and annotated weed image datasets that encompass the diversity of crop and weed species, as well as the complexity of the Australian grain production environment.

Background

Site-specific weed control (SSWC) involves the specific targeting of weeds with control treatments creating the potential to substantially reduce weed control inputs in low weed density situations. The availability of low-cost, durable processors and digital cameras, combined with increasingly accurate recognition technologies, has enabled highly accurate weed recognition capability for fallow and in-crop scenarios. Globally there is currently considerable research and development activities aimed at delivering SSWC across a range of production systems. Australian grain producers lead the world in the use of SSWC in fallow systems and their positive experiences have created the opportunity to fill a demand for the use of this approach for in-crop weed control.

Reflectance-based weed detection

In the 1980s and 1990s the development of technologies that allowed the detection of living plants led to the introduction of SSWC treatments for fallow weed control (Haggar *et al.* 1983; Felton 1990; Visser and Timmermans 1996). The weed detection systems used were based on a relatively simple process of using spectral filters and photodiode sensors to detect growing (green) plant tissue. As all living plants present in fallows are considered weeds, the reflection of near infrared light (NIR) by the chlorophyll in living plants enables the discrimination between these plants and the background soil or crop residues (Visser and Timmermans 1996). With the use of additional light sources, these weed detection systems can be used in a range of light conditions, including at night.

In Australia, reflectance-based weed sensing systems have been in use for over two decades in spot-spraying systems that are now widely adopted by Australian growers for fallow weed control (McCarthy *et al.* 2010). The application of herbicide in spot-spraying treatments can effectively control fallow weeds with substantially reduced amounts of herbicide. The substantial savings in weed control costs through the use of SSWC treatments has created opportunity to use more expensive herbicide treatments and non-chemical methods for the management of herbicide resistant weed problems (Walsh *et al.* 2020).

Camera-based weed detection

The expanded use of digital cameras and machine learning (ML) algorithms for image-based weed recognition in combination with smaller more powerful processors has enabled the development of field-scale and real-time SSWC for in-crop scenarios. The Raspberry Pi is an example of a low-cost single board computer that was developed as a teaching resource to promote computer science in schools. When coupled with a digital camera, the Raspberry Pi has many uses in simple computer vision related tasks, including fallow weed detection scenarios. SSWC systems for real-time use have been developed previously using Raspberry Pi computers for plant feature-based weed detection (Sujaritha *et al.* 2017; Tufail *et al.* 2021). Recent work has focussed on promoting to the Australian weed control community, the accessibility and availability of these technologies for construction of fallow weed detection. At present, although these camera-based weed detection systems are less-expensive, provide greater development opportunity and potentially more effective than current reflectance-based sensors, their use has been limited.

Development of machine learning (ML) based in-crop weed recognition for Australian grain production

Accurate recognition of commonly occurring weeds in Australian grain crops requires a highly sophisticated approach that can manage the complexities of crop-weed scenarios. The substantial benefits to using SSWC for fallow weed control has created a demand for the introduction of this approach for in-crop weed control across the cropping regions. The development of accurate weed recognition systems in horticultural crops is more easily achievable, with highly structured and predictable planting arrangements with slow travel speeds and consistent backgrounds. By contrast, the differences between crop and weed appearances are less pronounced in large-scale grain production systems, increasing the difficulty of developing reliable SSWC. Dense crop coverage in grain production systems exacerbates this challenge as large amounts of visual clutter makes it difficult to distinguish individual plants. Reflectance and simple image-based weed detection methods (e.g. colour thresholds and leaf edge detection) developed for fallow SSWC are not capable of dealing with this complexity. The substantial advance that a ML approach offers is the ability to reliably differentiate between weed and crop plants potentially to the point of identifying plant species. This opens a whole new application domain for in-crop SSWC. The use of digitally collected imagery has been identified as an approach that collects the type and quantity of data that allows for accurate discrimination between crop and weed plants (Thompson *et al.* 1991; M. Woebbecke *et al.* 1995). Imaging sensors, such as the standard digital camera, provide richer data streams with three channels (red, green and blue [RGB] images) of spatial and spectral intensity information. The richer data collected by these systems can be used for machine learning (ML) approaches that develop accurate weed recognition algorithms (Wang *et al.* 2019). With the promise of highly accurate (99%) in-crop weed recognition, there is now considerable research towards developing SSWC opportunities in cropping systems. These efforts are now resulting in commercial availability of detection systems for in-crop SSWC.

Recent examples of weed recognition algorithm development for Australian grain cropping

As part of a recently completed project 'Machine Learning for weed recognition', with GRDC investment weed recognition algorithms were developed for annual ryegrass (*Lolium rigidum*) and turnip weed (*Rapistrum rugosum*) plants present in wheat and chickpea crops. The weed recognition context evaluated was the early post-emergence stage where crop canopies are open, and weeds are readily visible in images collected from above. Using digital cameras mounted at a set height above the crop canopy, images of wheat and chickpea crops were collected in Narrabri and Cobbitty (NSW) during the winter growing seasons of 2019 and 2020. This image dataset was collected over two growing seasons and covers variable background and lighting conditions as well as different crop and weed growth stages. To prepare the image dataset so that it can be used to develop and train ML recognition algorithms, annual ryegrass and turnip weed plants in images were manually annotated with bounding boxes using 'Labelbox' image annotation software (Figure 1).

Figure 1. Sample bounding box annotations. Top row (red boxes): annual ryegrass (*Lolium rigidum*). Bottom row (green boxes): turnip weed (*Rapistrum rugosum*).

A range of convolutional neural network (CNN) architectures are freely available to use in developing object recognition tasks. These architectures are being continually challenged and improved by the machine learning community. To evaluate weed recognition capability, two recently developed ML architectures, YOLOv5 (June 2020) and EfficientDet (June 2020) as well as the more 'classical' architecture, Faster R-CNN (2015) were trained on the annual ryegrass and turnip weed dataset to develop recognition algorithms. To determine whether the background (crop type) of the images had an impact on weed recognition, the 2000 image dataset was split into three scenarios. In scenario one, only images of weeds in wheat were used for training (~1300) and testing (~300). In scenario two, only images of weeds in chickpea were used for training (~200) and testing (~50). In scenario three, the datasets were combined - images of weeds in both wheat and chickpea were used for training (~1500) and testing (~350).

The precision for all classes (wheat, chickpeas, annual ryegrass, turnip weed and background) reaches up to 0.3 for the YOLOv5-S algorithm (Table 1). This is much lower than the standard of 0.5 achieved by this algorithm on urban image datasets, clearly indicating the difficulty of weed recognition in cropping systems. There was consistently higher accuracy in the recognition of turnip weed (~0.6) than annual ryegrass (~0.08) for all ML architectures across all three crop scenarios. Superior accuracy in recognition of the broadleaf weed (turnip weed) in comparison to the grass weed (annual ryegrass) is an indication of the respective challenges for these weed types. Broadleaf weeds have a very different and distinct phenotype when compared to a cereal grain crop. This makes identifying them a simpler task for both human experts and ML algorithms. Conversely, grass weeds can be nearly indistinguishable from the crop and even pose a difficult challenge for human experts when annotating the data. Recognition of turnip weed was substantially more accurate in wheat (0.6) than in chickpea (0.1) crops, potentially reflecting the influence on accuracy of differences in plant morphologies between the crop and weed species, but also that there was a smaller chickpea data set.

Table 1. Summary of precision results for YOLO v5 XL, YOLOv5 S, EfficientDet-D4 and Faster R-CNN ResNet-50 deep learning architectures. Each model was trained on three scenarios, weeds in wheat, weeds in chickpea and weeds in both wheat and chickpea. Cells coloured dark grey indicate best performance with progressively lighter grey shading highlighting reducing precision. White cells coloured red indicate poorest performance.

Context	Algorithm	Approx. parameters (M)	Rank	All	Annual ryegrass	Turnip weed
Ryegrass and *turnip weed* in **wheat**	YOLOv5 XL	87.7	2	0.28	0.079	0.640
	Faster R-CNN ResNet-50	41.5	4	0.178	0.048	0.471
	EfficientDet-D4	19.5	5	0.184	0.024	0.506
	YOLOv5 S	7.3	1	0.300	0.080	0.600
Ryegrass and *turnip weed* in **chickpea**	YOLOv5 XL	87.7	1	0.136	0.036	0.116
	Faster R-CNN ResNet-50	41.5	4	0.058	0.010	0.034
	EfficientDet-D4	19.5	5	0.055	0.011	0.015
	YOLOv5 S	7.3	2	0.130	0.050	0.084
Ryegrass and *turnip weed* in **wheat** and **chickpea**	YOLOv5 XL	87.7	2	0.288	0.069	0.577
	Faster R-CNN ResNet-50	41.5	5	0.139	0.023	0.330
	EfficientDet-D4	19.5	4	0.169	0.020	0.437
	YOLOv5 S	7.3	1	0.310	0.076	0.590

In a recently completed 'Intelligent Robotic Non-Chemical Weeding project which was part of a GRDC Innovation Program, ML based weed recognition algorithms were developed for turnip weed and annual ryegrass plants present in wheat and chickpea crops during the late-post emergence stage. Weed images were collected by a camera contained within a shroud with a constant light source (Figure 2). The shroud allowed images to be collected of weeds present beneath the crop canopy in a consistent light environment.

The collected images were subsequently labelled using a labour-intensive, pixel-wise annotation process for a more precise algorithm that returns detections at the pixel-level rather than the previous bounding box level. The algorithms from this approach resulted in high levels of weed recognition precision for turnip weed 0.75 and annual ryegrass 0.65 in wheat (Figure 3). These substantially, higher levels of precision compared to the early post-emergence results are likely due to a combination of factors. These include the use of a more precise pixel-wise annotation technique compared to the bounding box approach, consistent lighting used in the collection of all weed images with these images taken in the same field. Essentially the more accurate weed recognition algorithm developed for the late post-emergence scenario was based on a more specific and precise weed image dataset.

Figure 2. Autonomous platform with suspended shroud containing a digital image collection system and a constant light source.

