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NSW
THURSDAY 12
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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GRDC Grains Research Update
WALGETT

Thursday 12 August 2021
Walgett Sporting Club, Cnr Fox & Monkeila Streets

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

AGENDA		
Time	**Topic**	**Speaker(s)**
9:00 AM	**GRDC welcome**	Graeme Sandral (GRDC)
9:10 AM	**Nematodes and crown-rot in western farming systems** - interactions, impact and management; development of a new seed treatment for crown-rot	Steve Simpfendorfer (NSW DPI)
9:40 AM	**Managing chickpea harvest losses**	Denielle Smith (Northern Grower Alliance)
10:10 AM	**Managing upper canopy blackleg and sclerotinia in lower and medium rainfall western canola crops**	Maurie Street (Grain Orana Alliance)
10:45 AM	**Morning tea**	
11:10 AM	**Managing mice** • Management and baiting strategies • Population ecology - how long can plagues last and why?	Steve Henry (CSIRO)
11:45 AM	**Diseases, fungicide resistance and pathotype changes - what's happening and what are the implications for growers and advisers?** • Powdery mildew resistance • Changes in wheat stripe rust pathotypes • Growing resistance by a range of diseases to different fungicide groups	Steven Simpfendorfer (NSW DPI)
12:15 AM	**Chickpea Ascochyta Update**	Kevin Moore (NSW DPI) & Hayley Wilson (NSW DPI)
12:45 PM	**Lunch**	
1:35 PM	**Drone weed mapping for spot spraying: Know what's there before you spray** - consistent weed detection driving down the weed seed bank	Tony Single (Tigah Pty Ltd)
2:00 PM	**Canola harvest management**	Maurie Street (Grain Orana Alliance)
2:30 PM	**Sorghum production in western zones** • Row configuration, plant populations and water use efficiency • Pros and cons of early sowing • Establishment in cold soil conditions.	Loretta Serafin (NSW DPI)
3:00 PM	**Close**	

Contents

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Summer crop choice in northern farming systems – impacts on root lesion nematode, charcoal rot, AMF and winter cereal crop pathogen levels

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Key words

pathogens, PREDICTA®B, disease risk, crop rotation, break crop, Fusarium crown rot

GRDC code

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Take home messages

- Summer crop choices are complex and should include consideration of their relative impact on pathogens and beneficial soil biota such as arbuscular mycorrhizae fungi (AMF)
- Mungbean resulted in the greatest increase in AMF populations but also elevated disease risk for charcoal rot and the root lesion nematode (*Pratylenchus thornei*) compared with sorghum, cotton, maize, sunflower and millet
- Summer crops generally reduced Fusarium crown rot risk for following winter cereal crops but variation appeared to exist in their relative effectiveness
- Maize, cotton, sorghum and mungbean appear to be potential alternate hosts for the winter cereal pathogen *Bipolaris sorokiniana* (common root rot), while sunflower does not appear to be a host
- Quantification of individual summer crop choices on pathogen levels has highlighted potential areas requiring further detailed investigation to improve management of these biotic constraints across northern farming systems.

Introduction

Crop choice decisions often involve trade-offs between different aspects of farming systems. In particular, crop choice should consider the need to maintain residue cover, soil water and nutrient availability, and managing pathogen inoculum loads using non-host crops to avoid or reduce risk of problematic diseases (e.g. Fusarium crown rot). This is increasingly challenging as many cropping systems face evolving diseases and weed threats. Hence, understanding how different crops impact on these aspects is critical.

With limited winter rotation crop options in the northern grains' region, summer crops offer advantages as break crops within cropping sequences. Incorporating a mix of summer and winter crops allows variation in herbicide and weed management options, often also serving as disease breaks within the system. For example, sorghum is known to be resistant to the root lesion nematode *Pratylenchus thornei* (*Pt*), allowing soil populations to decline. However, the increasing use of summer crops in many regions, has seen an increase in the frequency of other diseases (e.g. charcoal rot caused by the fungus *Macrophomina phaseolina*). Similarly, using long fallows to transition from summer to winter crop phases can induce low levels of beneficial arbuscular mycorrhizae fungi (AMF) populations associated with long-fallow disorder. In this paper, we interrogate the data collected from northern farming systems research sites over the past 6 years to examine how different summer crop options impact on levels of both pathogen and AMF populations within farming systems.

What was done?

Seven research sites were established in 2015 to test a range of different farming systems in different environments across northern NSW, southern and central Qld. Over the life of the project, the team has sampled and analysed soil (0-30 cm) using the PreDicta® B quantitative PCR (qPCR) DNA analysis to examine how pathogens and other soil biology have varied over a range of crop sequences. A specific PreDicta® B test panel targeted at quantifying a wide range of pathogens important to the northern grains region has been used throughout the project. Here we have looked specifically at the impact of summer crops grown in these crop sequences to calculate the extent of change in DNA populations of pathogens and AMF associated with crop choices. It should be noted that populations are what have naturally developed within each system at the various sites and were not artificially inoculated.

Data from site-crop combinations where a particular pathogen or AMF was not present or below testing detection limits was excluded, as this does not provide a useful indication of the propensity of a crop choice to impact a particular pathogen or AMF population. PreDicta®B data from soil samples collected at sowing and after harvest of each summer crop were used to calculate relative changes or multiplication factor for populations over their growing season for the various summer crop rotation options. This multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0) in pathogen levels following growth of different summer crops.

What did we find?

Root lesion nematodes

Root lesion nematodes (RLN, *Pratylenchus* spp.) are microscopic plant parasites which feed on crop roots. Two important species are known to infect crops in eastern Australia, namely *Pratylenchus thornei* (*Pt*) and *P. neglectus* (*Pn*). *Pt* is known to be the more important species in higher clay content soils in northern NSW and Southern Qld while *Pn* is generally more prevalent in lighter soil types in south-eastern Australia. *Pn* generally feeds and causes root damage in the top 15 cm of soil whilst *Pt* can feed and damage roots down the entire soil profile. Root damage restricts water and nutrient uptake from the soil causing yield loss in intolerant winter cereal and chickpea varieties. Only *Pt* densities were prevalent at high enough densities across northern farming system sites to examine the effect of summer crop options on soil *Pt* populations.

Summer crops are known to vary in their susceptibility to *Pt* with sorghum, cotton, millet and sunflower considered moderately resistant-resistant (MR-R). Maize is considered susceptible-MR (S-MR) whilst mungbean is S-MRMS (GRDC root lesion nematode fact sheet - https://grdc.com.au/__data/assets/pdf_file/0031/385627/GRDC_FS_RootLeNematodesNorth_190213.pdf). The range in resistance ratings can relate to differences between varieties. Our results support these general findings. Mungbean resulted in the highest average increase in *Pt* populations, whilst sorghum favoured the lowest population increases (Table 1).

Table 1. Effect of summer crop choice on *Pratylenchus thornei* soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	1.4	8.3	3.2	2.0	3.4	5.0
Range	0.2 - 6.6	4.0 - 21.3	0.8 - 13.7	1.4 - 2.8	3.2 - 3.7	4.0 - 6.0
No. observations	31	20	10	5	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Charcoal rot (Macrophomina phaseolina)

Charcoal rot, caused by the fungus *Macrophomina phaseolina*, is primarily a disease of summer crops including sorghum, maize, cotton, mungbean and sunflower in northern NSW and Qld. Infection causes light brown lesions on crowns and roots and results in increased lodging and/or premature plant death when stress associated with dry weather occurs late in the growing season. *M. phaseolina* has a wide host range of more than 500 weed and crop species including winter cereals.

Table 2. Effect of summer crop choice on *Macrophomina phaseolina* (charcoal rot) soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	9.5	150.0	20.8	7.2	28.9	3.9
Range	1 - 27	5 - 1191	1 - 117	4 - 11	6 - 50	2 - 6
No. observations	23	23	9	4	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

All six of the summer crops grown increased average *M. phaseolina* populations by between 3.9 to 150.0 times demonstrating the known wide host range of this fungal pathogen (Table 2). However, considerable differences were evident between the various summer crop options with mungbean elevating populations 5 to 40 times more than the other crops (Table 2).

Arbuscular mycorrhizae fungi (AMF)

AMF colonise roots of host plants and develop a hyphal network in soil which reputedly assists the plant to access phosphorus and zinc. Low levels of AMF have been associated with long fallow disorder in dependent summer (cotton, sunflower, mungbean and maize) and winter crops (linseed, chickpea and faba beans). Although wheat and barley are considered to be low and very low AMF dependent crops respectively, they are hosts and are generally recommended as crops to grow prior to sowing more AMF dependent crop species, in order to elevate AMF populations.

There are two PreDicta® B qPCR DNA assays for AMF with combined results from both assays presented. It is important to remember that in contrast to all the other pathogen assays outlined, AMF is a beneficial fungus, so higher multiplication factors are good within a farming system context.

Table 3. Effect of summer crop choice on arbuscular mycorrhizae fungi (AMF) soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	3.5	26.8	10.7	5.7	12.0	7.2
Range	0.4 - 12.4	2.2 - 61.5	1.8 - 32.0	3.4 - 8.0	6.3 - 17.6	6.5 - 7.9
No. observations	41	22	10	4	3	2

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Mungbean resulted in the highest average increase in AMF populations, whilst sorghum was the lowest (Table 3). Interestingly, even though millet was grown as a short cover crop twice within these farming systems, it resulted in around a 7-fold increase in AMF populations. Hence, millet may be a good option for restoring ground cover over summer and AMF populations which both decline following extended dry conditions.

Fusarium crown rot (Fusarium spp.)

Two PreDicta® B qPCR DNA assays detect genetic variants of *Fusarium pseudograminearum* with a separate third combined test detecting *F. culmorum* or *F. graminearum*. All three *Fusarium* species cause basal infection of winter cereal stems resulting in Fusarium crown rot and the expression of whiteheads when heat and/or moisture stress occurs during grain filling. Fusarium crown rot has increased in northern farming systems with the adoption of conservation cropping practices which include the retention of standing winter cereal stubble. Yield impacts however are sometimes offset by the higher levels of plant available water often available to the plant during grain fill in such systems when compared to tilled systems. The *Fusarium* spp. which cause this disease can survive 3-4 years within winter cereal stubble depending on the rate of decomposition of these residues. Recent research from PhD student Toni Petronaitis has also highlighted that inoculum levels can increase during fallow and non-host crop periods, with saprophytic vertical growth of the pathogen inside standing stubble under wet conditions. Inoculum within standing winter cereal stubble can then potentially be redistributed across a paddock with shorter harvest heights of break crops such as chickpeas. Hence, changes in Fusarium crown rot DNA levels may not represent actual hosting of the pathogen, rather they potentially include inoculum dynamics associated with saprophytic growth and/or redistribution of winter cereal stubble inoculum during harvest. DNA data for all three tests were combined for this interpretation to provide an overall level of *Fusarium* spp. DNA.

Table 4. Effect of summer crop choice on *Fusarium* spp. (Fusarium crown rot) soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	1.7	2.9	0.4	0.5	-	-
Range	0.03 - 10.3	0.4 - 9.7	0.1 - 1.0	0.2 - 0.8	-	-
No. observations	19	8	3	2	-	-

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Limited observations were available to support conclusions on the relative effect of summer crops on *Fusarium* spp. associated with Fusarium crown rot. However, cotton and maize appeared most effective at reducing inoculum loads (Table 4). Results were more variable with sorghum and mungbean, but both generally reduced or only moderately increased Fusarium crown rot inoculum levels. Inoculum dynamics associated with saprophytic growth of *Fusarium* spp., potential redistribution during harvest of summer and winter break crops and the role of grass weed hosts appears worthy of further investigation to improve management of this disease across farming systems.

Common root rot (Bipolaris sorokiniana)

Bipolaris primarily infects the sub-crown internode of winter cereal crops causing dark brown to black discolouration of this tissue referred to as the disease 'common root rot'. Common root rot reduces the efficiency of the primary root system in susceptible wheat and barley varieties resulting in reduced tillering and general ill-thrift in infected crops. This disease has increased in prevalence across the northern region over the last decade with the increased adoption of earlier and deeper sowing of winter cereals which exacerbates infection. There is little information on the effect of summer crop options on *B. sorokiniana* levels within Australian farming systems. One international study from Pakistan determined that millet, sorghum, mungbean and maize were hosts of *B. sorokiniana*, whilst sunflowers were a non-host (Iftikhar et al. 2009). Similar research has not been conducted in Australia.

Table 5. Effect of summer crop choice on *Bipolaris sorokiniana* (common root rot) soil populations

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	3.9	2.6	6.8	7.4	0.04	-
Range	0.5 - 9.6	0.3 - 9.3	0.3 - 12.0	na	na	-
No. observations	12	6	3	1	1	-

* multiplication factor highlights the extent of increase (>1.0), maintenance (=1.0) or decrease (<1.0)

Although limited observations were available to support conclusions on the relative effect of summer crops on *B. sorokiniana* populations, the data appears to support the only previous study of host range from Pakistan (Iftikhar et al. 2009). Mungbean, sorghum and maize appeared to generally increase populations, whilst sunflower considerably decreased levels of this pathogen (Table 5). Cotton, which was not included in the Pakistan study, also appears to generally increase *B.*

sorokiniana soil populations (Table 5). These results indicate that the role of summer crops need to be considered when managing common root rot in northern farming systems. Further research is required to confirm the relative host range of this increasingly important pathogen.

What does it all mean?

Summer crop choice remains a complex balancing act but this research has highlighted some of the impacts on pathogen and AMF populations. For example, mungbean had the largest increase in beneficial AMF levels but had the negatives of elevating charcoal rot and *Pt* risk compared with the other summer crop options examined. Mungbean also did not appear to be as effective at reducing Fusarium crown rot risk for subsequent winter cereal crops compared with other summer crop options where data was available. The underlying reasons behind these apparent differences requires further investigation of Fusarium crown rot inoculum dynamics with a farming systems context.

These northern farming systems experiments have further highlighted the potential differential role of summer crop species as alternate hosts of the common root rot pathogen *Bipolaris sorokiniana*, supporting an overseas study. The use of qPCR within these experiments is unique in that it allows the relative changes in pathogen or AMF levels associated with various summer and/or winter crop choices to be quantified. This is more valuable than simple presence/absence data, in that it allows growers and their advisers to understand and manage potential changes in disease risk within their paddocks to limit impacts on profitability.

References

Iftikar S, Asad S, Munir A, Sultan A and Ahmad, I. (2009). Hosts of *Bipolaris sorokiniana*, the major pathogen of spot blotch of wheat in Pakistan. *Pak. J. Bot.* 41: 1433-1436.