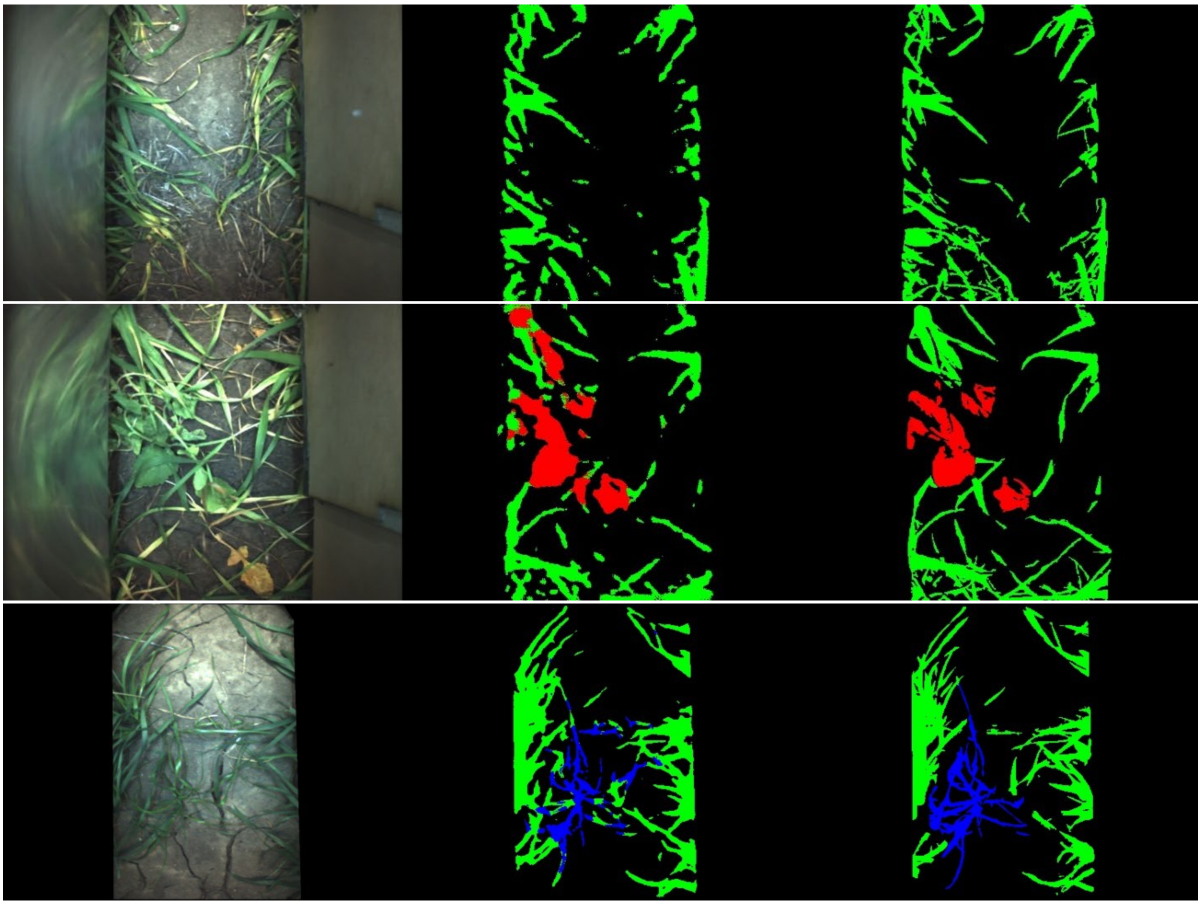

Figure 3. Sample images of image segmentation. Each row is a different example. Images from the left to right columns are: the input RGB image, segmentation results from the ML algorithm, and pixelwise manually segmented 'ground-truth' training data. In the segmented images, green pixels are wheat, red pixels are broadleaf weed, and blue pixels are ryegrass weed.

Summary

The development of weed recognition technologies for SSWC is now focused on the use of ML approaches that will enable accurate detection and identification of weeds in fallows and crops. As well as high potential accuracy, the focus on this approach is being driven by recent ML developments and the low-cost and ready availability of suitable digital cameras and processors. Camera based systems that use algorithms for fallow weed detection have proven high levels of accuracy that are similar if not better than the current reflectance based sensing systems. Increasing interest in the development of in-crop SSWC has resulted in a focus on more sophisticated weed recognition systems for use in both crop and fallow situations. Future SSWC in Australian grain production will be driven by highly accurate ML developed weed recognition algorithms. At present though there is a need to define the weed image dataset requirements, image annotation processes and appropriate ML architectures that are required to enable this opportunity.

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Optical sprayers - management optimisation and field experience with their use on robotic platforms

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Pushing the tech boundary - Grower experience with camera sprayers on robotic platforms

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Fusarium crown rot seed fungicides: independent field evaluation 2018-2020

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Keywords

fungicide seed treatments, yield loss, wheat, barley, durum, disease

GRDC code

DAN00213: Grains Agronomy & Pathology Partnership (GAPP) - A strategic partnership between GRDC and NSW DPI (Project BLG208) and DAN00175: National crown rot epidemiology and management program.

Take home messages

- Current fungicide seed treatments registered for the suppression of Fusarium crown rot (FCR) inconsistently reduce the extent of yield loss from FCR
- Syngenta® experimental (Tymirium™ technology) had consistent and stronger activity on limiting yield loss from FCR
- However, under high infection levels significant yield loss may still occur in drier seasons
- Fungicide seed treatments, including the Syngenta experimental, should not be considered standalone control options for FCR
- Seed treatments should be used as an additional tool within existing integrated disease management strategies for FCR.

Introduction

Fusarium crown rot (FCR), caused predominantly by the fungal pathogen *Fusarium pseudograminearum* (*Fp*), is a major constraint to winter cereal production across Australia. A range of integrated management strategies, including crop rotation, varietal selection, inter-row sowing, sowing time, stubble and fallow management are required to minimise losses. A number of fungicide seed treatments have been registered for the suppression of FCR in recent years with a further product from Syngenta likely to be available to Australian growers prior to sowing in 2023. Although chemical companies conduct their own widespread field evaluation across Australia, growers and their advisers value independent evaluation of the potential relative fit of these fungicide seed treatments within integrated management strategies for FCR.

What we did

A total of 11 replicated plot experiments (generally 2 x 10 m with minimum of 3 replicates) were conducted across NSW from 2018-2020 with one additional field experiment conducted in Victoria (Horsham) and two in WA (Merredin and Wongan Hills) in 2018 only (Table 1). The winter cereal crop and number of varieties differed between experiments with wheat (W), barley (B) and/or durum (D) evaluated in each experiment (Table 1).

Six fungicide seed treatments: Nil, Vibrance® (difenoconazole + metalaxyl-M + sedaxane at 360 mL/100 kg seed), Rancona® Dimension (ipconazole + metalaxyl at 320 mL/100 kg seed), EverGol®Energy (prothioconazole + metalaxyl + penflufen at 260 mL/100 kg seed) and Syngenta experimental (Tymirium™ technology based on cyclobutrifluram at 40 and/or 80 g active ingredient/100 kg seed). All fungicide seed treatments were applied in 1 to 3 kg batches using a small seed treating unit to ensure good even coverage of seed.

All field experiments used an inoculated vs uninoculated randomised complete block design with inoculated plots infected by *Fp* inoculum grown on sterilised wheat grain added at 2.0 g/m of row at sowing. This ensures high (>80%) FCR infection in inoculated plots with uninoculated plots only exposed to any background levels of *Fp* inoculum naturally present across a site. This design allows comparison between the yield effects of the various fungicide seed treatments in the presence and absence of FCR. Yield loss from this disease is measured as the difference between inoculated and uninoculated treatments.

What did we find?

Lower levels of in-crop rainfall between March and September generally lowered the yield potential at each site in each season, but also increased the extent of FCR yield loss. This was highlighted in the nil seed treatments where yield loss ranged from 11 to 48% in 2018, 14 to 20% in 2019 and 11 to 37% in 2020 (Table 1).

Table 1. Effect of various fungicide seed treatments on yield loss (%) associated with Fusarium crown rot infection in 14 replicated inoculated vs uninoculated field experiments – 2018 to 2020

Year	Location	Crop[A]	Rainfall[B] (mm)	Yield[C] (t/ha)	%Yield loss from Fusarium crown rot[D]					
					Nil	Vibrance	Rancona Dimension	EverGol Energy	Syngenta 40 gai[E]	Syngenta 80 gai[E]
2018	Merriwagga, NSW	2W	63	1.44	44	nd[F]	nd	32	25	18
	Mallowa, NSW	2W	73	1.73	48	nd	nd	nd	26	24
	Gilgandra, NSW	2W	93	2.14	42	35	27	28	16	9
	Merredin, WA	2W	182	2.66	35	nd	nd	nd	23	13
	Horsham, Vic	2W	185	2.56	21	nd	nd	nd	+2[I]	+5
	Wongan Hills, WA	2W	291	3.27	11	nd	nd	nd	1	0
2019	Gulargambone, NSW	W/B	141	3.12	20	2	5	9	-[G]	+2
	Narrabri, NSW	W/B	200[H]	4.01	14	10	9	7	-[G]	6
2020	Boomi, NSW	3W/D	202	4.91	37	nd	28	nd	24	18
	Gurley, NSW	W/B	234	6.50	13	nd	nd	nd	-	1
	Rowena, NSW	W/B	247	6.21	12	7	nd	4	-	2
	Trangie, NSW	3W/D	412	4.13	26	20	23	19	4	2
	Gilgandra, NSW	3W/D	420	4.07	12	6	7	7	3	0
	Armatree, NSW	3W/D	425	4.37	11	nd	nd	7	3	+1

[A] Winter crop type variety numbers where W = wheat variety, B = barley variety and D = durum variety.
[B] Rainfall in-crop from March to September at each site. Critical time for fungicide uptake off seed and expression of FCR.
[C] Yield in uninoculated treatment (average of varieties) with nil seed treatment.
[D] Average percentage yield loss from FCR for each seed treatment (averaged across varieties) compared with the uninoculated/nil seed treatment.
[E] gai = grams of active ingredient.
[F] nd = no difference, %yield loss from FCR with fungicide seed treatment not significantly different from the nil seed treatment. Values only presented when reduction in %yield loss from FCR significantly lower than the nil seed treatment.
[G] 40 gai treatment not included at these sites.
[H] Included two irrigations at GS30 and GS39 of 40 mm and 30 mm respectively due to drought conditions.
[I] Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (i.e. the treatment reduced impact from both the added FCR inoculum as well as natural background levels of fusarium present at that site.)

Vibrance and Rancona Dimension significantly reduced the extent of yield loss from FCR in 6 of 14 experiments whilst EverGol Energy reduced FCR yield loss in 8 of 14 field trials (Table 1). However, the Syngenta experimental product significantly reduced yield loss from FCR in 10 of 10 trials at the 40 gai rate and 14 of 14 field experiments at the 80 gai rate (Table 1). The reduction in yield loss was also generally stronger with this product compared with the other fungicide seed treatments and better at the 80 gai than 40 gai rate (Table 1).

Significant yield loss (9 to 26%) still occurred with the Syngenta experimental treatment at generally drier sites which exacerbated yield loss from FCR (>35% in nil seed treatment). However, the 80 gai rate at these 'disease conducive sites', still at least halved the extent of yield loss compared with the nil seed treatment (Table 1). At wetter sites where yield loss from FCR was lower (<26%) the Syngenta experimental reduced the extent of yield loss to <6% with a yield increase at some sites due to reduced impact from background levels of FCR infection (Table 1). Moisture stress during grain filling is known to exacerbate yield loss from FCR and favour the growth of *Fp* within the base of infected plants. Dry soil conditions around seeding depth throughout the season is also likely to restrict the movement of fungicide actives off the seed coat into surrounding soil and subsequent uptake by root systems. This would reduce movement of the fungicides into the sub-crown internode, crown and tiller bases where FCR infection is concentrated. It is currently not clear whether reduced efficacy under drier conditions may be related to one or both of these factors.

What about durum?

Durum wheat is known to have increased susceptibility to FCR compared with many wheat and barley varieties. Consequently, the increased prevalence of FCR in farming systems with the adoption of conservation cropping practices, including retention of cereal stubble, has seen durum removed from rotations due to this increased disease risk. The durum variety DBA Lillaroi⊕ was compared with three bread wheat varieties at four sites in 2020 (Table 2).

Table 2. Effect of Syngenta experimental seed treatment at two rates on the extent of yield loss[A] (%) from Fusarium crown rot in three bread wheat (W) and one durum (D) variety at three sites in 2020

Variety	Boomi 2020			Trangie 2020			Gilgandra 2020			Armatree 2020		
	Nil[B]	Syngenta 40 gai	Syngenta 80 gai	Nil	Syngenta 40 gai	Syngenta 80 gai	Nil	Syngenta 40 gai	Syngenta 80 gai	Nil	Syngenta 40 gai	Syngenta 80 gai
Lancer⊕ (W)	29	23	20	30	10	8	13	2	0	9	4	+7[C]
Mitch⊕ (W)	39	18	11	13	+2	+5	9	2	1	5	0	0
Trojan⊕ (W)	34	22	18	20	4	2	12	1	0	14	2	2
Lillaroi⊕ (D)	48	32	24	45	11	6	16	5	+2	14	6	+2

[A] Average percentage yield loss from FCR for each seed treatment compared with the uninoculated/nil seed treatment for that variety.

[B] Nil = no seed treatment.

[C] Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (i.e. the treatment reduced impact from both the added FCR inoculum as well as natural background levels of fusarium present at that site).

The extent of yield loss from FCR with nil seed treatment was generally higher in the durum variety (14 to 48%) compared with the three bread wheat varieties (5 to 39%). With the exception of the Boomi site, the wheat variety Mitch⊕ tended to have reduced yield loss from FCR compared with the other entries (Table 2). Yield loss from FCR was reduced with the Syngenta experimental in both the bread wheat and durum varieties (Table 2). Even in the higher loss site at Boomi in 2020, the 80 gai rate halved the extent of yield loss in the durum variety Lillaroi⍉ with better efficacy in the other three sites.

Conclusions

Current fungicide seed treatments registered for the suppression of FCR can inconsistently reduce the extent of yield loss from this disease. The Syngenta experimental (Tymirium technology) appears to have more consistent and stronger activity on limiting yield loss from FCR. However, under high infection levels, as created with artificial inoculation in these experiments, significant yield loss may still occur, particularly in drier seasons. Dry soil conditions around seeding depth throughout a season may reduce the uptake of fungicide actives applied to the seed coat. Drier seasons also exacerbate FCR expression which would place additional pressure on fungicide seed treatments. Consequently, fungicide seed treatments, including the Syngenta experimental, should not be considered standalone control options for FCR. Rather, they should be used as an additional tool within existing integrated disease management strategies for FCR.

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Fungicide resistance in wheat powdery mildew across NSW and northern Victoria in 2020

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Keywords

fungicide resistance, reduced sensitivity, disease, varietal resistance, management

GRDC code

DAN00213: Grains Agronomy & Pathology Partnership (GAPP) - A strategic partnership between GRDC and NSW DPI (Project BLG208) and CUR1905-001SAX

Take home messages

- The wheat powdery mildew pathogen has a very high risk of developing fungicide resistance
- Resistance to Group 11 (QoI) fungicides has been detected across most of the southern growing region and was detected in parts of NSW in 2020
- Widespread resistance or reduced sensitivity to Group 3 DMIs is considered an extremely high risk and a DMI 'gateway' mutation was detected at very high frequency across NSW and northern Victoria in 2020
- Careful use and rotation of available fungicide actives will help control the spread of resistance in wheat powdery mildew
- Agronomic practices that minimise disease pressure reduce the need to apply fungicides
- Good management will help protect the long-term efficacy of current fungicides.

Introduction

A key challenge in 2020 winter cropping season was the level of wheat powdery mildew (WPM), caused by *Blumeria graminis* f. sp. *tritici* (*Bgt*), across much of NSW and northern Victoria. High mineralised soil nitrogen levels following 2-3 years of drought favoured thick canopies and elevated leaf nitrate levels which favour WPM infection. WPM infections progressed into heads late in the season in some regions. Infection occurred in a range of bread wheat and durum varieties, especially Scepter⏀ and Vixen⏀ (Table 1) which are susceptible-very susceptible (SVS) to WPM and grown widely across the affected regions. WPM occurred predominantly in high-value, irrigated cropping regions, which create ideal conditions for disease development but was also prevalent in a number of dryland crops in the wet 2020 season. There were concerns around fungicide management with less than desirable control achieved. Factors contributing included:

- potentially reduced fungicide sensitivity and/or resistance in the pathogen,
- application timing - i.e., too much time between stripe rust fungicide timings to cope with the quicker cycle time and rapid infection that occurs with WPM and/or,
- spray coverage, especially of heads, which are a horizontal target.

Many crops had 2-4 in-crop fungicide applications during the season, yet WPM continued to progress. *Bgt* has a remarkable ability to adapt to fungicide treatments, which makes this pathogen a high resistance risk for the development of fungicide resistance.

In response, a collaboration with the Centre for Crop Disease Management (CCDM) based at Curtin University in WA was rapidly established to collect and analyse WPM samples for levels of fungicide resistance.

Wheat powdery mildew is favoured by susceptible wheat varieties growing in mild and humid weather (15° to 22°C, relative humidity > 70%), with a dense crop canopy, high nitrogen levels, good soil moisture profiles and extended periods of damp, humid conditions under the canopy. *Bgt* survives on wheat stubble and volunteer wheat plants. Spores can be spread to crops by the wind over moderate distances (kilometres). The pathogen is crop specific and only infects wheat, not barley or other grain crops.

What we did

WPM samples were collected by collaborating agronomists, sent to Tamworth for processing to help ensure viability in transit and sent to CCDM for molecular analysis of frequency of mutations for DMI (F136 'gateway' mutation, triazoles) and QoI (A143 mutation, strobilurins) resistance within the WPM population in each sample. Nineteen viable WPM samples were analysed by CCDM from across NSW and northern Victoria, with sample distribution being; NE Vic (4), SE NSW (5), SW NSW (8), NE NSW (1) and NW NSW (1)(Table 1). Further laboratory and glasshouse testing is continuing with CCDM to determine the relative sensitivity of these WPM populations to various DMI actives.

What we found

The F136 mutation, also known as a 'gateway', has been previously associated with reduced sensitivity to some DMI (Group 3, triazole) fungicides. This mutation is normally found together with other mutations that are ultimately responsible for the resistant phenotype observed in the field. Once the frequency of the F136 and other mutations in a WPM pathogen population reach moderate levels, then reduced sensitivity to DMI fungicides is possible under field conditions. Very high frequencies may result in resistance to WPM and spray failure under field conditions with some DMI actives. The F136 'gateway' mutation itself does not necessarily mean field failure. It is however an initial warning that issues with continued DMI fungicide use exist. Field efficacy of DMI fungicides in the presence of this 'gateway mutation', can vary considerably with individual DMI actives, depending on what other mutations exist once this 'gateway' mutation occurs within a WPM population.

All 19 NSW/Vic WPM samples had a F136 frequency of between 62 to 100% (Table 1). Such a high frequency of DMI resistance across NSW/Vic was surprising but not unexpected given the lack of field control in these crops in 2020. A lower frequency of the QoI A143 muttaion was detected which ranged from 51 to 98% (Table 1). Presence of this mutation in the WPM pathogen population is associated with complete resistance to strobilurin fungicides (e.g., azoxystrobin) and can become ineffective under field conditions at frequencies above 50%. This is alarming, as four of the WPM pathogen populations appear to have dual resistance to DMI (Group 3) and QoI (Group 11) modes of action (MOA). The strobilurins are known to rapidly succumb to fungicide resistance, which is why they are always mixed with another MOA fungicide group (usually DMIs, Group 3). The high frequency of DMI F136 in NSW/Vic WPM pathogen populations is likely increasing the rate of selection for QoI resistance.

A concerning aspect in relationship to the QoI A143 resistance gene, is that it confers cross resistance to all fungicides within the group 11 mode of action group (strobilurins).

Table 1. Location of 19 wheat powdery mildew samples collected across NSW in 2020 and frequency of DMI (triazole) gateway and QoI (strobilurin) mutations

Location	State	Variety	DMI F136	QoI A143
Katamatite	NE Vic	Scepter⍉	100%	90%
Katamatite	NE Vic	Scepter⍉	100%	90%
Cobram	NE Vic	Scepter⍉	100%	46%
Cobram	NE Vic	Scepter⍉	100%	28%
Balldale	SE NSW	Scepter⍉	100%	98%
Walbundrie	SE NSW	Scepter⍉	100%	5%
Rennie	SE NSW	Suntop⍉	85%	27%
Rennie	SE NSW	Scepter⍉	85%	20%
Deniliquin	SW NSW	Scepter⍉	99%	35%
Deniliquin	SW NSW	Scepter⍉	99%	20%
Deniliquin	SW NSW	Scepter⍉	83%	20%
Jerilderie	SE NSW	Scepter⍉	100%	37%
Hillston	SW NSW	Vittaroi⍉	96%	21%
Hillston	SW NSW	Vixen⍉	94%	3%
Hillston	SW NSW	Vixen⍉	85%	6%
Yenda	SW NSW	Cobra⍉	100%	44%
Yenda	SW NSW	Vixen⍉	100%	12%
Edgeroi	NE NSW	Lillaroi⍉	82%	29%
Wee Waa	NW NSW	Bindaroi⍉	62%	51%

Fungicide resistance terminology

To address the 'shades of grey' surrounding fungicide resistance and how it is expressed as a field fungicide failure, some very specific terminology has been developed.

When a pathogen is effectively controlled by a fungicide, it is defined as sensitive to that fungicide. As fungicide resistance develops, that sensitive status can change to:

- **Reduced sensitivity**
  When a fungicide application does not work optimally but does not completely fail.

  This may not be noticeable at field level, or the grower may find previously experienced levels of control require higher chemical concentrations up to the maximum label rate. Reduced sensitivity must be confirmed through specialised laboratory testing.