Acknowledgements

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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

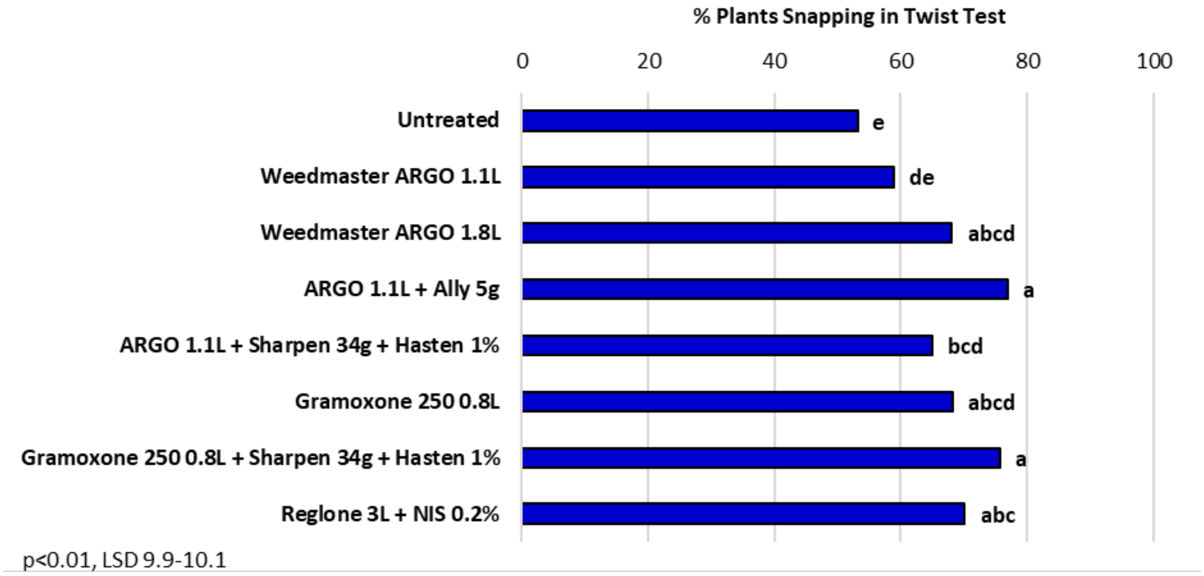

Figure 2. Stem twist test results 7-15 days after application, as indication of stem dry down.

(Mean of 4 trials 2018)

NIS = non-ionic surfactant

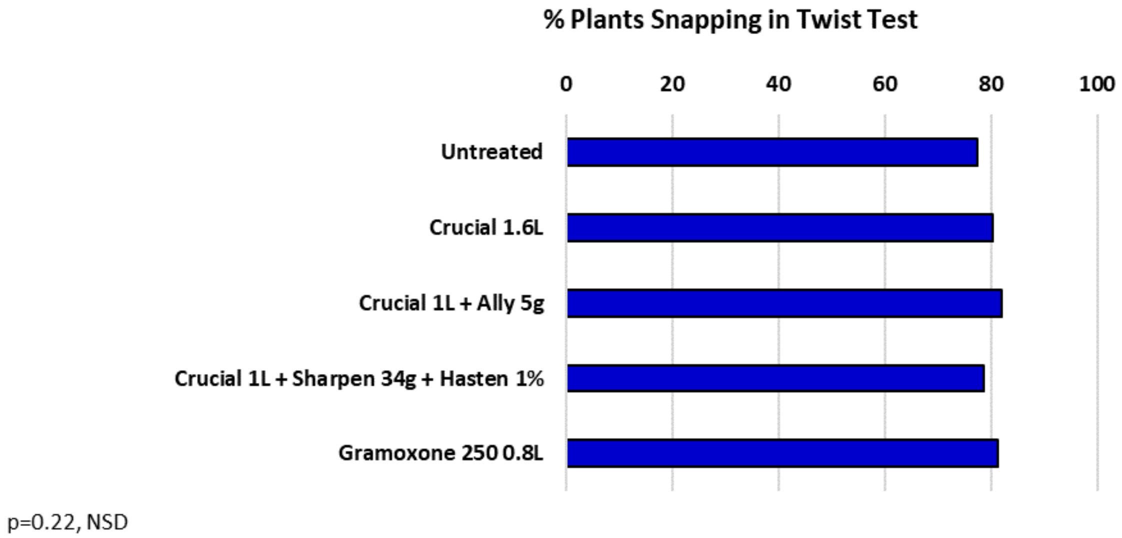

Figure 3. Stem twist test results 6-10 days after application, as indication of stem dry down.

(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/m²	**Grain/m²**	**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.

Acknowledgements

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Was canola fungicide investment justified in low and medium rainfall environments in 2020?

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Key words

canola, fungicide, Sclerotinia, upper canopy blackleg, Alternaria black spot, powdery mildew

GRDC codes

GOA2006-001RTX

Take home messages

- Return on investment was strong in only two of five trials, with both these trials being in the south and having higher levels of upper canopy blackleg (branch infection) as well as some Sclerotinia. Best return was from a single fungicide spray at 30% bloom stage
- Application at the recommended timings (30% and 50% bloom) were more likely to result in a yield benefit than an early application (10% bloom)
- Reduction in disease infection did not necessarily result in a positive grain yield response, similarly a positive grain yield response did not always increase profitability
- Overall, with modest yield responses in a high production year, money may be better invested in inputs with a more reliable return on investment.

Introduction

Application of fungicide to manage disease in canola, especially Sclerotinia and upper canopy blackleg (UCB) is a common practice in the higher rainfall, eastern and southern areas of the GRDC Northern Region, but there is little data on the cost-effectiveness in low and medium rainfall zones. In mid to late winter 2020 canola crops had high yield potential across much of the GRDC Northern Region. With forecasts for further rainfall for the spring period, many growers and advisors were considering the need for fungicide in areas where application is not common.

In response Grain Orana Alliance (GOA) and Brill Ag established five canola fungicide response trials through southern and central NSW to determine the response to fungicide in low and medium rainfall environments in a high yield potential season. The trials tested several fungicide products and their timing. The trials were assessed for the common diseases Sclerotinia and UCB as well as the less common diseases Alternaria black spot and powdery mildew that were also present at most sites. This paper outlines the key findings on the effectiveness of fungicide to control each disease as well as the grain yield response from fungicide control and the economics of their application.

Methodology

Trial sites were geographically spread to represent a range of climates and farming systems (Table 1). Trials were a randomised complete block design with four replicates for each treatment. Each trial was sprayed with a ute-mounted boom spray onto existing commercially grown and managed crops to ensure that the canopy remained intact, minimising open space for air to circulate which may have suppressed disease development. The sprayed plots were usually 40-50 m² in size with a smaller area of approximately 15-20 m² harvested with a small plot harvester when the crop was ripe (direct head) to minimise any potential influence from neighbouring treatments. All other crop husbandry prior to applications were completed by the grower.

Table 1. Site description for five canola fungicide response trials conducted in NSW, 2020.

Location	Region	Average annual rainfall	Average growing season rainfall	Variety
Ganmain	Eastern Riverina	475 mm	280 mm	HyTTec® Trophy
Kamarah	Northern Riverina	440 mm	220 mm	Pioneer® 44Y90 CL
Temora	South-west slopes	520 mm	310 mm	Pioneer® 45Y91 CL
Warren	Central-west plains	510 mm	210 mm	HyTTec® Trophy
Wellington	Central-west slopes	580 mm	300 mm	Victory® V75-03CL

Four products were used with multiple combinations of timings and rates (Table 2).

Table 2. Description of fungicide products used in five canola fungicide response trials conducted in NSW, 2020.

Trade Name	Active Ingredient 1	Group	Active Ingredient 2	Group
Aviator Xpro®	Prothioconazole	3	Bixafen	7
Miravis® Star**	Pydiflumetofen	7	Fludioxonil	12
Prosaro®	Prothioconazole	3	Tebuconazole	3
Veritas®	Tebuconazole	3	Azoxystrobin	11

***Miravis Star was applied under a research permit . It is currently under evaluation with APVMA.*

There were three application timings targeted at 10, 30 and 50% bloom (30 and 50% bloom only at Kamarah and Warren). The 30 and 50% timings are commonly suggested timings, with the 10% bloom timing added to reflect grower practice at those sites. Treatments at individual sites are shown in Tables 4-8 later in the paper. These spray timings are overlaid on daily rainfall in Figure 1. After good rains in early to mid-August at all sites, rainfall during the late winter/early spring period was generally below average.

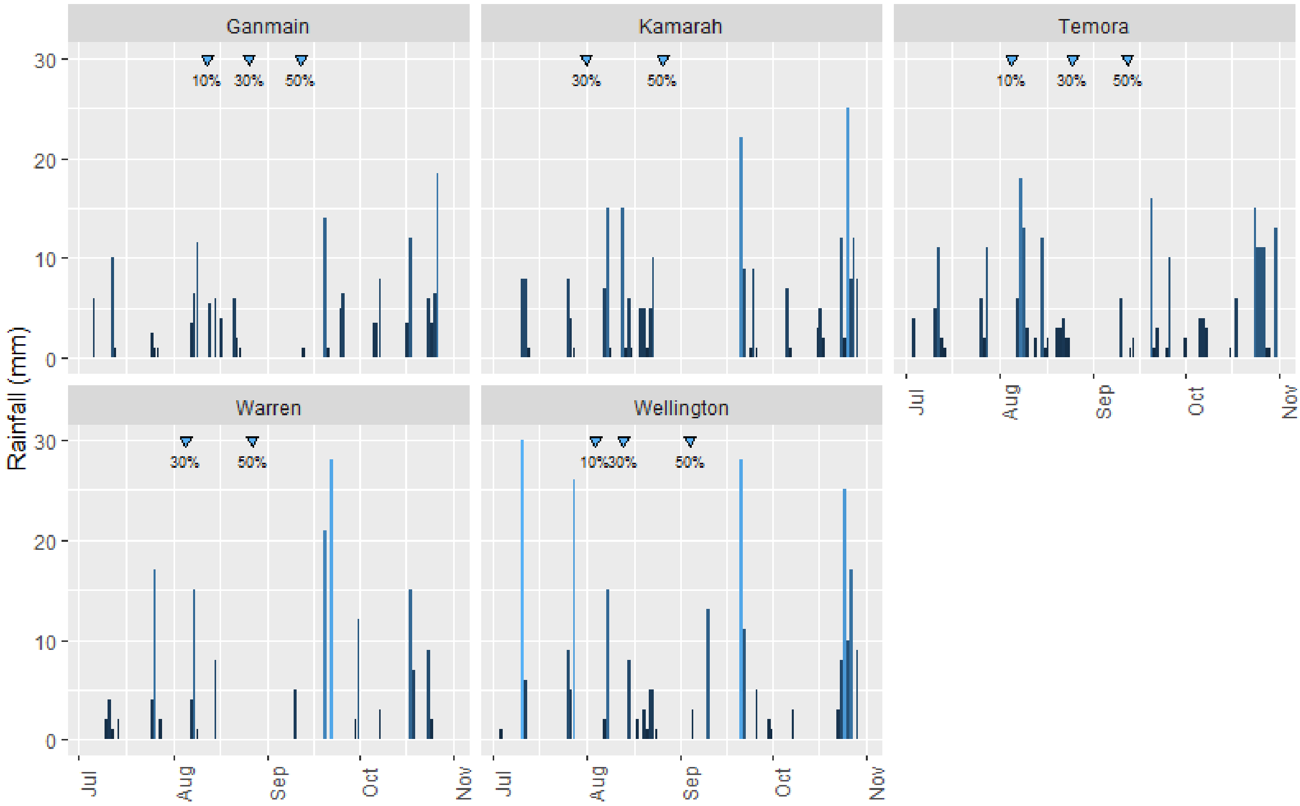

Figure 1. Daily rainfall received (vertical columns) and spray timings (inverted triangles) for five canola fungicide response trials conducted in NSW, 2020. Timings are bloom stage timing, e.g., 10% is 10% bloom stage.

Disease assessment

Diseases prevalence was assessed at one timing, targeted around 60-80 seed colour change (windrowing stage) with the methodologies detailed below.

Sclerotinia – two random sample areas of 1 m^2 were assessed in each plot, with the number of plants with Sclerotinia (basal, main stem and branch) counted along with the total number of plants in the assessment area to determine infection rates.

Upper canopy blackleg – a 0-4 score was allocated for the same two locations that were assessed for Sclerotinia:

- 0 = no infection observed
- 0.5 = at least one lesion found
- 1 = lesions present
- 2 = lesions common
- 3 = lesions common causing damage
- 4 = lesions common causing branch death

Alternaria black spot – the upper canopy blackleg scoring system was adapted for Alternaria with some minor tweaks:

- 0 = no infection observed
- 0.5 = at least one lesion found
- 1 = lesions present
- 2 = lesions common with 1-5% of pod/stem area infected

- 3 = lesions common with 5-15% of pod/stem area infected and low-level early pod senescence.
- 4 = lesions common with >15% of pod/stem area infected and high level of early pod senescence.

Powdery mildew – an assessment was made of the proportion of stem area infected with powdery mildew (two locations per plot as per Sclerotinia).

The trial results were analysed by ANOVA with 95% confidence level. Results are detailed in Tables four to eight below.

Results

Sclerotinia petal testing

Petal samples from 12 flowers from untreated areas were sent to the CCDM for determining the level of Sclerotinia present at each site. Sclerotinia was confirmed as present on petals at each of the five sites, with 100% of petals infected at Ganmain and Temora and down to 55% of petals infected at Wellington.

Table 3. Canola Sclerotinia petal infection rates at from five canola fungicide response trials conducted in NSW 2020.

Site	Petals infected (%)
Ganmain	100
Kamarah	78
Temora	100
Warren	87
Wellington	55

Geographic disease distribution

The highest levels of Sclerotinia infections were at the most south-eastern site Temora, where canola intensity and canopy moisture levels favoured disease development (Figure 2). There was no broader Sclerotinia infection of plants at Warren, despite petal tests confirming Sclerotinia as present at the site. Upper canopy blackleg (UCB) on branches ranged from only trace levels at the north-western site at Warren, to high levels of infection likely causing yield loss at the southern sites at Kamarah and Temora. Powdery mildew and Alternaria black spot (on pods) was most severe in the northern trials.

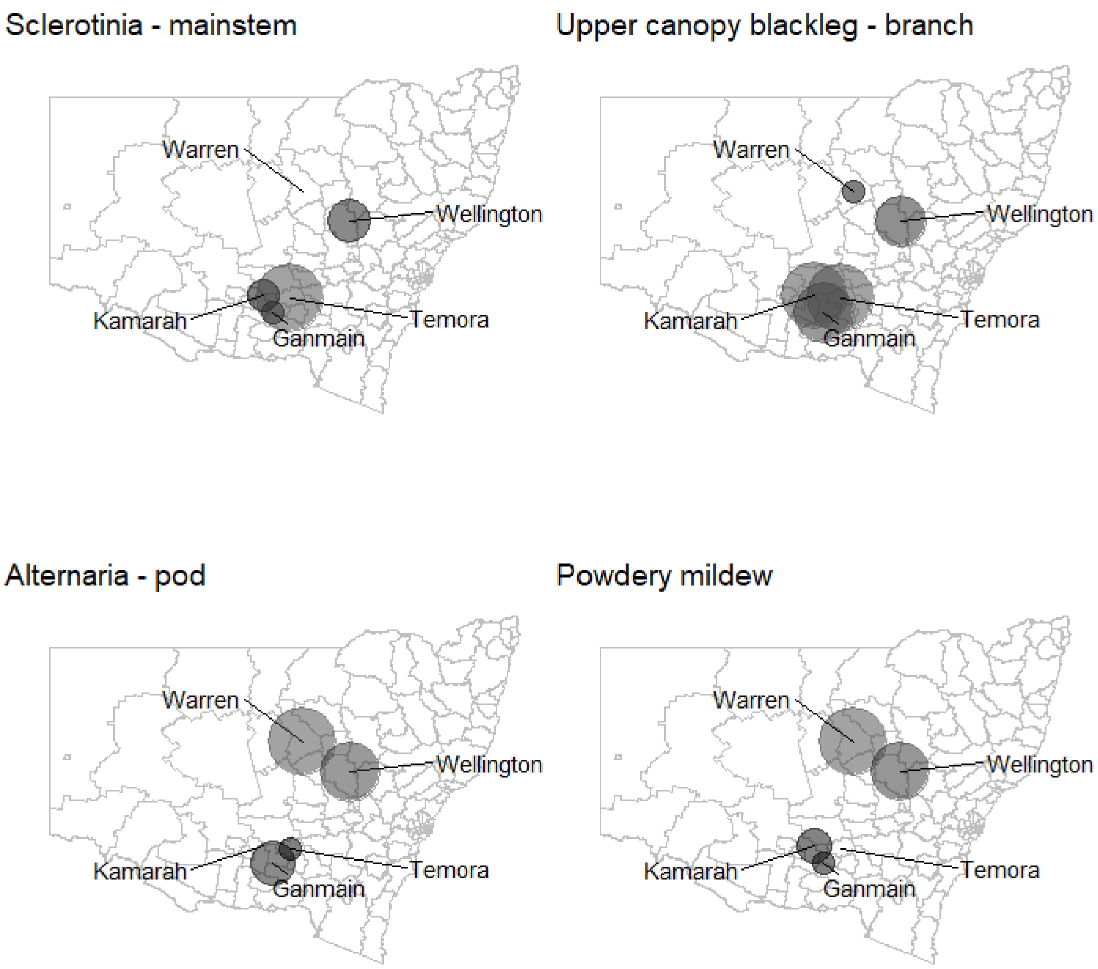

Figure 2. Severity of the diseases Sclerotinia stem rot (main stem), upper canopy blackleg (branch), Alternaria (pod) and powdery mildew across five canola fungicide response trials in NSW in 2020. Larger circles represent greater infection levels (data presented from untreated control). Data presented is dimensionless and no comparison can be made across diseases.