- **Resistance**
  When a fungicide fails to provide disease control in the field at the maximum label rate.

  Resistance must be confirmed by laboratory testing and be clearly linked to a loss of control when using the fungicide correctly in the field.

- **Lab detection**
  A measurable loss of sensitivity can often be detected in laboratory *in vitro* tests before or independent of any loss of fungicide efficacy in the field. Laboratory testing can indicate a high risk of resistance or reduced sensitivity developing in the field.

The Australian grains crop protection market is dominated by only three major mode of action (MoA) groups to combat diseases of grain crops; the DMIs (Group 3), SDHIs (Group 7) and strobilurins (or quinone outside inhibitors, QoIs, Group 11). Having so few MoA groups available for use increases the risk of fungicide resistance developing, as growers have very few alternatives to rotate in order to reduce selection pressure for these fungicide groups.

With two of the three fungicide MoA groups now compromised in some paddocks in New South Wales and Victoria, all growers and advisers need to take care to implement fungicide resistance management strategies to maximise their chances of effective and long-term disease control.

The Australian Fungicide Resistance Extension Network (AFREN), a GRDC investment, suggests an integrated approach tailored to local growing conditions. AFREN has identified the following five key actions, “The Fungicide Resistance Five”, to help growers maintain control over fungicide resistance, regardless of their crop or growing region:

1. Avoid susceptible crop varieties
2. Rotate crops – use time and distance to reduce disease carry-over
3. Use non-chemical control methods to reduce disease pressure
4. Spray only if necessary and apply strategically
5. Rotate and mix fungicides/MoA groups.

Managing fungicide resistance

It is important to recognise that fungicide use and the development of fungicide resistance, is a numbers game. That is, as the pathogen population increases, so does the likelihood and frequency of naturally resistant strains being present. A compromised fungicide will only control susceptible individuals while the resistant strains within the population continue to flourish.

As a result, it is best if fungicides are used infrequently and against small pathogen populations. That way, only a smaller number of resistant individuals will be present to survive the fungicide application, with many of these remaining vulnerable to other competitive pressures in the agro-ecosystem.

Keeping the pathogen population low can be achieved by taking all possible agronomic steps to minimise disease pressure and by applying fungicide at the first sign of infection once the crop has reached key growth stages. In cereals, the leaves that contribute most to crop yield are not present until growth stage 30 (GS30/start of stem elongation.) Foliar fungicides applied prior to this are more often than not a waste of money and unnecessarily place at risk the longevity of our cost-effective fungicide resources by applying an unneeded selection pressure on fungal pathogens for resistance.

Integrated management strategies

Management practices to help reduce disease pressure and spread include:

- **Planting less susceptible wheat varieties**
  Any level of genetic resistance to WPM slows the rate of pathogen and disease development within a crop and reduces the reliance on fungicides to manage the disease. Avoid growing SVS and VS wheat varieties in disease-prone areas.

- **Inoculum management**
  Killing volunteer wheat plants during fallow periods and reducing infected wheat stubble loads will reduce the volume of spores spreading into an adjacent or subsequent wheat crop.

- **Practicing good crop rotation**
  A program of crop rotation creates a dynamic host environment that helps reduce inoculum levels from year to year. Rotating non-susceptible wheat varieties can also provide a more dynamic host environment, forcing the pathogen to adapt rather than prosper.

- **Disease levels can be higher with early planting**
  Later planting can delay plant growth until after the initial warm and damp period of early winter that favours WPM. This is important as infection of young plants can lead to increased losses at maturity. Later sown crops also tend to develop smaller canopies which are less conducive to powdery mildew infection. However, delayed sowing can have an associated cost of reduced yield potential in some environments which should be carefully considered by growers.

- **Careful nitrogen management**
  As excess nitrogen favours disease development, nitrogen application should be budgeted to measured soil N levels and target yield so as to be optimised to suit the growing purpose.

- **Encouraging air circulation**
  Actions that help increase airflow into the crop canopy can help lower the relative humidity. This can include wider row spacing, reduced plant populations (note yield potential should still be maximised). In mixed farming systems grazing by livestock can be used to reduce and open up the early season crop canopy, with potential to reduce the level of disease inoculum present at commencement of stem elongation when the 'money leaves' start to appear.

Fungicide recommendations for wheat

Planning of fungicide rotations needs to consider all fungal pathogens that may be present in the crop. Otherwise the fungicide treatment for one pathogen may select for resistance in another. For example, whilst there is little evidence of the development of fungicide resistance in rust populations globally, growing S-VS rust varieties means the only control option is fungicides. This can potentially have off-target selection pressure on the development of other fungal pathogens such as *Bgt* which is very prone to developing fungicide resistance.

Careful fungicide use will minimise the risk of fungicide resistance developing in WPM in Australia and help ensure the longevity of fungicides.

Advice to NSW and Victorian wheat growers includes:

- **Avoid using Group 11** fungicides in areas where resistance to QoIs has been reported.

- **Minimise** use of the **Group 3** fungicides that are known to have compromised resistance.
- **Monitor Group 3** fungicides closely, especially where the gateway mutation has been detected.
- **Rotate Group 3** fungicide actives within and across seasons. In other words, do not use the same Group 3 product twice in succession.
- **Avoid** more than three applications of fungicides containing a **Group 3** active in a growing season.
- **Group 11** fungicides should be used as a preventive, rather than for curative control and should be rotated with effective **Group 3** products.
- **Avoid** applying **Group 7** and **Group 11** products more than once per growing season, either alone or in mixtures. This includes in-furrow or seed treatments, as well as subsequent foliar sprays. Combined seed and in-furrow treatments count as one application.

Growers and agronomists who suspect DMI reduced sensitivity or resistance should contact the CCDM's Fungicide Resistance Group at frg@curtin.edu.au. Alternatively, contact a local regional plant pathologist or fungicide resistance expert to discuss the situation. A list of contacts is on the AFREN website at grdc.com.au/afren.

Further information on fungicide resistance and its management in Australian grains crops is available at the AFREN website at grdc.com.au/afren.

Conclusions

NSW and Victorian growers need to be aware that issues with fungicide resistance already exist with WPM which could result in reduced fungicide sensitivity or potentially spray failures with DMI (triazoles) and QoI (strobilurin) fungicides. Further testing by CCDM is ongoing as to the level of reduced sensitivity to different DMI actives in these WPM pathogen populations, which will be communicated to growers and their advisers. Fungicide resistance is real and needs to be managed using an integrated approach to limit further development of fungicide resistance within WPM pathogen populations and in other at-risk fungal pathogens (e.g., net-blotches in barley and yellow spot or Septoria tritici blotch in wheat).

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Can we make sorghum production more reliable in western zones?

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Key words

sorghum, yield, risk, early sowing, water use efficiency, row configuration, plant population

GRDC codes

DAN00150 Sorghum in the western zone
UOQ 1808-001RTX Optimising sorghum agronomy

Take home message

- Grain sorghum offers the opportunity to include a summer rotation crop, rotate herbicide chemistry, split labour, split logistics and importantly, increase cash flow
- Ensuring profitable, low risk sorghum production in western regions remains a challenge in some seasons
- Early sown sorghum reduces the risk of crop exposure to heat and moisture stress at critical flowering and grain fill periods through altering the crop growth pattern, water use and time to flowering
- Solid plant offers more advantages in seasons where yields are likely to be above 3.0 t/ha. Using skip or wide row configurations can potentially reduce the risk of crop failure by saving soil water for post anthesis but can also limit yield potential
- Growers should target establishing plant populations close to 5.0 plants/m^2
- Additional trial data should be generated this coming season, which will help provide localised data around crop water use and flowering windows for a range of hybrids.

Sorghum in western zones – its not a new thing!

Grain sorghum has been grown in north west New South Wales (NW NSW) for many years. In the last 20 years sorghum production peaked in 2005-6 when an estimated 100,000 ha was planted to sorghum (NSW DPI grains report 2012). In 2000-2010, the average area planted to sorghum in NW NSW was approximately 25,000 ha, with yields averaging just over 2 t/ha.

In the last decade, the area planted to sorghum has been considerably reduced, with growers increasingly planting to both chickpea and cotton, due to less perceived growing risk and higher returns. One of the main challenges in recent years has been growing profitable sorghum in an increasingly variable climate, where periods of extreme heat and moisture stress seem to be more common.

Since 2017, the Grains Research and Development Corporation (GRDC), University of Queensland (UQ), NSW Department of Primary Industries (DPI) and Queensland Department of Agriculture and Fisheries (QDAF) have partnered in a research program to test the boundaries of sowing sorghum earlier than usual (or 'earlier than is generally recommended')and measuring the impacts on plant establishment, crop development, grain yield and quality. Research trials have been conducted in central and southern Queensland (Qld) as well as Moree, Mungindi and the Liverpool Plains in northern NSW.

The aim of this research was to generate new data that would increase the confidence of growers to include sorghum in rotations in the western zones.

Early sowing – pros and cons

Establishment

Traditionally the sorghum planting window commences in early -mid September when soil temperatures reach 16 -18°C. We have conducted trials over the last three seasons where we have planted sorghum when soil temperatures are at a minimum of 12°C, that is, commencing sowing in early -mid August at sites north and south of Mungindi and north of Moree.

These trials have proved that early sowing is possible, but success is dependent upon:

1. Ability to source high quality seed (germination and vigour)

The largest factor impacting on seed establishment in our trials has been the inherent seed germination and vigour. Results of seed quality testing of our trial seed to date has shown high variability in seed lot germination percentages (Figure 1) between hybrids, seedlots and across temperatures. More significant differences in germination appeared between hybrids with germination reducing as temperature increased from 15 to 35 °C.

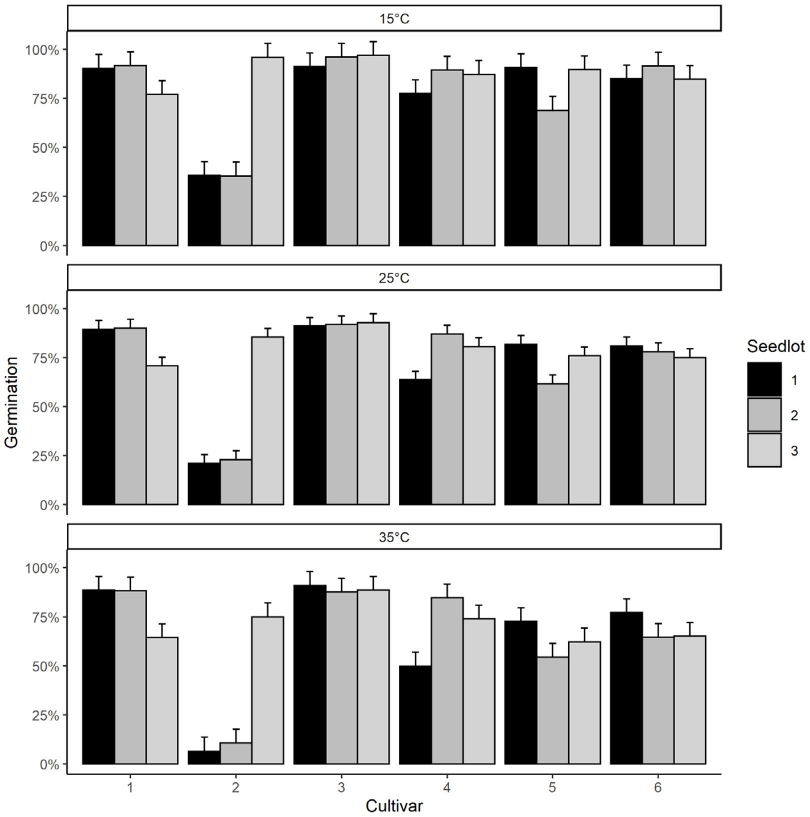

Figure 1. Germination percentage for each genotype and seedlot used in trials between 2018 and 2021 at 3 temperatures. Seedlot 1 was sourced in 2018-19, seedlot 2 was sourced in 2019-20 and seedlot 3 was sourced in 2020-21. Seed was kept in cool storage until evaluation in 2020. Error bars show pooled standard error (n=4).

While variability in seed quality is expected based on varying production conditions and is managed by seed companies to the best of their ability, the challenge for growers and advisors is obtaining information on their seed prior to planting. As is often said, “you can’t manage what you don’t know”. This becomes more difficult when there is a lack of a standardised commercial test to accurately measure the germination seed vigour on seed lots prior to planting.

2. Acceptance of reduced establishment percentages

Commercial planting rates are usually calculated on an expected seed establishment percentage of around 80%. Our trials have shown that early sowing results in much lower seed establishment percentages. This could be attributed to several factors including

1. Colder soil temperatures
2. Longer time for seed to imbibe and emerge
3. Disease/pests or
4. Inadequate soil moisture around the seed to complete the process.

At “Bullawarrie” Mungindi in 2020-21, the average establishment percentage from actual seed sown was 31% for time of sowing 1 (TOS1), sown on the 4th August. This was in comparison to 78% from time of sowing 2 (TOS 2) sown on the 1st September (Figure 2). Establishment percentages were averaged across hybrids and populations. Soil temperatures (average soil temps) for the 7 days following sowing were 9.3 and 14.7 ° C at 8 am for TOS 1 and TOS 2 respectively. Differences in hybrid establishment have been correlated with the germination percentage of the seed. There have therefore been no significant differences between hybrids establishment under cold conditions. Additional research is planned this season to test alternative methods to improve establishment in the field.

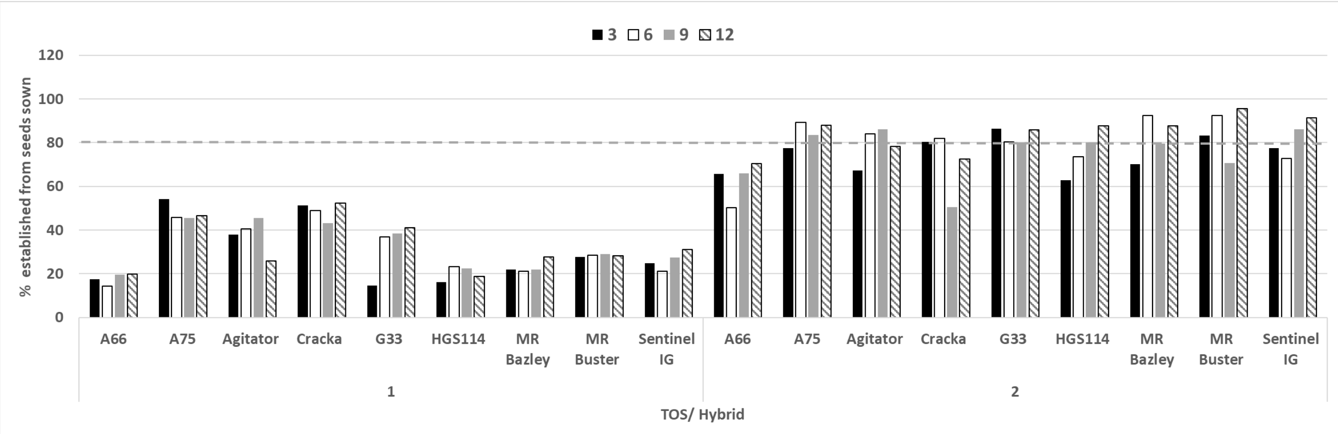

Figure 2. Percent of established plants from actual seeds sown at "Bullawarrie” 2020-21. Legend shows actual target plant population (per m^2). Data obtained from plant counts collected at 35-38 days post sowing.

3. Monitoring of soil temperatures at sowing depth

Soil temperatures can fluctuate widely during late winter and early spring (Figure 3). These fluctuations are exacerbated at shallower soil depths as there is less insulation against the changing day/ night temperatures.

Growers looking to plant early sorghum should target soil temperatures of at least 12°C and rising for a period of 7 days. Soil temperature needs to be measured at the intended sowing depth and at the same time e.g. 8 am EST.

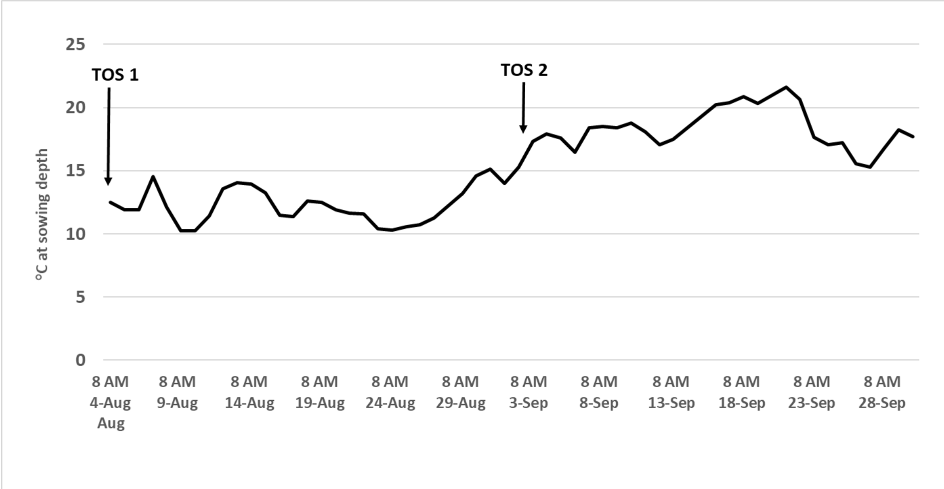

Figure 3. Soil temperatures at "Bullawarrie" Mungindi in 2020-21. Soil temperatures were measured at sowing depth.

4. Adequate soil moisture around the seed

Early sowing of sorghum into cooler soil temperatures, means a longer period is required for the seed to imbibe and emerge compared to a normal sowing time. In most cases, sowing in early – mid August results in an emergence time of 2-3 weeks.

As such, there needs to be adequate moisture at planting to ensure the seed does not dry out and stop the germination process. This could exacerbate plant stand uniformity issues and further reduce establishment.

Flowering

The advantages of being able to plant and establish sorghum in August in western areas largely relate to moving the flowering window forward into mid-late November when average maximum temperatures are lower. An earlier flowering window reduces the risk of heat stress and reduced pollen viability from high temperatures. Conditions were better for TOS 1 flowering (light grey dotted box) in 20-21, despite the spike in temperatures in mid-November (Figure 4). Average maximum temperatures were higher during the flowering window of TOS 2 (black dotted box).

Early sown sorghum is slower to move through the vegetative growth stages, meaning it takes more days to reach 50% flowering. However, the aim of early sowing is still to move the flowering window forward. This was demonstrated at “Bogamildi” Moree, when comparing time of sowing 1, 2 and 3 (Figure 5).

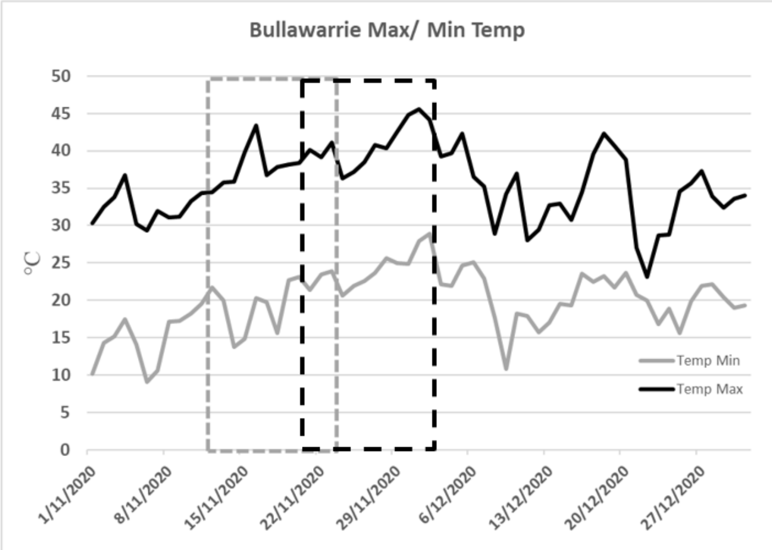

Figure 4. Maximum and minimum temperatures at "Bullawarrie" Mungindi in 2020-21. Dashed boxes indicates the flowering window of TOS 1 (grey) and TOS 2 (black).

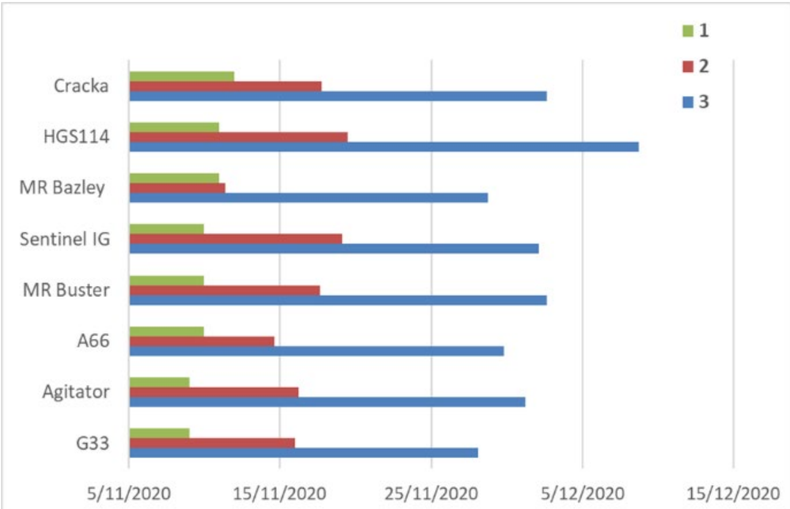

Figure 5. Flowering dates at "Bogamildi" Moree in 2020-21. Time of sowing dates were (1) 5th August, (2) 2nd September and (3) 28th September.