Ganmain

There was no grain yield response to the various fungicide treatments tested at Ganmain.

There was some reduction in Sclerotinia, UCB (branch), powdery mildew and Alternaria incidence, but disease levels were generally low. All fungicide treatments at the 30 and 50% bloom stage reduced Sclerotinia incidence compared to the untreated, but the 10% bloom fungicide treatment (Aviator Xpro only) did not reduce incidence. UCB (branch) was present but not at levels that would impact grain yield (rating of less than 2). Some reduction in incidence was achieved with single applications at 10 and 30% bloom applications of Aviator Xpro, second applications did not reduce incidence further than single spray treatments. A single application of Miravis Star at 30% also reduced incidence. Alternaria on pods was also common but not consequential, with incidence reduced by 50% bloom applications of Aviator Xpro. Powdery mildew was present at low levels, but disease incidence reduced further wherever Prosaro was applied at 50% bloom.

The Ganmain crop was HyTTec Trophy which has effective major gene (Group ABD) resistance to blackleg which may have reduced the severity of UCB infection. Although incidence on branches was easy to find, it was generally not at levels that would impact grain yield. There was only low level of blackleg on pods (data not shown). A further factor that reduced infection risk of this crop was that it flowered the latest of all the crops, with most (30-50% bloom) of the flowering period coinciding with a dry four-week period in late winter/early spring. For the period 1 July to 31 October, Ganmain had the least rainfall (160 mm) of the five sites.

Table 4. Canola grain yield, quality and disease response to fungicide in a crop of HyTTec Trophy at Ganmain 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UC BL Br.	Alt. pod	PM (%)
Aviator Xpro 650 mL/ha 10%	2.47	44.2	5.7	0.6	1.4	2.5	10
Aviator Xpro 650 mL/ha 30%	2.59	43.5	0.3	0	1.4	2.1	5.4
Prosaro 450 mL/ha 30%	2.56	42.9	0.3	0	1.7	2.5	2.9
Miravis Star 30%	2.61	43.9	0.5	0	1.4	2	5
Aviator Xpro 650 mL/ha 10% + Prosaro 450 mL/ha 50%	2.48	44	0.8	0	1.7	2.4	2.7
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	2.56	43.5	0.6	0	1.4	2.4	1.2
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	2.61	43.4	0	0	1.9	2.2	1.5
Aviator Xpro 550 mL/ha 30% + Aviator 550 mL/ha 50%	2.52	43.6	0	0	1.4	1.5	5.6
Aviator Xpro 650 mL/ha 50%	2.53	43.9	0.6	0.3	1.7	1.9	4.5
Prosaro 450 mL/ha 50%	2.47	43.8	0.3	0	2.1	2.8	1.6
Untreated	2.49	42.9	3.3	1.8	2.2	2.8	9.1
l.s.d. (*p<0.05*)	n.s.	1	1.2	0.5	0.8	0.5	3.2

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper canopy blackleg branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Kamarah

There was a positive grain yield response (up to 0.4 t/ha) to all single-spray treatments at Kamarah except Prosaro at 50% bloom. There was no additional benefit of two-spray strategies over one fungicide spray.

Sclerotinia (main stem) infection was low, but all treatments reduced the incidence of the disease except the single applications of Prosaro (both 30 and 50% bloom) or Aviator Xpro at 50% bloom. Fungicide application at 30% bloom (except Veritas) reduced UCB (branch) infection, from levels that would likely reduce yield in the untreated control. All fungicide treatments provided some (but not complete) reduction in the incidence of powdery mildew.

The period between 30 and 50% bloom was relatively wet at Kamarah which may have partly contributed to higher branch blackleg infection than Ganmain. A further contributing factor is that the cultivar 44Y90 CL, despite having effective crown canker resistance, does not have effective major gene resistance.

Table 5. Canola grain yield, quality, and disease response to fungicide in a crop of 44Y90 CL at Kamarah 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UCI Br.	Alt. pod	PM (%)
Aviator Xpro 650 mL/ha 30%	2.87	42.7	0	0	1.9		4.1
Prosaro 450 mL/ha 30%	2.89	43.3	0	0	2.2		5
Veritas 1 L/ha 30%	2.71	42.3	0.5	0	3.1		8.6
Miravis Star 30%	2.70	42.7	0	0	1.9		4.9
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	2.78	42.5	0	0	1.5		3.2
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	2.70	43.1	0	0	2		4.9
Aviator Xpro 550 mL/ha 30% + Aviator 550 mL/ha 50%	2.75	42.7	0	0	1.6		3.4
Aviator Xpro 650 mL/ha 50%	2.74	42.6	4.4	0.6	2.8		7.5
Prosaro 450 mL/ha 50%	2.67	42.6	3.4	0	2.6		7.4
Untreated	2.49	42.7	2.8	0	3.4		15
l.s.d. (*p<0.05*)	0.20	1	1.1	0.5	0.6		4.2

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper canopy blackleg branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Temora

There was a positive grain yield response of up to 0.6 t/ha at Temora. Aviator at 10 and 30% bloom but not 50% bloom improved yields as did Miravis Star at 30% bloom. Prosaro at 30% did not increase yield but did at 50% bloom. Most (but not all) two-spray treatments improved yield.

Sclerotinia infection was highest of all five sites at Temora, but still only a moderate infection level of 12.2% of main stems infected where no fungicide was applied. Aviator Xpro at 10 and 50% bloom, and Veritas at 30% bloom did not reduce Sclerotinia incidence. Aviator Xpro at 10% followed by Prosaro at 50% bloom did not improve yield. Application of Aviator Xpro at 10 and 30%, Miravis Star at 30% bloom and all the two spray strategies reduced UCB (branch), but the best treatment still only reduced the score to a range from 1.5 to 2.1. Application of Prosaro and Veritas at 30% bloom and Prosaro and Aviator Xpro at 50% bloom did not reduce branch blackleg. Miravis Star at 30%, Aviator Xpro followed by Aviator Xpro (30 and 50% bloom) or Prosaro or Aviator Xpro at 50% bloom reduced Alternaria incidence on the pods but did not give full control.

A two-spray strategy generally provided good reductions of both Sclerotinia and blackleg, but no two-spray treatment resulted in higher grain yield than a single application of Aviator Xpro at 30% bloom.

Table 6. Canola grain yield, quality, and disease response to fungicide in a crop of 45Y91 CL at Temora 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UCI Br.	Alt. pod	PM (%)
Aviator Xpro 650mL/ha 10%	3.50	43.2	13.8	1.5	1.5	2	*Nil*
Aviator Xpro 650 mL/ha 30%	3.73	43.5	3.1	1.5	2.1	1.9	*Nil*
Prosaro 450 mL/ha 30%	3.37	43.6	2.6	0.3	2.9	2.1	*Nil*
Veritas 1 L/ha 30%	3.45	42.9	9.9	2	2.9	2.1	*Nil*
Miravis Star 30%	3.58	43.2	2.3	0	2.1	1.4	*Nil*
Aviator Xpro 650 mL/ha 10% + Prosaro 450 mL/ha 50%	3.73	42.6	6.1	0.3	1.7	1.9	*Nil*
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	3.46	43.1	1	0	1.9	1.6	*Nil*
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	3.70	43.5	1	0	2.1	1.8	*Nil*
Aviator Xpro 550 mL/ha 30% + Aviator 550 mL/ha 50%	3.71	43	1.3	0.3	2	1.6	*Nil*
Aviator Xpro 650 mL/ha 50%	3.45	43.1	7.4	0.8	2.6	1.2	*Nil*
Prosaro 450 mL/ha 50%	3.62	43.6	4.6	0.8	3.3	2.1	*Nil*
Untreated	3.07	43.7	12.2	3.6	3.1	2.4	*Nil*
l.s.d. (*p<0.05*)	0.44	0.8	6.3	1.7	0.7	0.7	n.s.

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper canopy blackleg branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Warren

No fungicide treatments resulted in a significant increase in grain yield.

There was no Sclerotinia infection at Warren and low (inconsequential) levels of upper canopy blackleg. The main diseases apparent were powdery mildew and Alternaria infection on pods and stems. Powdery mildew infection was the highest of all five sites, with 67% of stem/branch area infected with powdery mildew by crop maturity (windrow timing) in the untreated control. Fungicide treatments with Prosaro applied at 50% bloom reduced powdery mildew incidence to close to very low levels with no benefit to yields (Prosaro does not claim control of powdery mildew in canola on its label). Alternaria infection on pods was high with only two-spray fungicide treatments providing a small level of control. The Warren site also had high levels of Alternaria on stems/branches, with all fungicide treatments giving some reduction in incidence (data not shown). Unlike branch blackleg observed at other sites, Alternaria did not manifest into cankers that eventually resulted in branch death but were usually superficial. It is difficult to ascertain if Alternaria infection on pods had any effect on grain yield, as no fungicide treatment resulted in clean pods. It is likely that fungicide would need to be applied when all pods are formed (e.g., end of flowering) to achieve good control of Alternaria, but all fungicide products need to be applied by the 50% bloom stage.

Table 7. Canola grain yield, quality, and disease response to fungicide in a crop of HyTTec Trophy at Warren 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UCI Br.	Alt. pod	PM (%)
Aviator Xpro 650 mL/ha 30%	3.72	41.3			0	3.6	19.5
Aviator Xpro 800 mL/ha 30%	3.60	41.1			0	3.6	17.1
Prosaro 450 mL/ha 30%	3.52	41			0	4	17.7
Veritas 1 L/ha 30%	3.39	40.2			0	3.6	20.6
Miravis Star 30%	3.56	40			0	4	43.1
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	3.70	39.6	*Nil*	*Nil*	0	3	2.5
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	3.75	40.6			0	4	5.3
Aviator Xpro 650 mL/ha 50%	3.43	40.9			0.2	3.2	16.9
Prosaro 450 mL/ha 50%	3.47	40.5			0.2	3.6	5.8
Untreated	3.43	40.5			0.2	4	67.4
l.s.d. ($p<0.05$)	0.35	1.6	*n.s.*	*n.s.*	*0.1*	0.4	14.8

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper Canopy Blackleg Branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Wellington

There was a positive (0.2-0.3 t/ha) grain yield response for two of two-spray fungicide treatments, but no single-spray treatments increased yield. Sclerotinia infection levels were low and upper canopy blackleg infection levels were moderate at Wellington. All fungicide treatments except Prosaro and Veritas at 30% bloom provided control of Sclerotinia and upper canopy blackleg branch incidence. Powdery mildew incidence was moderate with best control where Prosaro was applied at the 50% bloom stage. Alternaria infection levels in the untreated control were high on pods (score of 3.9) and stems (score of 4, data not shown for stems) with best reductions from the single Aviator Xpro 50% bloom application (score of 1.4). Fungicide application did a better job of reducing Alternaria on the stems than on pods, again due to the inability to spray fungicide beyond 50% bloom stage to protect all pods. The large differences between Alternaria scores on the stems did not manifest into major differences in grain yield, indicating that Alternaria may have only been superficial.

Table 8. Canola grain yield, quality and disease response to fungicide in a crop of Victory V75-03CL at Wellington 2020.

Fungicide treatment and timing (% bloom)*	Yield (t/ha)	Oil (%)	Sclero MS (%)	Sclero Br. (%)	UCI Br.	Alt. pod	PM (%)
Aviator Xpro 650mL/ha 10%	3.78	43.1	1.1	0	0.7	3.4	24.4
Aviator Xpro 650 mL/ha 30%	3.71	42.9	0.6	0	0.7	3.5	21
Aviator Xpro 800 mL/ha 30%	3.75	43.4	0.4	0.4	0.9	3.1	15.9
Prosaro 450 mL/ha 30%	3.51	43	5.8	0.3	1.9	3.6	15.2
Veritas 1 L/ha 30%	3.62	43.1	3.5	3.3	1.4	3.6	18.2
Aviator Xpro 650 mL/ha 10% + Prosaro 450 mL/ha 50%	3.90	43.3	0	0	0.4	3.3	4.4
Aviator Xpro 650 mL/ha 30% + Prosaro 450 mL/ha 50%	3.77	42.7	0.5	0	0.7	3.4	8.2
Prosaro 375 mL/ha 30% + Prosaro 375 mL/ha 50%	3.81	43.2	0.8	0.3	0.7	3.2	5.2
Aviator Xpro 650 mL/ha 50%	3.76	43.7	1.1	0	1.1	2.1	12.5
Prosaro 450 mL/ha 50%	3.77	42.5	0.9	0.4	0.8	3	6.1
Untreated	3.64	43	4	1.7	1.9	3.9	18.8
l.s.d. (*p<0.05*)	0.17	0.9	2	2.2	0.6	0.6	8.7

** Product recommendations for timing of application in canola vary. Not all products have claims at the 10% timing used in these trials or for all diseases evaluated (no products have claims for control of Alternaria or powdery mildew in canola). Check product labels for details.*

Sclero MS = Proportion of plants with Sclerotinia infection on the main stem. Sclero Br. = proportion of plants with Sclerotinia infection on a branch. UC BL Br = Upper Canopy Blackleg Branch infection with protocol outlined in methodology. Alt. pod = Alternaria pod infection score with protocol outlined in methodology. PM (%) is proportion of stem are infected with powdery mildew. Shaded cells indicate results are significantly better than untreated i.e., less disease or more yield/oil.

Fungicide economics

To determine the economic benefit of the fungicide treatments, grain yield was multiplied by price (allowing for oil increments) and costs of fungicide product and application costs were subtracted. This partial gross margin was then analysed as a variate in the same way that grain yield was analysed (Miravis Star was not included in the economic analysis as it has not yet commercially available).

We assumed a price of:

- $550/tonne for canola (+/- 1.5% for each 1% oil above or below 42%)
- $54.50/L Aviator Xpro
- $74.50/L Prosaro
- $21/L Veritas
- $13/ha application cost

At Ganmain there was no (statistical) difference in the partial gross margin (gross income less treatment and application costs) of any treatment compared to the untreated control. There was a higher partial gross margin at Kamarah only from the application of both Aviator Xpro and Prosaro at 30% bloom. At Temora, the highest partial gross margin was from a single spray of Aviator Xpro at 30% bloom. At both Warren and Wellington, there was no economic benefit of any fungicide treatment compared to the untreated control.

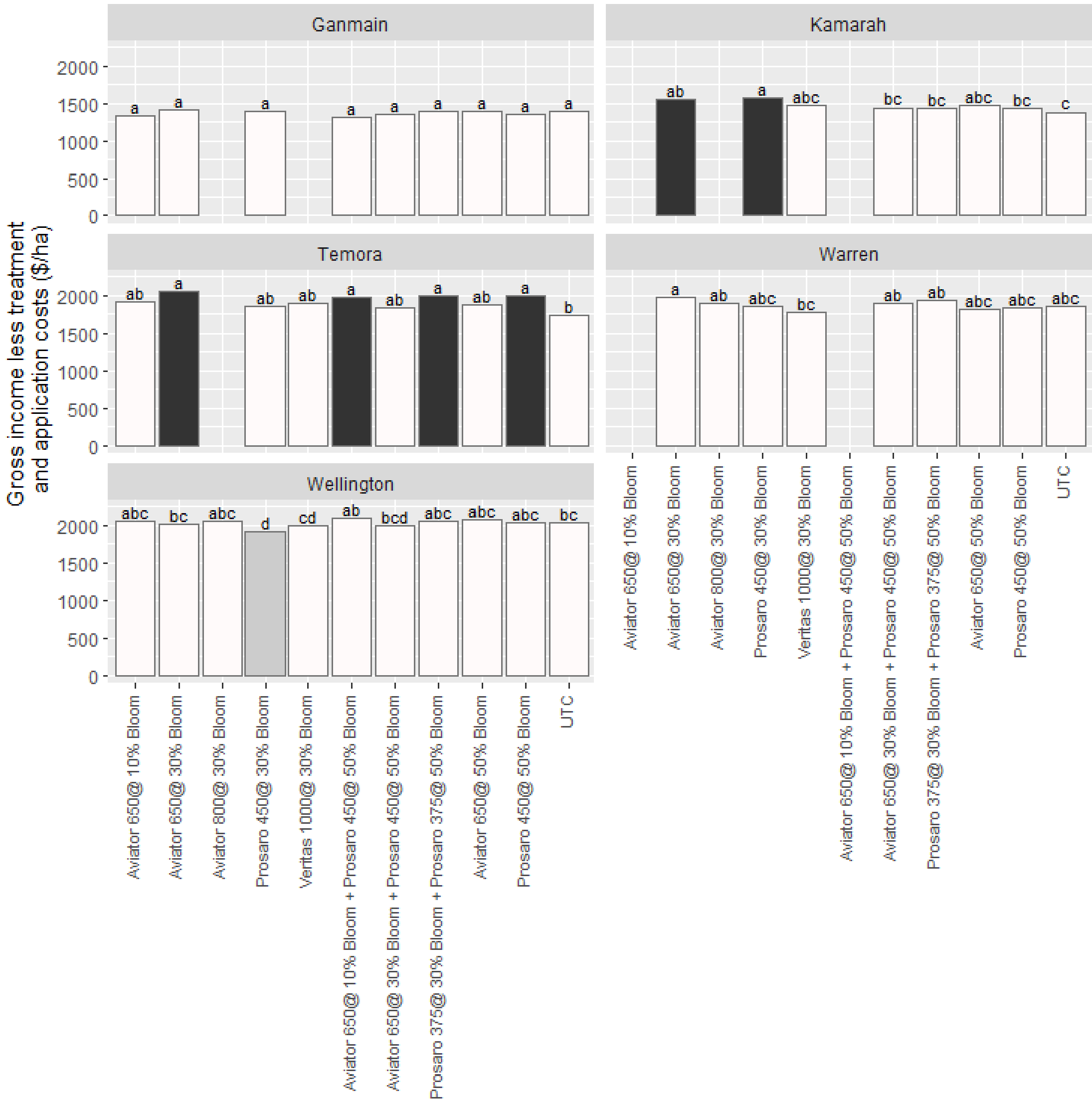

Figure 3. Partial gross margin (gross income less fungicide product and application costs) of fungicide treatments across five sites in NSW in 2020. Treatments with the same letter are not significantly different at p=0.05. Treatments in black are significantly higher than untreated control (UTC) and treatments in grey are significantly lower than UTC.

Discussion and conclusion

Many southern and central NSW canola crops in low-medium rainfall zones had a foliar fungicide applied to them in 2020. The primary driver was protection from Sclerotinia stem rot predicted by a wet first half to the cropping year leading to higher yield potential and medium-term forecasts predicting above average rain through spring. The secondary concern was UCB, especially in southern regions. The presence of Sclerotinia spores was confirmed by petal testing at all trial sites and blackleg was observed at all sites. Despite presence of these diseases at all sites, improvements in grain yield were not common or consistent and economic benefits from fungicide were evident at only two sites.

Petal testing indicated that Sclerotinia inoculum was present at all sites. That visual inspections at Warren and Wellington did not find any apothecia would tend to indicate that infections may have come from neighbouring paddocks. On the other hand, the presence of inoculum was not a good predictor of the ensuing levels of infection.

At all sites, a period of dry weather was experienced through late August and early September which may have limited the development of Sclerotinia in the canopy, however, all sites received good rainfall thorough the early flowering period and again during the late flowering period at most sites.

However, Sclerotinia and blackleg were not the only diseases present in these trials and, although separate assessments were made on the impact of fungicide treatment on the multiple diseases present, it is impossible to attribute yield response (where observed) to any one disease. Yield responses may have been due to reduction in infection of one or more diseases.

Sclerotinia and blackleg were at low levels in the two northern trials (Warren and Wellington) whereas powdery mildew and Alternaria infection were relatively high but spraying fungicide did not provide an economic benefit at these two sites. (None of the products tested have label claims for these two diseases in canola).

Some reduction in Alternaria was achieved with fungicides but it was difficult to ascertain the level of yield loss as even a two-spray strategy was not enough to fully protect pods. The latest spray timing on label is 50% bloom and at this stage only 20-30% of pods have formed. Powdery mildew was a talking point at windrowing time in many crops in the central-west. We found good reductions in in symptoms where Prosaro was applied at 50% bloom yet there did not appear to be significant yield losses even at high levels of infection. Prosaro does not have a label claim for control of powdery mildew in canola.

There was a more compelling case for the economic benefit of fungicides in two of the three southern sites, but not with all treatments. Both responsive sites (Kamarah and Temora) were in cultivars without effective major gene resistance to blackleg, so yield response may have been due to upper canopy blackleg (branch) infection as well as Sclerotinia (especially at Temora). A single spray of Aviator Xpro at 30% bloom provided the most consistent economic benefit in the two responsive southern sites, at Temora returning a net $323/ha net advantage over the untreated.

Overall, despite the presence of several diseases including Sclerotinia and UCB and high yield potential, positive responses to fungicide applications were not universal across sites. In hindsight the dryer conditions in late Autumn to early Spring may have limited disease progression and hence reduced the necessity for fungicides. However, as fungicides are prophylactic, growers and advisors can only work with the information they had at the time.

Many growers and advisors saw the application of fungicide as an insurance policy rather than as an investment and were comfortable knowing they had some of the best crops they had ever grown protected from the potential negative yield effects of key fungal diseases. There are several other 'investments' that could be made into a canola crop where returns are more predictable (such as nitrogen) and ideally the investments that give a reliable return should be addressed before spending more money on 'insurance'.

However, given that 2020 was such a good season with very high yield potential, and that economic benefits were not always present, should give growers the confidence that in seasons with only 'average' grain yield potential, expenditure on fungicide may not be justified and money may be better invested elsewhere.

Management factors that growers can implement in 2021 to reduce fungicide requirement during the flowering period include:

- Select cultivars with effective major gene blackleg resistance. Monitor updates to the GRDC Blackleg Management Guide to guide decision making

- Match phenology and sowing date so that crops do not flower too early. Early flowering will usually result in greater exposure to disease - especially upper canopy blackleg
- Closely monitor short-term forecasts as diseases require moisture for infection
- Consider using some of the decision support tools that may quantify the risks of canola diseases and the need for fungicide applications. Download the SclerotiniaCM and BlacklegCM decision support Apps for your tablet or iPad device
- Avoid sowing canola in or near paddocks that have had high levels of disease infection recently
- When a fungicide is required, apply at the correct time (~30% bloom) and with good coverage to avoid needing a second fungicide.

By reducing the need for fungicide, growers may be able to invest in other inputs where higher returns are guaranteed.

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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.

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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

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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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ⓟ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.

Chickpea Ascochyta update

Kevin Moore and Hayley Wilson, NSW DPI

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Notes

Drone weed mapping for spot spraying: Know what's there before you spray – consistent weed detection driving down the weed seed bank

Tony Single, Tigah Farming

Key words

Single Shot, weed, detection, drone, optical, spray, fallow, technology, IWM

Take home message

The Single Shot drone-based weed detection sensor allows farmers to manage weeds more cost-effectively in fallows. Decoupling weed mapping from spraying allows more informed decision making, resulting in more effective and consistent weed detection with minimal false positives, as well as enabling future technologies such as robotic and drone spray systems.

Australian grain producers are almost exclusively reliant on herbicides for weed control in fallow situations, particularly if we want to avoid the aggressive soil disturbance from cultivation that results in unacceptable moisture loss and soil structure decline.

To remain sustainable our challenge is to overcome increasing herbicide resistance along with herbicide tolerance and weed species shift.

While the development of non-herbicide solutions for weed control, such as microwave, bio-control and novel genetic solutions may be in the pipeline, the cornerstone of cost-effective weed control is still herbicide based.

Recognising this, our family looked for solutions to enable us to carry out site-specific weed management in our fallows. One which would allow us to map individual plants so we could treat individual weeds in a broadacre farming system, giving us another tool to manage herbicide resistance and maintain cost-effective weed control.

This resulted in us building our own solution, the team, which includes our family along with robotic specialists has, over the last ten years, developed the Single Shot drone-based weed detection sensor.

Used commercially on our farm for more than two years, Single Shot is capable of mapping 200 hectares an hour, consistently picking up weeds to the size of the top of a beer can. The information is then processed locally with minimal uploads/downloads to the internet, allowing the same day production of a weed map.

These weed maps can then be loaded into any compatible GPS section-controlled sprayer, allowing cost effective spot spraying without the need for a dedicated optical sprayer.

Spot spraying is fast becoming a cornerstone of our integrated weed management program. The ability to legally use spot-spray registrations and rates helps ensure effective weed kills, minimising the use of sub-lethal broadacre rates on hard to kill weeds. Accurate and consistent weed detection minimises escapes and the area to be sprayed can be assessed prior to application, a legal requirement for many labels.

Weed mapping before you spray

While a single pass with a traditional optical sprayer has the benefit of being 'turn-key' ready to drive out to the paddock, decoupling the weed detection process from the spraying process provides significant practical advantages to me as a farmer.

Firstly, you can decide whether you need to spray, you can choose how you want to spray – be that as a blanket, a spot spray or a combination, you can choose the size of weed you are targeting – with instant feedback on the percentage of the paddock you will be spraying.

We have found on some occasions there were a lot more weeds in the paddock than we thought and we were able to make the decision to use a blanket application as opposed to only finding out there are too many weeds halfway through an application with existing technology.

The technology also allows me to fly a paddock to detect if there are any surviving weeds after a spray application. Surviving weeds have a higher probability of being resistant. If weeds are detected, I then have a weed map I can use to enact control measures from a different herbicide group.

Knowing how much of the paddock I am going to spray before I mix the chemicals allows me to adjust herbicide choice and rates to manage costs. It also decreases waste and increases efficiency.

Mapping ensures you are meeting regulatory requirements – as you know what percentage of the paddock you will be spraying at the labelled optical spray rates.

A big advantage of the Single Shot system is that you are not limited in nozzle choice compared to existing optical sprayers. This makes it far easier to meet regulatory requirements and maximise spray efficacy.

Decoupling the mapping from the spraying means the prevailing light conditions have no influence on application timing, increasing flexibility.

Ancillary uses – the sky's the limit

As with most new technologies, ancillary uses are still being discovered. A recent commercial example was mapping surviving weeds in autumn, that had set seed, so only the areas with weed seed set could be spot sprayed in spring with a pre-emergent herbicide.

It is also possible to make a map from multiple passes so that every weed detected from multiple passes in one season could be combined in a map and used to apply pre-em's at the beginning of the next season.

From a green-on-green perspective the system has been used to identify large surviving weeds in early-growth stage wheat crops, opening up control options that wouldn't normally be viable on a broadacre scale.

The system is currently being developed to measure cotton establishment with the aim of developing a tool to determine if and what areas of a paddock would be justified replanting. It has also been used to create Digital Elevation Models (DEMs) of irrigation paddocks quickly and cost effectively.

There are opportunities in terms of identifying weeds in skips of row crops, which can then be effectively used as a green-on-green application.

After mapping all the weeds in a paddock we can apply the travelling salesman algorithm to calculate the shortest path between weeds in the paddock. This is the enabling technology needed for novel weed control systems that can be robot mounted, without the need to travel the whole paddock in rows.

It will also enable spray drones to be used more effectively, significantly reducing the flight length and spray volume required to cover all weeds as opposed to the whole paddock.

Barriers to adoption

As with any new technology, there are some hurdles to overcome. To operate many drone based systems, an easily obtainable drone pilot licence must be held.

Organisation is important, while producing a spray map the same day as the drone flight occurs is possible, you do need to plan ahead and have the maps prepared before you start spraying.

To successfully adopt the system, the user also needs to have access to a boom spray compatible with the software used on the drone system – including having a compatible GPS section controller and the ability to maintain spray rates when sections are turning on and off for brief moments.

However, on our farm we have found these hurdles easy to overcome and well worth the time invested. This technology is very new, we are still finding new ways to use the information generated to benefit our farming system.

Case Study - Tigah Farming

To date on Narratigah, we have only used Single Shot for stand-alone spot spray applications, using our existing 36m Goldacre's trailed sprayer without making any modifications. Table 1 summarises applications we have made using our booms. These booms only have 7 sections and require a significant lead in time to ensure the section is fully open when it passes over the weed. Other users with more suitable booms have reported significantly higher savings and efficiencies.

The table is not completely valid in that we potentially would have chosen different herbicide mixtures if we were making blanket applications, but it does give an idea of the savings that can be achieved without making any modifications to the boom.

Table 1. Savings with current unmodified booms

Total area covered	Total area sprayed	Percentage spot sprayed	Average chemical cost if blanket per ha	Average herbicide cost saved per ha	Total savings before drone costs
4837ha	1018ha	21%	$15.95	$12.20	$58,197

Recently we have added a dedicated spot spray line to one boom with 18 x 2m sections, incorporating valves that turn on and off virtually instantly. This will give us the ability to spot spray and blanket spray simultaneously. Using the spray simulation function on the Single Shot software, Table 2 summarises the savings we expect to make with the new spray line compared to using the booms without modification.

The figures are from a real life example of a paddock we flew in March 2021. Using our boom without any modifications to the existing 7 section line, we spot sprayed 14% of the paddock. By going to 18 sections with fast acting valves we would have sprayed 9% of the paddock representing a 35% chemical saving.

When these additional savings are added to the savings in Table 1 and coupled with a much higher use pattern compared to stand alone applications only, it highlights the significant value this system will provide to our operation.