Row configuration and plant population

Changing plant population or row configuration are probably the easiest management levers to pull. The ideal plant population for growing sorghum in NW NSW is influenced by the yield potential and sowing date. Trials conducted by NSW DPI and GRDC have included plant populations from 1.5 – 7.0 plants/m^2 across four row configurations; solid 1m, single skip, super wide (1.5 m) and double skip. Plant populations were maintained regardless of the row configuration.

Where crop yields are likely to be > 3.0 t/ha, solid plant will provide higher yields. If a grower is achieving 2.5 to 3t/ha on a skip row configuration, the data suggests that a solid plant configuration would most likely increase yield by 0.5 -1 t/ha, or higher (Figure 6). At yields below 2.5 t/ha, responses to varying row configuration and plant population are less common (Figure 7).

In general, the higher the yield potential of the crop, the higher the plant population which can be supported. However, populations of 5 plants/m^2 can achieve yields close to 5.0 t/ha in NW NSW (e.g. Mungindi 10/11 – Figure 6), which is a much higher than average yield in this environment. Populations above 5 plants/m^2 (i.e. 7 plants/m^2) rarely produced statistically significant higher yields (data not shown) but incur an increased expense due to additional hybrid seed costs.

Plant populations below 3 plants/m^2 have been lower yielding in higher yield potential seasons and are also more difficult to achieve even plant distribution across a paddock.

In contrast, at grain yields under 3.0 t/ha, responses to plant population and row configuration tend to be flatter (Figure 7). Some advantages have been seen from very low populations (i.e. 1.5 plants/m^2). At these yields, responses to row configuration are also less than generally believed, particularly when yields are < 1.0 t/ha which usually indicates terminal moisture stress.

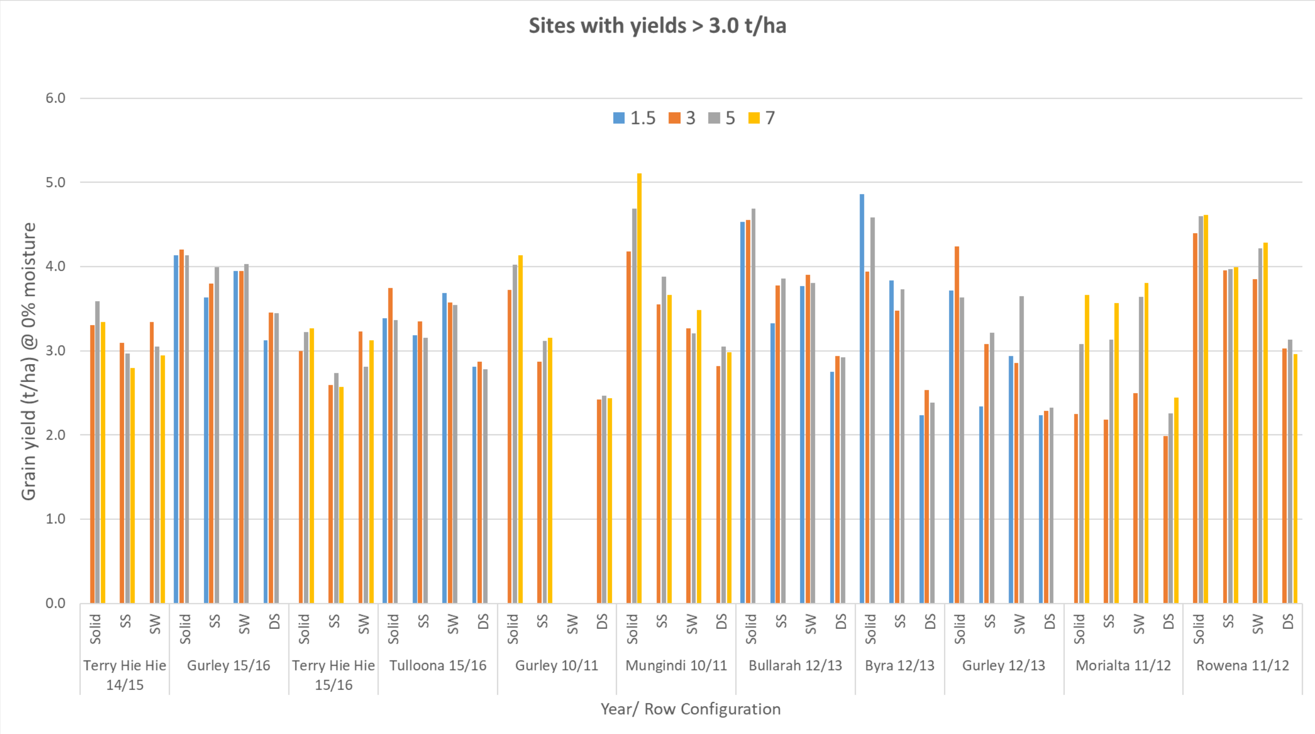

Figure 6. Trial sites with grain yields > 3.0 t/ha. Response to varying plant population (plants/m2) and row configuration in sorghum across north west NSW from 2010-2016 (Solid = solid plant, SS = single skip, SW = super wide (150 cm solid) DS = double skip).

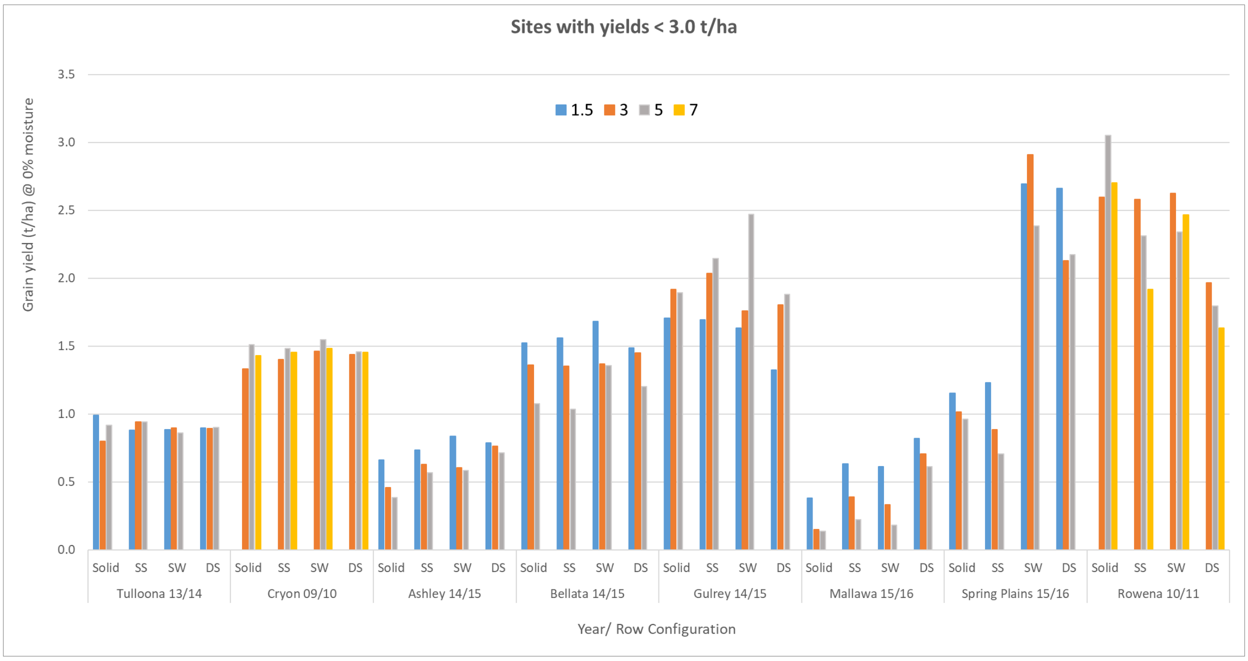

Figure 7. Trial sites with grain yields < 3.0 t/ha. Response to varying plant population (plants/m2) and row configuration in sorghum across NW NSW from 2010-2016. (Solid = solid plant, SS = single skip, SW = super wide (150 cm solid) DS = double skip).

Early sown crops often have reduced establishment, hence more seeds may need to be sown to achieve the target plant population. The other important point to consider when deciding on a plant population is that population alone is not responsible for crop yield. The optimum population also depends on the row configuration and the level of tillering within different hybrid sorghum varieties.

Water use efficiency

Water use, more specifically, water use efficiency, is a critical component to sorghum crop success in the western zone. The higher the water use efficiency, the more kilograms of grain will be produced for each millimetre of water supplied.

Sowing sorghum into cooler soil affects plant development, extending the number of growing days required to reach flowering. However, as temperatures are lower during this time of the year (August – October), the crops evaporative demand is also expected to be lower.

Therefore, it was anticipated that early sown sorghum would use less water in the vegetative stages, which would mean additional water in the soil profile would be available for the grain fill period. Using the Agricultural Production Systems Simulator (APSIM), simulations of total crop water use for the 8 trial sites between central QLD and the Liverpool Plains in the 2018-19 season (Figure 8) showed that more water was used during the grain filling stage in the early sown sorghum (TOS 1), compared to time of sowing 3 (TOS 3), the normal sowing time.

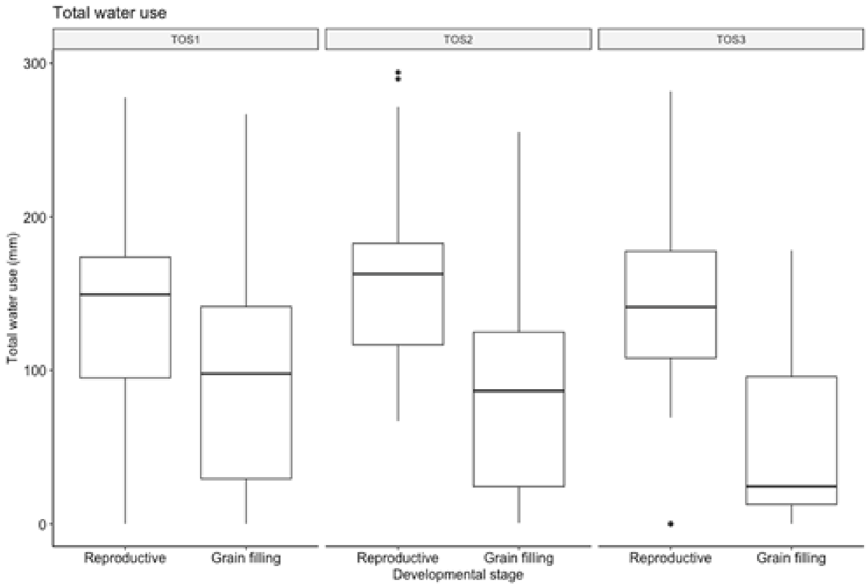

Figure 8. APSIM simulated water use (mm) between floral initiation and flowering (reproductive) and after flowering (grain filling) periods for all the treatments and sites trialled during the first season of trials (18-19).

Measurement of in-crop water use of two hybrids(MR Buster and Agitator)at Breeza in 2018-19 showed water use efficiency to be higher in TOS 1 and TOS 2 when crops were sown into cooler soil temperatures (11.2 and 10.3 °C) compared to the normal sowing time of TOS 3(Table 1). There was no difference between plant populations or hybrids in this season.

Table 1. Water use efficiency (kg/ha/mm) predictions at Breeza 2018-19 (averaged across population and hybrid).

Sowing time	**Water use efficiency (kg/ha/mm)**
Very early (TOS 1)	6.51_{a}
Early (TOS 2)	5.68_{a}
Normal (TOS 3)	2.44_{b}

L.S.D: 2.25

In the following season (2019-20), there was an interaction between sowing times and plant populations. Water use efficiency declined as plant population increased for both TOS 1 and TOS 2 (Figure 4). There was no difference between populations for TOS 3 which was sown into higher soil temperatures. MR Buster had a higher water use efficiency than Agitator in this season.

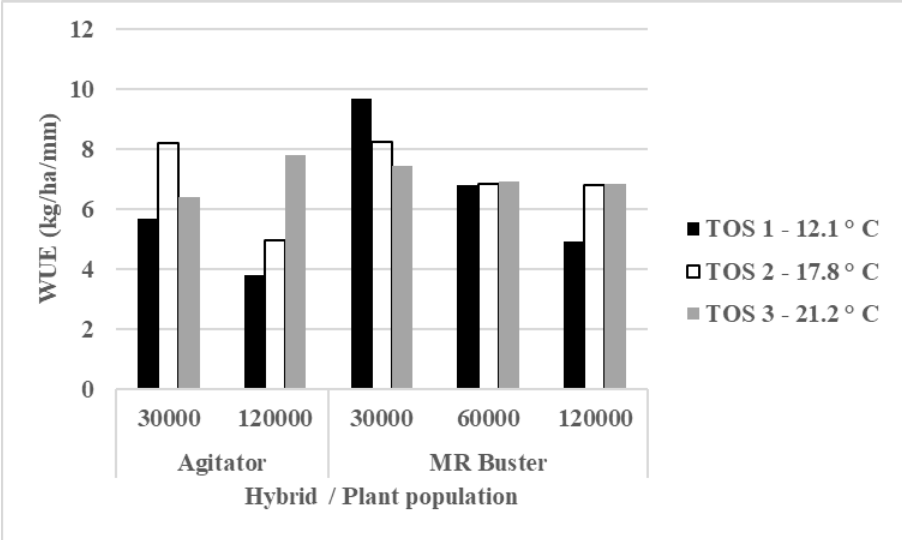

Figure 9. Water use efficiency response to varying sowing time at Breeza 2019-20 (LSD = 2.61 kg/ha/mm)

The next step in data collection to better understand water use in early sown sorghum is planned to occur this coming season. Additional measurements of water use in the vegetative and reproductive stages are planned for the Mungindi and Breeza sites, compared across populations and hybrids.

Conclusions

A complete package that will help to reduce risk and improve the reliability of sorghum production in NW NSW is hopefully only one more season of data away. A series of options for improving confidence in growing sorghum in this region have been examined. However, further interrogation of the available data sets combined with additional trial data from this coming season will help provide localised data, especially around crop water use and flowering windows.

To date, early sown sorghum has provided benefits which have far outweighed the risks. The integration of additional tools to help growers develop knowledge and skills around seed quality (germination and vigour), improving establishment and better predictions of hybrid flowering will only serve to improve our confidence in sorghum production.

The ideal management package will suggest avoidance of the peak heat and moisture stress periods in NW NSW and generate a profitable sorghum grain yield with optimised water use efficiency, whilst still maintaining system benefits such as stubble cover from a cereal crop. This is a significant challenge for the future of our industry, but also a massive opportunity waiting to be exploited.

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The impact of harvest management in chickpeas – desiccation and front of header losses

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Key words

chickpea desiccation, harvest losses

GRDC code

NGA00004: GRDC Grower Solutions for northern NSW and southern Qld

Take home messages

- Generally minor impact from desiccant treatments or application timing on yield or grain quality
- Decisions on harvest management choice should be determined by cost, attitude to Ally® plant back restrictions, weed spectrum present at harvest and speed of desiccation required
- Delayed harvest at low % grain moisture caused more damaged and split grain than desiccant treatment or timing
- Ideally target desiccation at ~85-90% pod maturity and schedule harvest 7 days later to reduce grain quality issues
- Large levels of pod and grain losses were measured at the front of the header in four commercial evaluations (~100-200 kg/ha)
- Losses reduced by ~50-90 kg/ha when harvested with air assist or when brushes were attached to the reel
- Impact from the harvest modifications would have improved returns by $34-67/ha
- In the trials conducted in 2018 and 2019, this represented an additional 5-18% yield.

Background

Northern Grower Alliance have been researching two important aspects of chickpea harvest management during the period 2017-2019.

The first has been to evaluate the impact of desiccant choice and timing on yield and grain quality. The second has focussed on the magnitude of header losses and the impact on yield and economics from changes in harvest approach.

Desiccation evaluation 2017-2019

The area of focus has evolved over the three seasons:

2017 – 5 trials evaluating current and new desiccation tools to assist in refining management programs. Treatments included glyphosate alone, glyphosate + Ally (metsulfuron-methyl), glyphosate + Sharpen® (saflufenacil), Reglone® (diquat), Gramoxone® (paraquat) (refer to label and follow use pattern for chickpeas) and Gramoxone + Sharpen.

2018 - 4 trials continuing the original activity. An additional 3 trials focussed on impact of desiccation timing (application ~3, 2 and 1 week prior to ‘planned’ commercial harvest). In all three timing trials, treatments were also harvested after a 14-day delay. Treatments repeated from 2017.

2019 - 3 trials primarily focussed on the impact of desiccation timing (application at ~70%, 80% and 90% pods at physiological maturity). Harvest was conducted for all timings ~7 days after application. Similar treatments to 2017 and 2018 but replaced Reglone with glyphosate + Ally + Sharpen.

Pod maturity was assessed at each application on a minimum of 10 main branches. Pods were considered mature when a 'yellow beak' was starting to extend on the enclosed grains. This stage often corresponded with a purplish tinge appearing on the pod coat.

Key points - desiccation evaluation 2017-2019

Leaf discolouration and leaf drop (visual ratings)

- Treatments increased % leaf discolouration and % leaf drop compared to the untreated but without consistent differences between treatments across sites
- Improvements in % leaf discolouration and % leaf drop compared to the untreated were greatest in 2017 (where high levels of October rainfall encouraged crop regrowth) and generally lowest in 2019 at sites that matured very rapidly under high moisture stress.

Stem dry down (physical rating)

- A 'twist test' was conducted to assess the % of plants where all stems snapped at harvest. This was done to provide an indication of stem ropiness or harvest readiness
- The most consistent treatments in 2017 and 2018 were the mixture of glyphosate + Ally or Gramoxone 250 + Sharpen. In 2019 there was no significant difference, in any trial, between any treatment and the untreated
- There was a positive dose response to glyphosate in 2017 and 2018 with increased stem snapping from the 1.8 L/ha rate (540 g ai/L formulation).

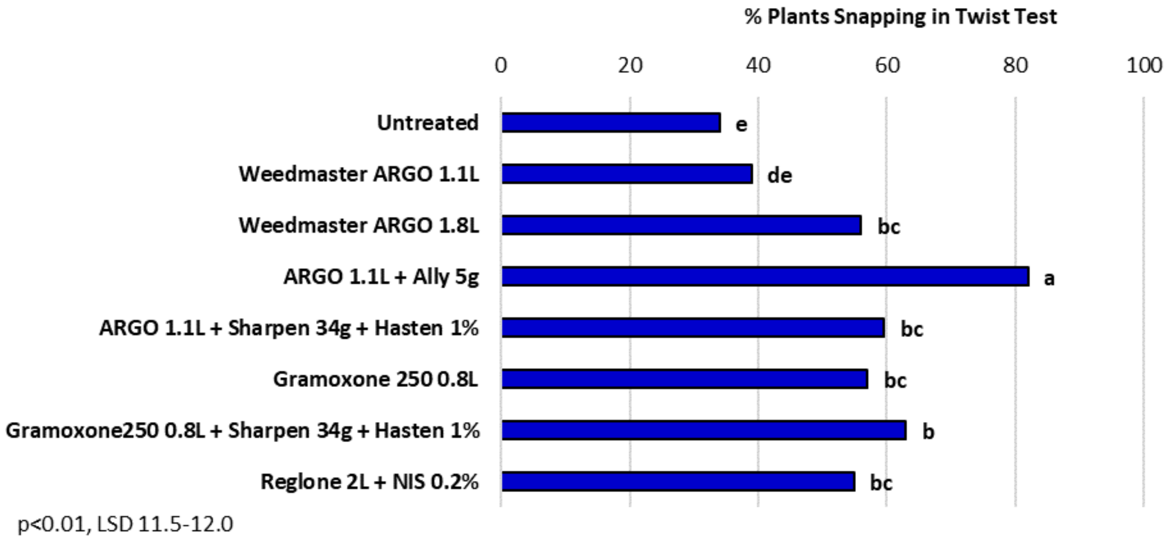

Figure 1. Stem twist test results 10-17 days after application, as an indication of stem dry down. *(Mean of 5 trials 2017)*