Table 2. Expected additional savings with boom modifications

Paddock size	Area to spot spray		Percentage of paddock to spray		Percentage reduction from modifications
	7 Section	18 Section	7 Section	18 Section	
189ha	26.7ha	17.3ha	14%	9%	35%

I anticipate the majority of future fallow spray passes will be made using a blanket and spot spray simultaneously. This will be extremely cost effective in terms of maximising efficacy, minimising herbicide cost and minimise the number of passes we make over a paddock.

By mapping existing weeds, prior to a germination event, the spot spray application can be tailored to the larger weeds, while cost-effectively applying a blanket targeting newly germinated weeds.

Even with relatively high densities of existing weeds the sensitivity can be adjusted to only target larger weeds, with a target of spot spraying 15 per cent of the paddock as an example.

Conclusion

Ultimately to achieve sustainability, as a farmer I want tools that make it cost-effective to achieve as close as possible to 100 percent season-long weed control in fallow before seed set with greater diversity of control options. The combination of being able to spot spray and knowing the percentage of the paddock I'm going to spray, allows the utilisation of modes of action at rates not viable as blanket applications.

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2021 Rethink your approach to canola harvesting to optimise crop performance

Maurie Street and Ben O'Brien, Grain Orana Alliance

Keywords

canola, windrowing, direct heading, desiccation, pod shatter

GRDC project code

GOA00002

Take home messages

- Timing of windrowing of canola can have a huge impact on profitability through its influence on yield and oil%
- Profit could be reduced by up to $50/day for every day that crops are windrowed before they are ready
- The window for windrowing on time is relatively small so it is difficult to logistically windrow all crops in the ideal period
- Direct heading of canola is a viable and comparable alternative to well-timed windrowing and can outperform windrowed crops
- In contrast, the window for direct heading crops to maximise yield and profit may be much larger than the window to windrow crops for optimum yields
- Desiccation, other than that for weed control, in most cases will not significantly speed up crop maturity.

Background

Windrowing of canola in the central west of NSW has been the traditional approach adopted by most growers. Survey data collected in 2017 by Grain Orana Alliance (GOA), a GRDC Grower Solutions Group, indicated that a decade ago, between 65% - 80% of canola growers were exclusively windrowing (GOA, 2019).

In 2009 GOA was asked to investigate if windrow timing (WRT) was impacting canola performance, specifically the oil percentage of harvested grain. In response, GOA established two trials in 2009 that compared different windrow timings. In both trials, the early windrowing resulted in significant yield penalties of up to 0.5t/ha, but only low levels of impact on oil content.

The outcomes from these two trials inspired subsequent trials undertaken by GOA, not only investigating the impact of WRT, but investigating the fit of direct heading, the use of desiccants, the use of PodCeal™, the impacts of delays in direct heading and Podguard™ technology.

In response to the work undertaken by GOA, more in-depth studies were undertaken by NSW DPI under the GRDC 'Optimised Canola Profitability Project' (CSP00187). These confirmed GOA's findings and developed new guidelines and resources for optimum windrowing timing.

GOA has previously presented and published on these topics. Detailed presentations and papers can be found on either the GRDC or the GOA websites. This paper summarises the key findings and presents a case for growers to reconsider how they might approach harvesting canola in the future.

What is the ideal windrowing timing?

WRT is the stage of crop maturity when the crop is cut and placed into windrows to dry and be later harvested when the grain has dried down to a deliverable moisture content (DMC) of 8%. The crop stage is identified by the percentage of the seed that has changed colour. For example, the previously accepted recommendation for the timing of canola windrowing was -

> "Windrowing should commence when 40-60% seed in the middle third of the main stem has changed colour from green to brown, black or red" (Carmody, 2009).

The changing colour is an indicator of those seeds reaching physiological maturity. At this point seed has reached its full potential in terms of seed size and oil content. Prior to this the seed is still growing (increasing in size) which is contributing to increasing yields and oil content. The recommendation of 40%-60% colour change infers that only 40-60% of the seed in the referenced part of the crop is mature and reached its full size. Immature seed at the time of windrowing will have any further growth or accumulation of oil stopped abruptly which will forgo potential further increases in yield or oil%. Windrow too early and yield and oil% will be forgone, with later timings giving the crop more time to realise its full yield potential.

However, what also occurs as the crop matures is an increase in brittleness. The process of windrowing can be aggressive and often results in seeds being lost from pods, ultimately ending up on the ground and reducing harvested yield.

Figure 1. Illustration of the balance needed between increasing yields and increasing potential losses with advancing maturity.

Ideal WRT should aim to maximise the increasing crop yield but not be too late as to reduce harvestable yield by shattering out canola either before but more likely during the windrowing process.

So what did GOA find?

Large scale replicated field trials run by GOA showed that WRT could have an impact on oil% but it was often quite small. The effect of WRT on crop yield however was often much larger, both in magnitude and economic impact. One of the first trials undertaken by GOA at Coonamble in 2009 showed that delaying WRT from 10% seed colour change (SCC) to 70% SCC, or eight days, yields increased by 500kg/ha. The increase represented a 30% yield improvement and at current canola prices, assuming $650/t ex farm (Newcastle port price less freight, July 2021), this would be worth $325/ha.

More recent (2015, 2016 & 2017) trials by NSW DPI under the GRDC co-funded 'Optimised Canola Profitability Project', have looked more closely at the impact WRT can have on yields and oil%. This work has shown in some cases that yield impacts were even greater than those seen in GOA's trials. One trial at Trangie in 2016 showed a 48% yield loss when the crop was windrowed at 6% SCC as opposed to ~60% SCC. At Edgeroi 2016 a 55% (~1.3 t/ha) yield loss from windrowing 8-10 days earlier than the peak yield was measured. Tamworth 2016 showed a potential yield loss of 1.2 t/ha or 32% from premature windowing. (Graham et al, 2018).

The consistent message from both GOA and NSW DPI is that WRT earlier than the current recommended timings of 40-60% SCC, has consistently resulted in significant yield penalties.

The trials have also demonstrated the potential to increase yields further by delaying WRT past the old, recommended timings. The GOA trial at Coonamble showed a further 16% increase in yield (280kg/ha) from only a five-day delay in WRT from 50% SCC to 70% SCC (Street, 2014). Delaying WRT at Trangie in 2016 from ~60% SCC to the 100% SCC increased yields by a further ~800kg/ha (Graham et al, 2018. Several other trials also support these findings, where delaying WRT past 60% SCC increased yields. This outcome is not unexpected given that up to 100% SCC some immature seeds within the crop are still developing and so could still contribute to yield. The question remains however, at what point do the losses from pod or seed shatter negate any further increases in yield?

So, what has changed and why does later windrowing perform so much better?

Plant populations have generally reduced over the years. Street (2014) suggested that with lower plant populations, proportionally less yield is carried by the main stem where we assess windrow timing. Graham (2018) confirmed that greater than ~70% of the crop yield may be carried on branches as opposed to the mainstem and that more importantly, the stems were less mature than the mainstem. As such, estimating crop maturity based on the mainstem also overestimated average crop maturity. Windrowing crops based on mainstem maturity meant that much of the crop was immature and still had substantial yield potential unrealised if windrowed then.

Varieties have also evolved. Variety trials are seldom if ever windrowed but direct headed. Varieties susceptible to pod shatter would likely experience a higher level of yield loss compared to other more resilient varieties, thus reducing the likelihood that any such varieties would progress to commercialisation against other varieties that are more resistant to pod shattering.

This also suggests that varieties of 20-30 years ago may have been more likely to shatter at earlier level of SCC ,tipping the scale towards an earlier windrowing time than it would be with today's varieties.

So when should I windrow?

As an outcome of this work new recommendations have been put forward to target the optimal windrow timing for canola, with two key changes:

1. Crop maturity should be based on the whole crop not just the mainstem
2. The optimum SCC has also moved later from 40-60% to 60-80%.

The current recommended timing is:

'Crops should be windrowed when 60-80% of the seed sampled from the middle third of the mainstem and the branches has changed colour from green to red, brown or black.'

A kit has recently been released 'Canola - Windrow on Time, Reap the Rewards' which details more the methodology to assess SCC and some illustrative references to help determine the level of SCC in your crops. An online version is available at-https://grdc.com.au/canola-windrow-on-time,-reap-the-rewards?utm_source=website&utm_medium=short_url&utm_term=&utm_content=Canola%20%E2%80%93%20Windrow%20on%20time,%20reap%20the%20rewards

What has also been demonstrated is the rapid rate at which seed colour change can occur. Results from a NSW DPI trial in 2017 demonstrated that seed colour change went from 29% to 90% in only a 5-day period. In GOA's 2010 trial at Coonamble, SCC went from 10% to 70% in just eight days and the trial at Warren in 2010 matured from 40% to 95% SCC in seven days. These results demonstrate that to windrow at the optimum timing of 60-80% SCC would only be a fraction of these times. As such, the window to windrow at an optimum crop stage can be very small.

Given the yield and financial impact that premature windrowing has, optimising yields in windrowed crops over a large area can be extremely difficult to achieve in practice. The fact that much of the canola crop, both the individual growers' and the districts', will require windrowing in the same small window, increases the difficulty in getting a windrower when needed.

How late is too late to windrow?

GOA undertook four trials that investigated the effects of delaying WRT past the previous timing recommendations. These trials used commercial windrowers and headers and reported harvested yields. They consider the potential losses from delayed windrowing through shattering; however, they are not quantified. In these trials there was no measurable decline in harvested yields even where WRT was delayed up to 95% SCC on the main stem. This is not to say that delayed WRT did not result in small increases in pod shattering, but any losses were compensated by increases in yields from other more immature parts of the plant.

In one trial however there was a measured a downturn in yield of 250 kg/ha as a result from a delayed WRT. However, the delay was measured as 7 days after 100% SCC and so represented an extreme case of late windrowing. This demonstrates that you can windrow too late and if growers are unable to windrow by the later stage of 80% seed colour change (whole plant) and/or significant pod shattering is likely during windrowing, leaving the crop to direct head may be a better choice.

Is direct heading a viable alternative to windrowing?

GOA has run several trials which have shown that yields from direct headed situations have generally matched the yields of a **well-timed** windrowing. However, when compared to that of an ill-timed windrowing i.e. too early or too late, direct heading outperformed the windrowed treatment.

Direct heading has often been made out to be very risky and not worth considering. Stories of very small harvesting windows before pod shattering occurs, increased exposure to weather damage, reductions in harvesting hours, delays to harvest commencement and slow harvest rates are common, however many such stories are not well founded.

Delayed direct heading and pod shattering

Results of a trial conducted in 2013 (Figure 2), demonstrated that the yields were stable in a standing direct headed crop and did not decline for two weeks after the first harvesting opportunity (Day 0). At this point there was a weather event resulting in a yield decline, after which the yield plateaued again. This suggests that in this situation, yield decline when harvesting is delayed tends to be stepped rather than linear and that shattering yield losses are most likely a function of weather extremes, which are fortunately infrequent but also unfortunately unpredictable.

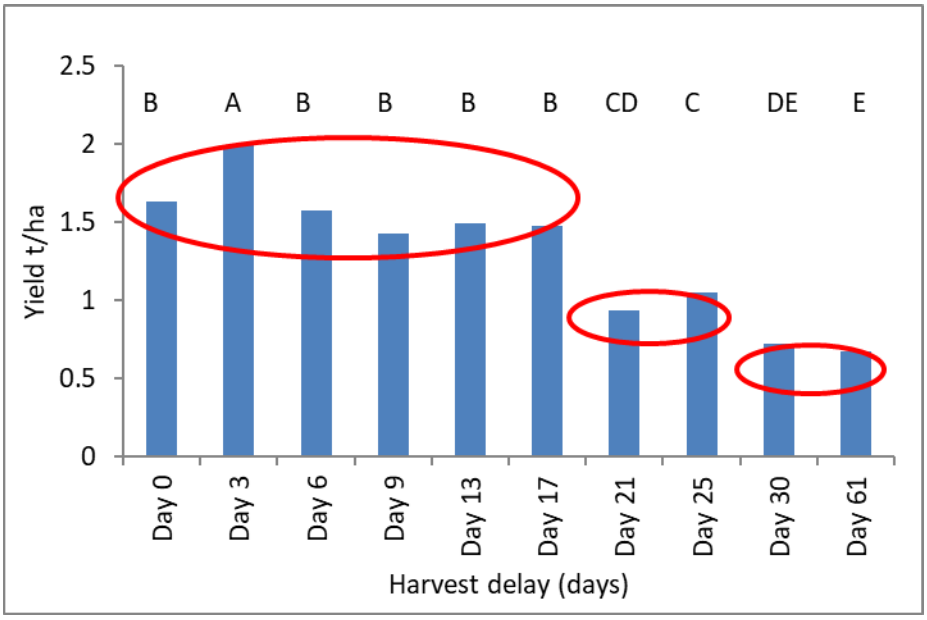

Figure 2. Harvested grain yields in response to delay in direct heading from the first harvest timing 'day 0'- Wellington 2013

PodGuard™ Canola promises of enhanced shatter tolerance

A unique genetic trait 'PodGuard™' has been bred into selected canola varieties which has increased tolerance to shattering. This trait may allow growers to either delay WRT until later stages of crop maturity to capture higher yields or allow growers to have confidence that pre-harvest shattering will be minimised in crops left to direct head.

GOA in conjunction with Bayer tested shattering tolerance of a PodGuard™ variety against a non PodGuard™ variety in a trial conducted in 2015. A severe shattering event was simulated consisting of dragging a two-inch steel pipe twice through the podding zone at harvest (i.e. 100% maturity) for a normal and delayed harvest timing.

At the first harvest timing (H1) without the simulated shattering event, the yields of the two varieties were comparable. However, when the simulated shattering was applied only the yield of the non Podguard™ variety 45Y25 was impacted, with yield reduced by around 600 kg/ha (~25%). Delaying harvest by 14 days (H2) resulted in no statistically significant yield decline in the PodGuard™ variety however the yield of the 45Y25 was reduced by ~500 kg/ha. Combining the simulated shattering event with the delay in harvest, the 45Y25 suffered around a further 500 kg/ha yield loss, while the PodGuard™ variety experienced no loss of yield, see Figure 3.

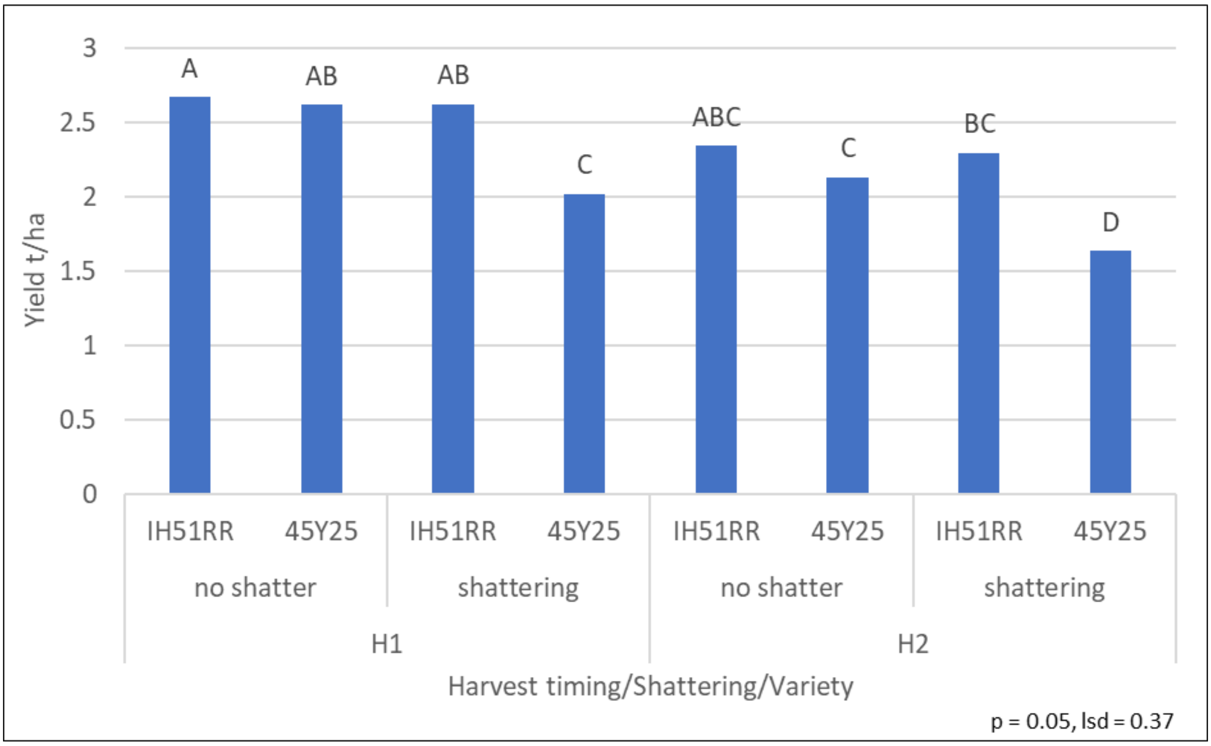

Figure 3. Harvested yield in response to harvest timing and simulated shattering by variety- Wellington 2015. H1 is harvested 'on time', H2 harvested with a 14-day delay. IH51RR contains PodGuard technology, 45Y25 does not.

During this trial, measurements were made to quantify the source and timing of the losses encountered. Details of these are covered in the full trial report on the GOA website which can be found at www.grainorana.com.au/documents?download=39

In summary, the PodGuard™ variety IH51RR has shown good potential to resist shattering from delays in direct heading or severe shattering events such as high winds or hail but worth also noting that although the 45Y25 suffered some yield loss from delays to harvest, it was not a complete disaster.

GRDC have also produced a 'Direct Heading Factsheet' that can be found at www.grdc.com.au/GRDC-FS-Direct-Heading-Canola

This factsheet examines many of the pros and cons and suggests that on top of yield advantages, farmers should also consider the additional benefits including the elimination of windrowing costs, applicability for heavy lodged crops that cannot be windrowed and for lighter crops where small windrows may be unstable in windy conditions.

However, it should be noted that windrowed crops are not immune to the impacts of adverse weather. Windrows, particularly those in light crops are highly susceptible to wind movement and subsequent yield loss. Hail can also impact windrows, as it can a standing crop, but in both cases, these are an insurable risk. Wet weather may also see some differences in grain quality. Anecdotally windrowed crops will stay wetter for longer after rain, delaying harvest and prolonging the risk of sprouting. This could lead to lower test weights and yields along with longer delays in recommencing harvesting.

How does timing of harvest vary between direct headed or windrowed crops and will desiccation help alleviate any differences?

One common concern for growers when considering direct heading is the perceived delay in the commencement of harvesting. It is thought that compared to windrowed crops, crops left for direct heading take a week or longer to dry down to acceptable grain moisture content before harvesting can commence.

One option to potentially manage this issue in direct headed crops is to apply a desiccant to the crop ahead of harvest to speed up the ripening process. Reglone™ has been registered for this purpose for some time, but its cost, difficulties in application and perceived unreliability often deters many from its use.

More recently glyphosate formulations such as Weedmaster™ DST marketed by Nufarm has been registered for use in canola for pre-harvest application. While the main label claim is for pre-harvest weed control, it also registered as a 'harvest aid', suggesting that it may also speed up the ripening process.

Over three years GOA has run four trials investigating the relative effectiveness of Weedmaster DST and Reglone, in reducing grain moisture content (GMC) to facilitate earlier harvesting. The key findings from this work were that Reglone, when applied to canola, showed some limited advantage in bringing GMC down quicker than natural ripening. In two of the 4 trials, there was no advantage to using Reglone (Geurie 2014 and Wellington 2015). At Wellington in 2013 the Reglone treatment would have allowed harvest to start approximately five days earlier. At Coolah in 2014, Reglone may have allowed an earlier harvest, but all treatments including the untreated was below 8% GMC within one more day and so offered little benefit.

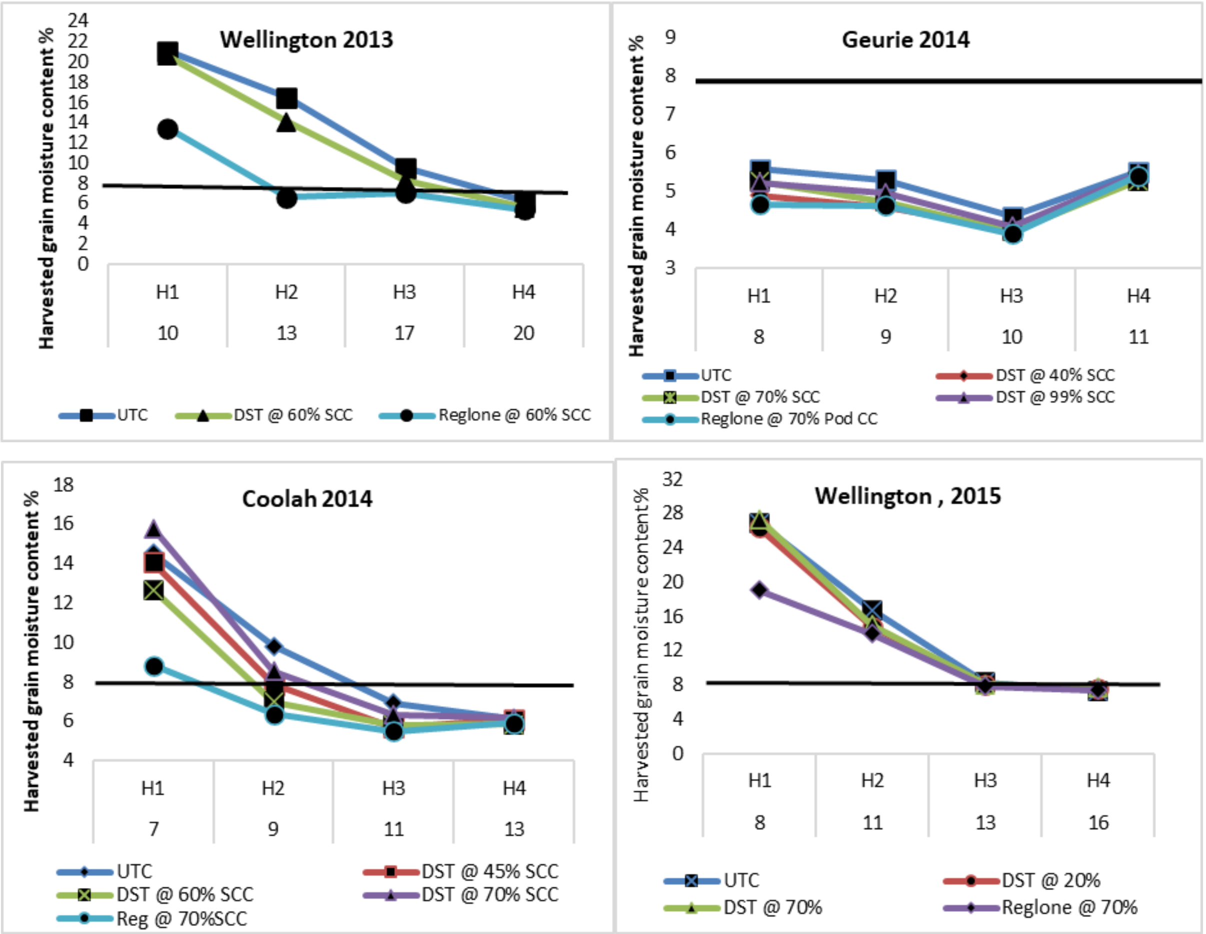

Figure 4. Harvested grain moisture contents in response to application of Reglone (REG) or Weedmaster DST (DST) at differing levels of seed colour change. As assessed at four different harvest timings (H1, H2, H3, H4). Numbers under the harvest timings indicate the number of days since the Reglone application (~70% SCC).

Weedmaster DST applied pre-harvest also showed little practical benefit at bringing harvest forward with no significant difference in GMC at any harvest timing between any DST treatment and the untreated crop.

Further details of the trials can be found at http://www.grainorana.com.au/documents?download=49

An interesting observation in these trials was the rate at which the crops ripened without any desiccation and the relevance this may have to potential time differences between harvesting of a windrowed crop and direct headed one. Reglone in the trials detailed above was applied at ~70% SCC and considering the new windrowing recommendations, this crop stage is within an optimal WRT. It can be seen in the graphs above the time it takes the untreated crops to dry down to 8% GMC in relation to 70% SCC.

Both Wellington trials took only 13 or 17 days for the untreated canola crop to reach 8% moisture, but in 2014, Geurie reached 8% moisture in under 8 days and Coolah within 10 days. Typical district experience would suggest windrows often cure for at least 10-14 days most years and thus suggest the time to harvest a direct headed crop would be within days of one that is windrowed and not weeks as often thought could be the case.

The view of longer delays to this may be brought about though early windrowing. The earlier a crop is windrowed, the sooner it is dry enough to harvest relative to a crop left standing to ripen naturally. It could be suggested that in many cases if growers do experience lengthy delays in commencement of direct heading in comparison to similar ones around, it could indicate windrowing has commenced too early, which we now know could be incurring significant yield penalties. Looking at this from the other way, is that if growers adopt the later WRT, the difference between harvesting of windrowed crops and direct headed crops is likely to be less than previously experienced.

Windrowing allows me to get started on harvest earlier so as not to interfere with harvesting of my other crops.

Many growers argue their preference for windrowing canola as it hastens harvesting. However, as evidenced above, the difference may not be as large as some think if windrowing at the correct timings. Windrowing may offer several days which may be useful, but for many, this may still not be enough. If growers choose to windrow early to result in more available days to complete harvesting, it should be remembered this could come at a significant cost. Numerous trials have shown that premature windrowing could be costing growers up to $50/ha/day.

This issue may be magnified in crops with mixed maturities due to uneven establishment or major soil type changes etc. There is no debate that windrowing crops with significant maturity differences will allow harvest of the greener areas sooner than if left for direct heading. However, it is worth the grower considering the relative proportions of each maturity, and to which the windrow timing be set on. But the green areas may well be the highest yielding areas of the paddock and windrowing those areas early to suit the more advanced low yield areas may seem counterproductive. Setting windrowing to the greener parts of the paddock may risk shattering during windrowing in the more mature parts. It could be argued that there is no right time to windrow a crop with significant areas of contrasting maturity. If the areas are less balanced it will become an easier question to answer, but it will always be a compromise for some part of the crop.

Growers are often concerned that delays in canola harvest will impact on traditional wheat harvest periods, increasing harvest downgrade risks in wheat. Worth noting that windrowing early to accommodate an earlier start to wheat harvest will almost certainly incur a loss, while a weather downgrade to wheat may not even occur. It is also worth considering crop values. Canola in 2021 is twice the price of wheat and more than three times the price of barley. It could also be suggested that crop harvest order should not need to be set in stone. Traditionally canola has been harvested ahead of barley and wheat, but there is no issue with harvesting barley ahead of canola.

Pulling it all together

Windrowing will remain popular with many growers for several reasons, however growers should strive to windrow to the new recommended timings of 60-80% SCC across the whole crop. Failure to do so could result in significant yield penalties and with current pricing of canola, this can amount to a significant financial penalty. Windrowing crops in the optimal window, which can be quite small, can be logistically difficult and some growers may need to sacrifice yields by starting windrowing of large areas earlier, but again this can be at an additional cost in lost income.

Direct heading of canola is a worthy alternative to windrowing and much of the negative connotations of the past are not as common as often thought. Direct heading will allow for the whole crop to reach its full potential yield and oil%, and trial work suggests that it will yield as well as a correctly timed windrowed crop. If the alternate is to windrow too early or too late because of weather complications or availability of a windrower, direct heading may be the best option.

Concern over rapid yield loss with delays to direct heading have not really been demonstrated in trial work or with commercial experience, which has shown yields to be often quite stable post crop maturity. With ever improving varieties or PodGuard varieties, concerns could be even further allayed.

Time differences between windrowed and direct headed crops may also not be as different as thought, provided windrowing of crops is done at the latest recommended timing. If growers choose to windrow early to finish early, that decision will come at a significant price paid in terms of decreased yield and oil%.

GOA's trial work on desiccation products has shown little advantage in terms of closing the gap on harvest timing, with Reglone, while not consistent, performing better that Weedmaster DST but overall neither achieving practically useful results.

Useful resources

GRDC Grow Notes- Canola: https://grdc.com.au/resources-and-publications/grownotes

Direct heading factsheet: www.grdc.com.au/GRDC-FS-Direct-Heading-Canola

Canola best practice management guide for south-eastern Australia: https://grdc.com.au/resources-and-publications/all-publications/publications/2009/08/canola-best-practice-management-guide-for-southeastern-australia

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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.