NIS = non-ionic surfactant

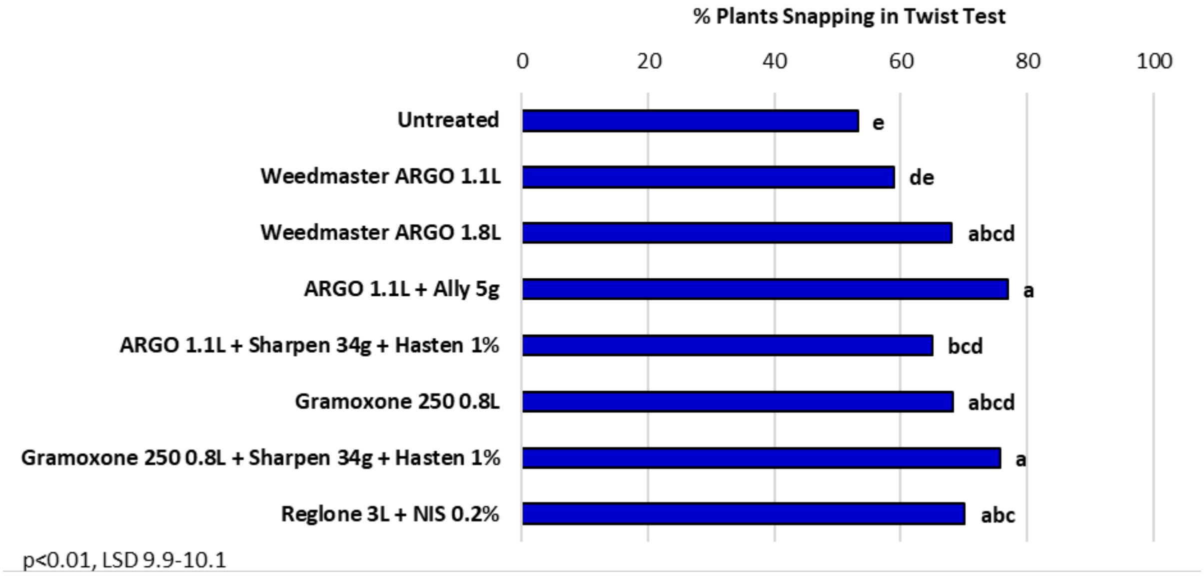

Figure 2. Stem twist test results 7-15 days after application, as indication of stem dry down.
(Mean of 4 trials 2018)

NIS = non-ionic surfactant

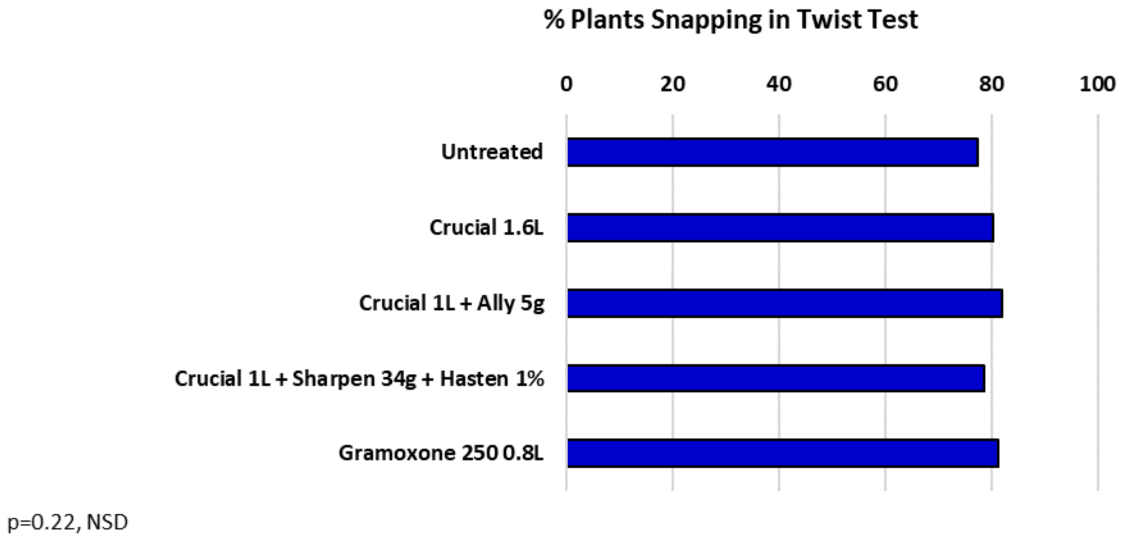

Figure 3. Stem twist test results 6-10 days after application, as indication of stem dry down.
(Mean of 3 trials 2019)

Yield

- In 14 of the 15 trials, there was no significant difference in yield between any treatment and the untreated
- In 2018, there was a significant reduction in yield from Gramoxone 250 at one site where the application was ~4 weeks prior to expected commercial harvest and then harvest was delayed by another 2 weeks. Crop stage at application was only 59% of pods at physiological maturity.

Grain quality (NIR and sievematic)

- Impact on grain quality was generally minor
- Test weight was significantly reduced in 2 trials in 2018 by Gramoxone 250 or Reglone when application occurred ~4 weeks prior to expected harvest. Crop stage at application was ~50-60% of pods at physiological maturity
- There was no significant impact on screenings from any desiccant treatment in 2018 (using a 4mm slotted screen as an indication of defective grain)
- Impact on grain moisture at harvest was minor with no significant difference between desiccant treatments and the Untreated in 12 of 15 trials. All treatments reduced grain moisture by ~1% in a 2017 trial where regrowth was evident and Gramoxone 250 significantly reduced harvest moisture at 2 of the 3 sites in 2019.

Grain grading (visual rating)

- Visual grain assessment on all trials from 2019 showed no significant impact from desiccant treatment or timing on the % green or yellow grain compared to untreated grain harvested at the same time
- In one trial, application of glyphosate alone at 70% of pods at physiological maturity reduced the percentage of mature grain by ~2% and increased the percentage damaged grain by a similar amount. There was no significant impact when glyphosate was applied at 90% pod maturity.

Germination

- Germination tests were conducted on seed samples from application timing trials in 2018 and 2019. Effects were generally minor
- Significant reductions in germination were observed from glyphosate + Ally applied at 58% pod maturity in 1 trial in 2018 and glyphosate + Sharpen + Ally applied at 66% pod maturity in 2019. In both cases, application of the same treatment at later crop stages had no effect
- Reduced germination was observed from all treatments at one site in 2019 when applied at 90% pod maturity where a rain event of ~18mm occurred between application and harvest. There was no consistent impact from treatments on germination from applications at the same site at 70 and 80% pod maturity.

NB The use of desiccants is not recommended when the grain is to be used for seed.

Overall

Differences between desiccant treatments and timing of application were less obvious than originally expected.

- The addition of Ally to glyphosate will generally improve stem dry down compared to other treatments, whilst higher label rates of glyphosate will improve the speed of discolouration and stem dry down.
- Impacts on yield and grain quality were relatively minor, even when application occurred up to 2 or 3 weeks earlier than currently scheduled.

However, in 5 of the 6 trials where harvest timing was also compared, it was clear that the earlier harvest of chickpeas had significantly lower levels of damaged grain. This effect was irrespective of whether the plots had been desiccated or untreated. Although differences in header setup can't be eliminated, it is likely that the lower levels of damaged or split grain is at least partly due to the higher levels of grain moisture at harvest. NB even the early application treatments had grain moisture lower than 10%, when tested within 24 hours of harvest, in 5 of the 6 trials.

Rather than suggesting that the industry desiccate chickpeas at an earlier maturity stage, this data should provide good confidence that desiccation at 85-90% pod maturity is highly unlikely to have any negative impact on yield or grain quality. When combined with harvest scheduled ~7 days after application, this should allow harvest at slightly higher grain moisture and significantly reduce the amount of damaged or split grain in samples.

Commercial harvest losses 2018-2019

Commercial observations have frequently indicated high levels of harvest grain and pod loss in chickpeas, particularly in crops with reduced biomass that 'feed' poorly into the header. This grain loss is different to grain that passes through the header (processing loss) or grain left on plants (harvest height loss). Front of header grain loss is made up of pods and grain that are knocked off by the reel, cut off by the knife but fall outside the header front or thrown out from the header by the drum or belt.

In 2018, data was generated at a site near Gurley where PBA Seamer⍉ was harvested with a header fitted with an air front. Replicated strips were established where the only difference was whether the air front was turned on or off during harvest.

Counts were taken of pods or grain on the ground together with the number of grains/pod and grain weight. In 2018, sampling zones were assessed across the harvested width with no pods or grain apparent on the ground prior to harvest. Results in Table 1 are for the pod and grain losses away from the header trail. These are the harvest losses that occurred at the front of the header but exclude any pods that were unharvested but still attached to plants.

Figure 4. Brushes attached to the header reel Bellata 2019

In 2019 three sites were evaluated with sampling away from the header trail to identify the pods or grain losses at the front of the header. Again there was no indication of pod or grain loss prior to harvest. Two of the sites had air assist fitted to the header that could be simply turned on or off. The third site evaluated lengths of brushes attached to the reel (Figure 1).

Table 1. Impact on chickpea yield losses from air assist or reel brushes

Location and year	Variety and yield	Header set-up	Yield losses on ground			Reduced grain losses kg/ha and ($/ha)
			Pods/m^2	Grain/m^2	Total kg/ha	
Gurley 2018	PBA Seamer ~0.62 t/ha	Air assist OFF	55 a	10	164 a	89 kg/ha ($67/ha)
		Air assist ON	22 b	8	76 b	
Wee Waa 2019	PBA Monarch ~1.0 t/ha	Air assist OFF	33 a	5	115 a	45 kg/ha ($34/ha)
		Air assist ON	21 b	3	70 b	
Bongeen 2019	PBA HatTrick ~0.45 t/ha	Air assist OFF	38 a	1	123 a	80 kg/ha ($60/ha)
		Air assist ON	14 b	0	43 b	
Bellata 2019	PBA HatTrick ~0.40 t/ha	Reel brushes OFF	62 a	11	217 a	63 kg/ha ($47/ha)
		Reel brushes ON	43 b	9	154 b	

Letters of significance show significant differences **within each site** (2 sample T test, p=0.05)
Economic impact calculated on a $750/t grain price
All results in Table 1 are for sampling away from the header trail. This shows the yield losses occurring at the header front.
Assessment of grains/pod and grain weight was conducted to calculate total grain loss.

Key points – commercial harvest losses 2018-2019

- The majority of grain losses were as whole pods rather than individual grains
- At all four sites between ~100 and 200 kg/ha of grain was lost at the front of the header using a conventional setup
- Use of air assist or brushes attached to the reel significantly reduced the losses of whole pods and the total grain loss, at all sites
- There was no significant difference in losses of individual grains
- The mean reduction in grain loss was 70 kg/ha (range 45 to 89 kg/ha)
- The mean reduction in grain loss was $52/ha (range $34 to $67/ha)
- The reduction in losses would have been equivalent to an extra 5-18% crop yield.

Overall

All four trials highlighted the amount of chickpea grain and income that can be lost at the front of the header at harvest. The impact of air assist or even the simple approach of attaching brushes to the reel provided benefits of ~$50/ha. However some caution is needed as both 2018 and 2019 were low yielding seasons with yields varying between 0.4 and 1.0 t/ha. The benefits of simple header adaptations may be more substantial in lower yielding years or where crop biomass or planting configuration is likely to result in poor levels of 'feeding in' of harvested material.

Further evaluation is warranted under more normal conditions to provide growers with realistic indications of the benefits of changes in chickpea harvest management.

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Grower experiences managing chickpea harvest losses

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Notes