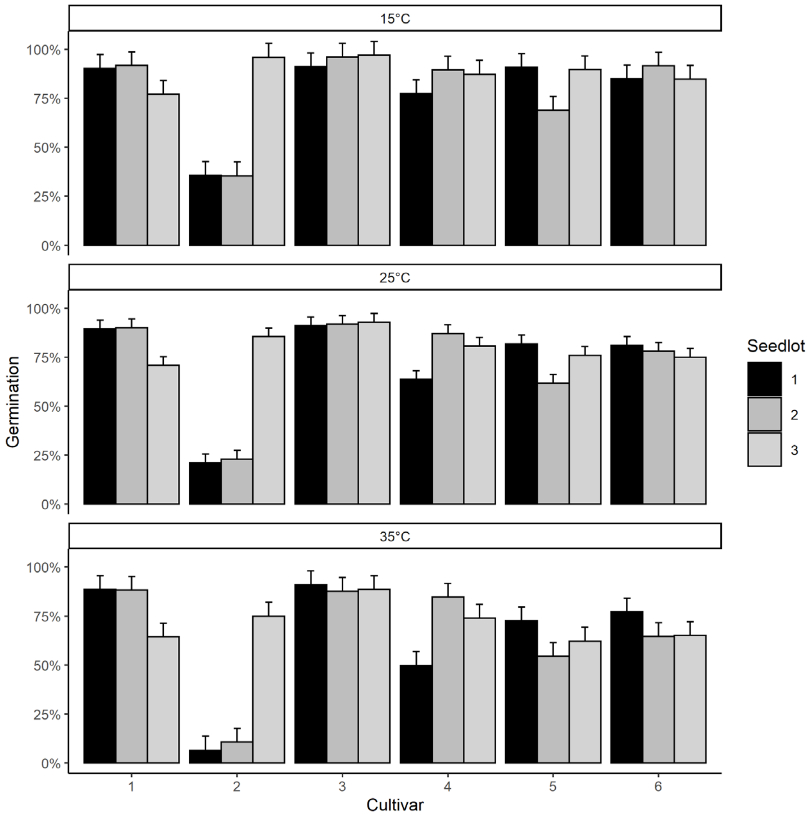

Figure 1. Germination percentage for each genotype and seedlot used in trials between 2018 and 2021 at 3 temperatures. Seedlot 1 was sourced in 2018-19, seedlot 2 was sourced in 2019-20 and seedlot 3 was sourced in 2020-21. Seed was kept in cool storage until evaluation in 2020. Error bars show pooled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

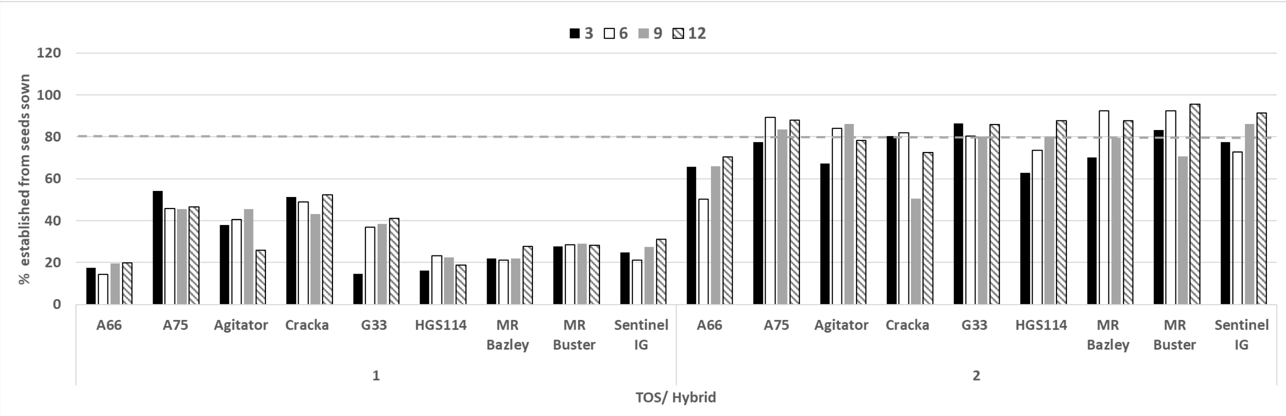

Figure 2. Percent of established plants from actual seeds sown at "Bullawarrie” 2020-21. Legend shows actual target plant population (per m^2). Data obtained from plant counts collected at 35-38 days post sowing.

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.

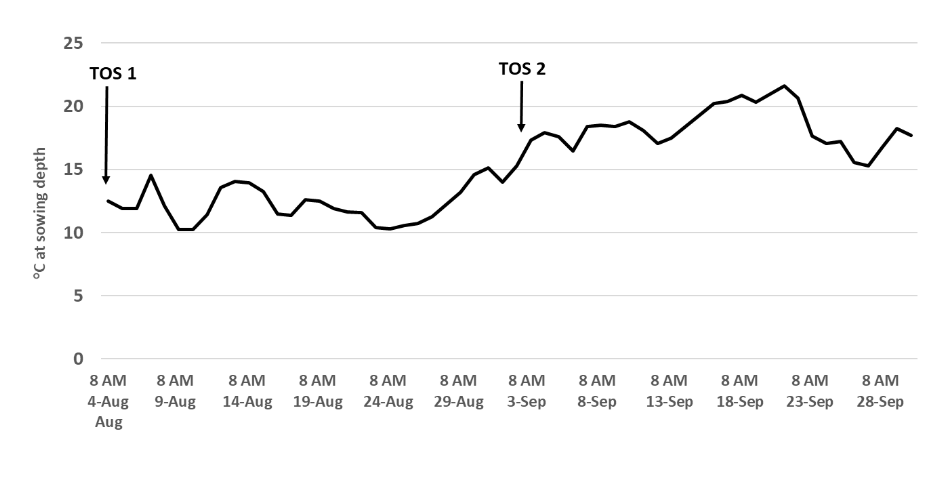

Figure 3. Soil temperatures at "Bullawarrie" Mungindi in 2020-21. Soil temperatures were measured at sowing depth.

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).

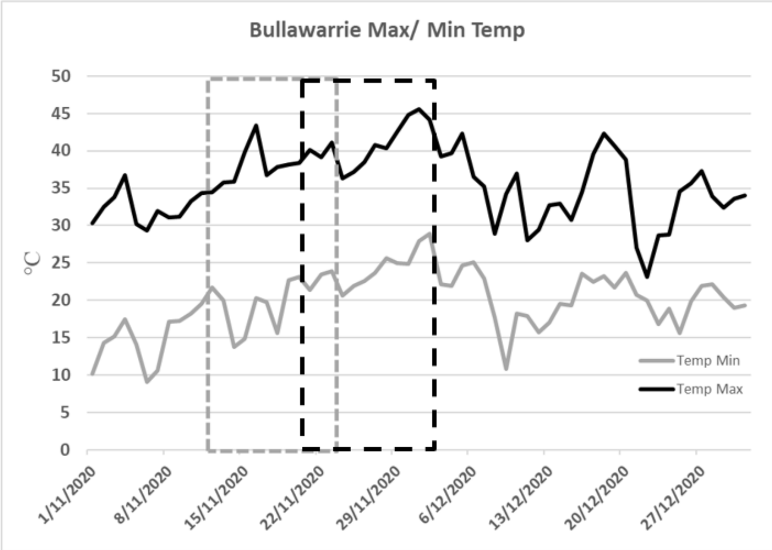

Figure 4. Maximum and minimum temperatures at "Bullawarrie" Mungindi in 2020-21. Dashed boxes indicates the flowering window of TOS 1 (grey) and TOS 2 (black).

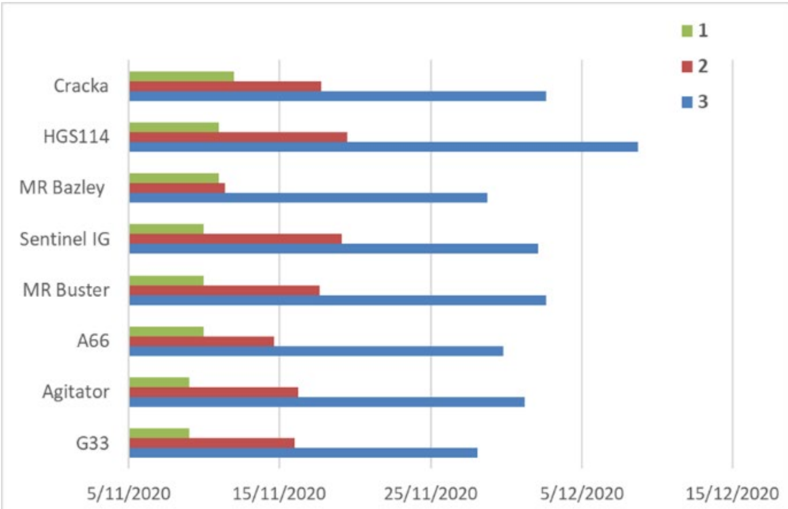

Figure 5. Flowering dates at "Bogamildi" Moree in 2020-21. Time of sowing dates were (1) 5th August, (2) 2nd September and (3) 28th September.

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.

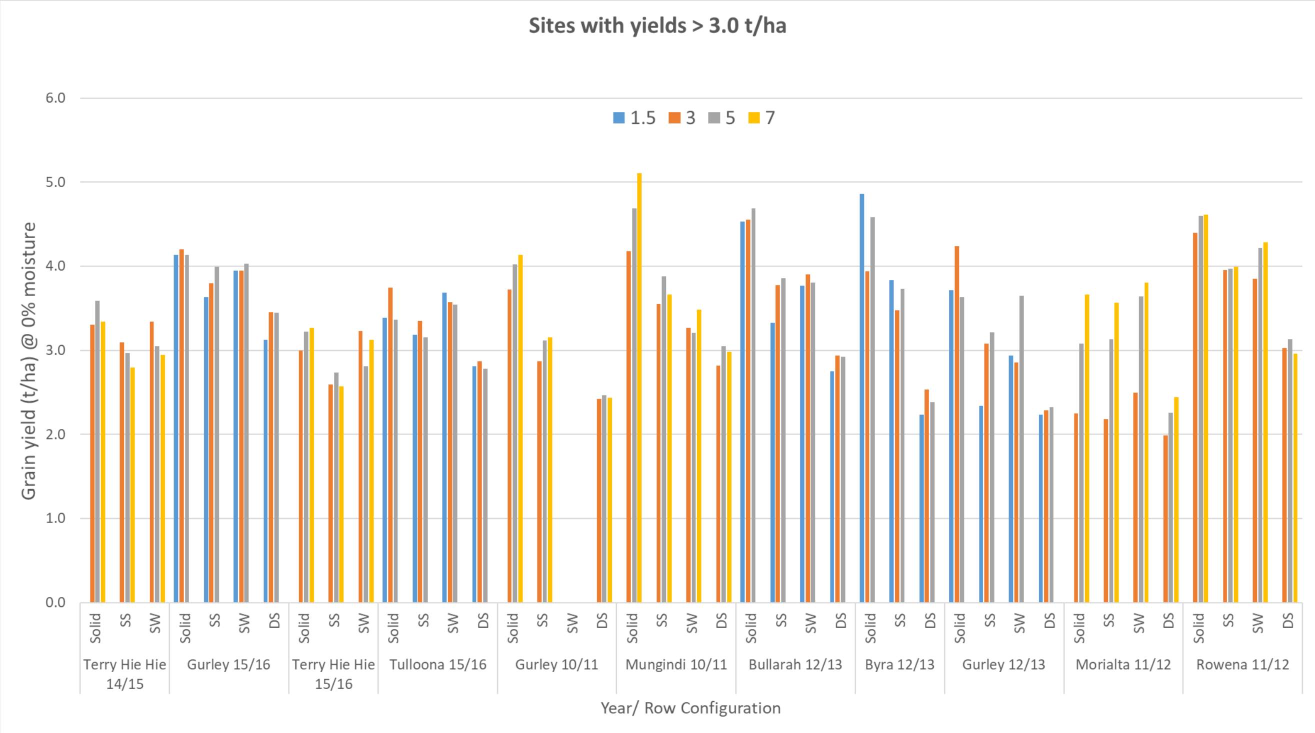

Figure 6. Trial sites with grain yields > 3.0 t/ha. Response to varying plant population (plants/m2) and row configuration in sorghum across north west NSW from 2010-2016 (Solid = solid plant, SS = single skip, SW = super wide (150 cm solid) DS = double skip).

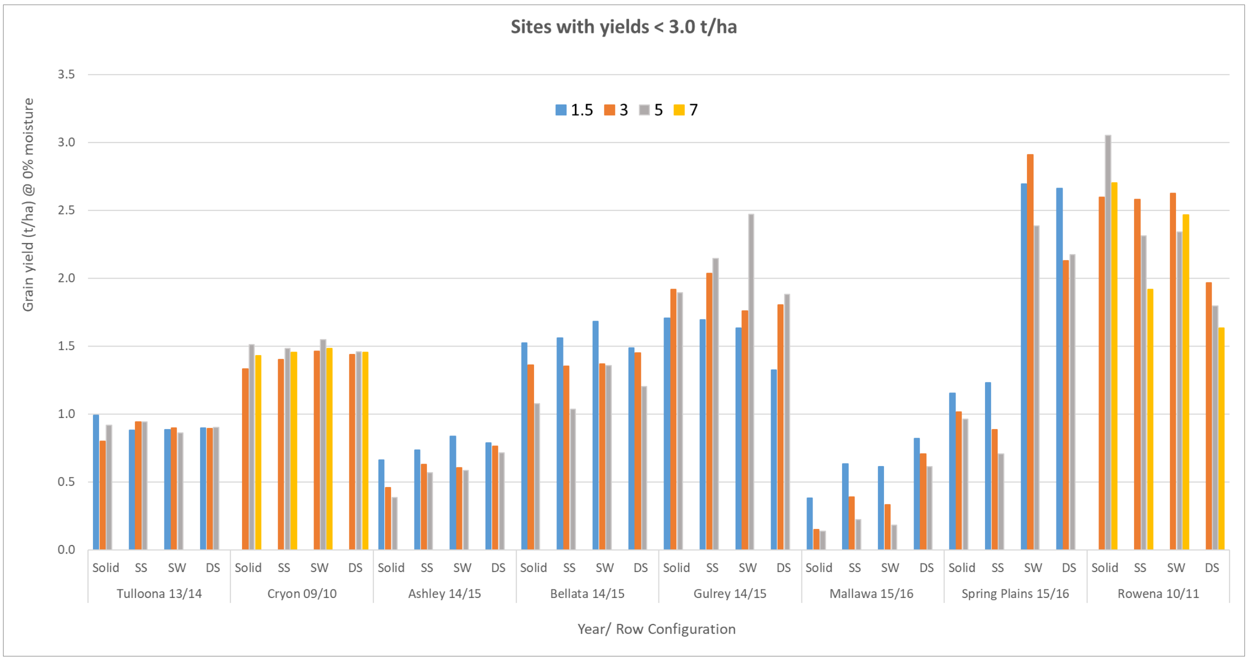

Figure 7. Trial sites with grain yields < 3.0 t/ha. Response to varying plant population (plants/m2) and row configuration in sorghum across NW NSW from 2010-2016. (Solid = solid plant, SS = single skip, SW = super wide (150 cm solid) DS = double skip).

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.

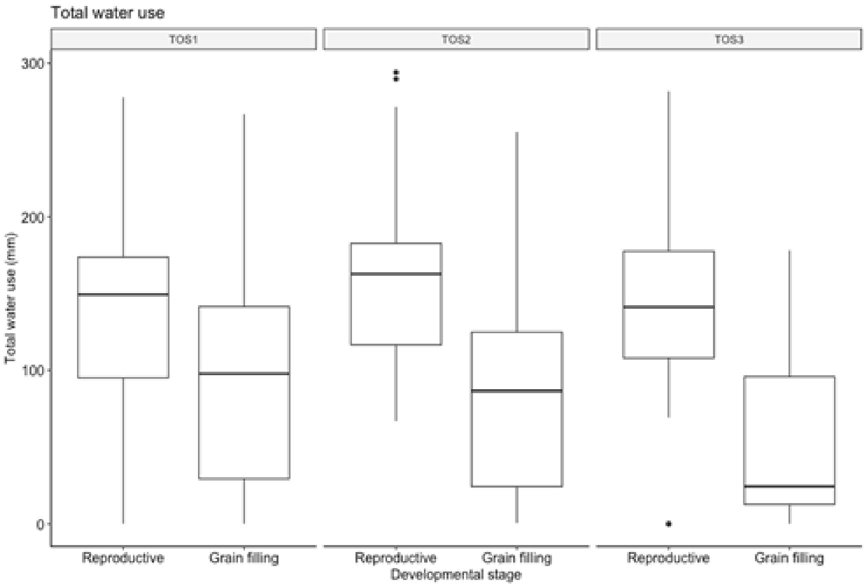

Figure 8. APSIM simulated water use (mm) between floral initiation and flowering (reproductive) and after flowering (grain filling) periods for all the treatments and sites trialled during the first season of trials (18-19).

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.

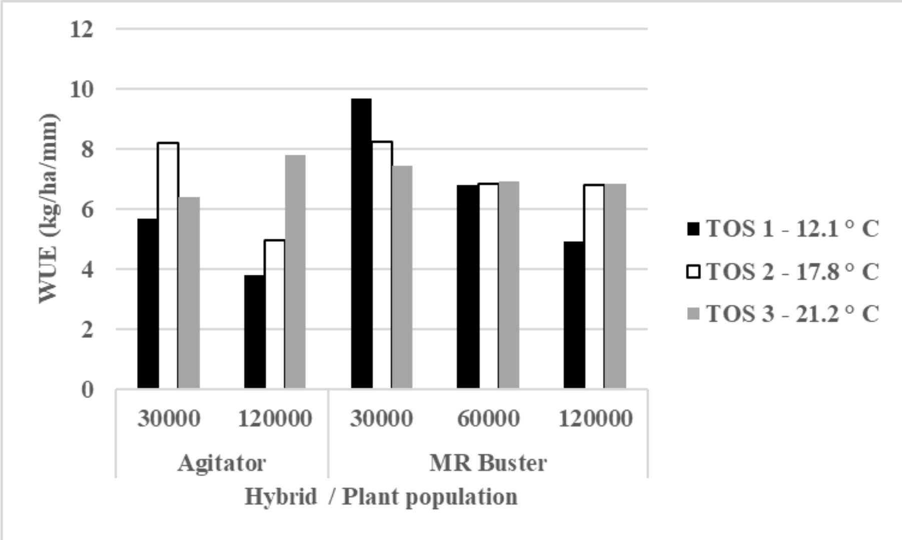

Figure 9. Water use efficiency response to varying sowing time at Breeza 2019-20 (LSD = 2.61 kg/ha/mm)

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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Within-paddock nitrogen variability and the potential role of cereal grain protein mapping for site-specific N management

Eva Moffitt, EM Ag Consulting

Key words

nitrogen, protein, GPC, wheat, variability, variable rate, VR, site-specific

Take home messages

- Wheat grain protein concentrations of less than 11.5 % generally indicate that nitrogen (N) supply was insufficient for a crop to meet its water limited yield potential
- If this 'rule-of-thumb' is applied across a landscape, a spatially referenced wheat grain protein concentration map is analogous with an 'N adequacy' map
- This layer can be used in conjunction with targeted deep N soil sampling as a basis for site-specific N inputs to reduce both instances of yield loss due to N undersupply and adverse environmental/economic consequences associated with N oversupply
- Research conducted in 2019/2020 across five paddocks (511.4 ha) in southern NSW supported the use of wheat protein mapping as a basis for site-specific N
- This approach may have a good fit for growers located on soils not prone to N losses that have variability in factors such as texture/CEC/OC%/PAWC, productivity (N removal) and/or management histories (e.g., amalgamated paddocks, variable N inputs)

Introduction

This paper will explore concepts around managing nitrogen (N) variability as part of a larger (whole system) approach to improving N management, with particular emphasis on the potential role of cereal grain protein mapping in site-specific N fertilisation. Results will be presented from paddock scale research conducted in 2019-20 that examined relationships between soil mineral nitrogen (SMN) levels and grain protein concentration across five paddocks in southern/central NSW.

The broader problem

Despite widespread knowledge of the importance of nitrogen (N) supply in broadacre cropping systems, N deficiency remains the most substantial contributor to the sizeable yield gap in Australian wheat production (Hochman and Horan, 2018). Furthermore, recent assessments have found that most Australian grain cropping systems are in negative N balance, that is, more N is being exported off-farm than is being applied as fertiliser or fixed from atmospheric N_2 (Angus and Grace 2017).

A major driver of N under-supply has been the naturally conservative approach of growers operating in highly variable rainfall environments, where adverse agronomic and environmental consequences of N oversupply have been experienced and/or are perceived. To this end, Australian growers have historically placed much reliance on mineralisation of organic N to meet crop demands (Angus et al., 2006), which has been desirable not only from an economic perspective, but also agronomically due to the positive relationship between both N supply and crop demand with soil moisture.

With resultant declining levels of soil organic matter (SOM; up to 60% under continuous cropping; Dalal & Chan, 2001) and the diminishing adaptive N supply ability of our soils, it is clear that a growing requirement exists for fertiliser N to maintain (or increase) productivity within the Australian grains industry.

For fertiliser rates to rise in a sustainable manner, it is also clear that there is considerable work to be done in improving the robustness of N fertiliser decision methods. In a 2015 survey of 132 commercial crop advisors in New South Wales, Schwenke et al. (2018) found that while most advisors regarded soil tests as moderately to very important for determining N fertiliser requirements, interviewed participants revealed that many of their clients either did not soil test, or of those that did, the number of paddocks tested was quite low. This supports findings by Lobry de Bruyn & Andrews (2016), who found that only 25-30% of Australian broadacre crop businesses conduct annual soil testing for nutrient levels.

One of the key barriers to N soil testing identified by Schwenke et al. (2018) is the view among growers that within-paddock spatial variability of N is high, which leads to distrust of whole-paddock bulked soil test results. Growers are instead more comfortable using 'rules-of-thumb' approaches based on paddock history and seasonal outlook. This suggests the lack of cost-effective, sound agronomic methods for quantifying and mapping spatial N variability is a substantial impediment to the overall improvement of N management in Australian cropping systems. This is supported by on-the-ground experience which would suggest that the lack of trusted variable rate (VR) N solutions available to growers presents a far greater impediment to the adoption of precision N practices than technological capacity or grower enthusiasm.

Supply and demand concepts

To better understand the challenges of successful site-specific N approaches, it is useful to examine the basic N dynamics at play in broadacre cropping systems. In simple terms, optimal N management refers to matching N supply to N demand – both parameters of which can be highly spatially variable in the Australian landscape.

For example, on the supply side of the equation – residual (carryover) N may vary according to previous crop and pasture productivity (influencing both N removal and N fixation), in-season mineralisation may vary according to soil type and management history (influencing SOM pools and moisture), N losses may vary according to factors such as soil texture and/or landscape position (influencing leaching and waterlogging/denitrification) while a myriad of other less predictable factors and/or interactions may also be at play (e.g. uneven fertiliser/manure applications, uneven removal of hay, redistribution of N by livestock).

On the demand side of the equation, variability of yield potential in the Australian landscape can be substantial over very short distances, often driven by differences in plant available water-holding capacity (PAWC) resulting from variability of soil properties such as texture, bulk density and subsoil constraints (Rab et al., 2009).

This presents a highly complex situation where both supply and demand of N may be spatially variable due to entirely different (and often independent) driving factors. To further complicate the situation, many of these factors are temporally variable, making it difficult to correctly quantify whole season patterns of N deficit using data collected at any one snapshot in time. For example, the spatial patterns of start-of-season SMN may not match those of the full season N supply if there are considerable differences in mineralisation between different zones of the paddock.

Current approaches to site-specific N in Australia

There are two main approaches to sub-paddock scale N management currently in practice and/or commercially available in Australia.

The first is to divide a paddock into a number of sub-units or 'management zones', which are considered more-or-less homogenous in their N supply and/or demand attributes (Rab et al., 2009). Zones are generally developed based on either historic productivity (e.g., using yield and/or remotely sensed imagery) or soil type (e.g., using apparent electrical conductivity (ECa), grid soil

Cation Exchange Capacity (CEC) mapping and/or aerial imagery). Each zone is then soil sampled separately and managed accordingly. While these approaches are generally considered to be an improvement on whole paddock testing, their main limitation is that the resolution of data collection is still quite low, therefore substantial reliance is placed on the accuracy of the zoning process. As moisture availability is generally the greatest yield constraining factor in Australian systems, it is likely that these methods do a reasonable job of differentiating areas of contrasting N demand, however, may not be as effective at detecting finer scale variability of N supply. To date, the majority of research around the accuracy of different zoning approaches has focused on crop responsiveness/N demand, with very little work assessing the homogeneity of N supply within zones (i.e., quantifying SMN variability).

The second approach is the use of remote or proximal sensing to directly develop site-specific N maps for mid-season N fertilisation. The most widely implemented spectral index used for this purpose is the Normalised Difference Vegetation Index (NDVI), which gives a representation of the amount of photosynthetically active biomass in a crop (Perry et al., 2014). These approaches have similar limitations to productivity-based management zone methods in that mid-season biomass is often correlated more closely with moisture availability (or other factors) than N nutrition per se. To address these limitations, work continues to identify alternative spectral indices that are more directly related to N nutritional status (e.g., CCCI, Basso et al., 2016; Red Edge, Richetti et al., 2020). In either case however, the successful implementation of these strategies generally requires the use of N-rich and N-poor calibration strips, ground-truthing and a good understanding of site-specific yield potentials relative to seasonal conditions. Indeed, a recent review by Colaço and Bramley (2018) of a large suite of globally published sensor evaluation studies found a lack of consistent evidence to confirm whether crop sensors in isolation can deliver benefits to N management. Instead, they suggest that future success will come in the way of more sophisticated algorithms that integrate spectral data with input from other sensors and data layers (e.g., moisture probes, weather forecasts, ECa mapping, etc.).

In addition to these two primary methods, there has also been limited use of 2-4 ha resolution grid deep N soil mapping for site-specific N in Australia, however this approach has generally been considered uneconomical due to the relatively expensive nature of deep sampling (Bramley and Janik, 2005).

Theoretical background to cereal grain protein based site-specific N

For many decades it has been recognised that a consistent relationship exists between cereal grain yield and cereal grain protein concentration according to N supply (e.g., Russell, 1963). This relationship consists of increasing grain yield and protein concentrations with greater N supply up to a certain point, after which grain yield begins to plateau while protein concentration continues to increase. At very high N levels, a decline in yield often occurs (Holford et al., 1992).

The point at which N supply has been optimised for maximum grain yield is termed the ‘critical grain protein concentration’ and has been found to be around 11.2–12.0% in most Australian hard white wheats through studies conducted in southern/central NSW (Brill et al., 2013, Sandral et al., 2018) and South Australia/Victoria (G. McDonald, review published in Unkovich et al., 2020).

While critical grain protein concentrations will vary between varieties and across seasonal conditions (Fowler, 2003), a simplified ‘rule-of-thumb’ interpretation under favourable (non-drought) conditions can be summarised as:

- Protein < 11.5% = insufficient N supply to meet yield potential
- Protein 11.5–12.5% = adequate/optimum N supply to achieve yield potential
- Protein > 12.5% = surplus N to crop requirement, possibly some yield penalty (Figure 1).

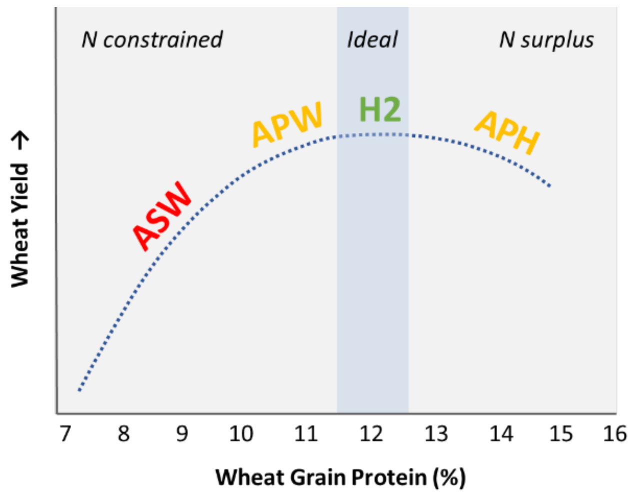

Figure 1. A generalised representation of the relationship between yield and grain protein concentration in wheat with increasing N supply. Labels refer to grades in the Australian wheat classification system

If we apply this rule-of-thumb spatially across a management area grown to a single wheat variety, a georeferenced map of wheat protein concentration is analogous to an 'N adequacy' map – i.e., it serves to distinguish areas of the paddock that had insufficient, ideal or surplus N according to their site-specific yield potentials. Provided that crop demand wasn't very much higher than budgeted N supply (resulting in a full drawdown of soil mineral nitrogen (SMN) across the paddock), and that soils are not prone to N losses, it is likely that protein patterns will provide a good spatial representation of residual (carryover) SMN.

Ground-truth soil testing at the start of the following season can be used to test this assumption and quantify out-of-season mineralisation. A good approach to determining the placement of soil tests is to divide the paddock into zones based on combinations of yield and protein results from the previous harvest. This process provides useful insights into not only N dynamics but also where non-N related constraints may warrant further investigation. These concepts are summarised in Table 1.

Table 1. Within-paddock combinations of cereal yield, protein attributes and their properties.

Classification	Interpretation	Residual N levels	Action
High Yield / High Protein	- Optimum scenario - Yield potential achieved, no major limitations - This area of the paddock may have higher mineralisation potential	Likely moderate to high, however soil test to confirm (particularly if crop N demand was higher than budgeted)	Determine rates based on soil test results and according to high yield potential
High Yield / Low Protein	- Sub-optimal N management - Yield could have been even higher - N deficiency likely occurred later in the season, as sufficient N was available to produce biomass/tillers - Could indicate 'tired' areas with lower mineralisation potential (e.g., historically high N removal/low SOM)	Likely low (assume post-harvest residual SMN was negligible, so levels are dependent on out-of-season mineralisation)	Increase N rates relative to paddock average in following season/s to support higher yields and build SMN
Low Yield / High Protein	- Non-N related problem - Further N additions would <u>not</u> have increased yield - If protein is *very* high, yield penalties from oversupply of N likely occurred - Most commonly related to lack of moisture supply (e.g., shallow or hostile subsoils, around trees), however may be another constraint such as pH, P	Likely high (mining of N may be advised to reduce yield penalties associated with N oversupply)	If the constraint cannot be amended, reduce N inputs relative to paddock average permanently to match lower yield potentials
Low Yield / Low Protein	- Sub-optimal N management - Yield potential was not met - It is unclear if other constraints exist that would continue to limit yield with higher N inputs - If N deficiency is the primary cause, SMN was likely low for the whole season	Likely low	Start by increasing N to determine the non-N constrained yield potential, then manage according to results

A major advantage of a protein-based VR N approach over currently available alternatives is that it combines both the supply and demand elements of the N balance equation. For example, low protein areas within a paddock may occur either due to low N supply (i.e., differences in carryover N, mineralisation, fertiliser inputs, etc.) OR higher yield potential (i.e., due to the dilution of protein by higher yield; Simmonds, 1995). Regardless of which factor is responsible (or both), the management decision will involve increasing N rates in the following season.

In this sense, the protein layer is also accounting for temporal variability of N dynamics by providing a retrospective assessment of the *whole season*, net N balance, rather than a 'snapshot in time' as occurs with data layers such as spectral indices or grid soil mapping.

Another advantage is the benefit afforded by the plant providing an indication of N adequacy according to the conditions it experienced, i.e., the *plant available* N. This circumvents a limitation of soil testing where mineral N may be present within the profile however the plant may not be able to access it (e.g., if subsoil hostilities prevent root access). In a similar manner, if subsoil conditions are favourable and the plant is able to access deeper SMN, this will be reflected by the plant's protein concentration however may be missed by an arbitrary soil sampling depth cut-off.

Setting rates

Due to fluctuations that occur in critical grain protein concentrations between seasons and some varieties, start-of-season soil sampling will remain an essential step to determining actual N rates. Soil sampling will also act as a ground-truthing step to test assumptions regarding patterns of carryover SMN and to test any unusual areas (e.g., if losses are suspected such as where waterlogging has occurred).

Where consistent protein zones are present, soil sampling should cover off on each of the major protein/yield combinations (see Table 1), aiming to get an idea of the paddock average and the spread (range) of SMN values. If protein data across the paddock is spatially noisy or does not have consistent zones, the paddock may not be a good candidate for VR N (i.e. SMN may not vary substantially, or variability might be on a sub-manageable scale). In this case, whole paddock testing and blanket rates may be more appropriate.

Once a paddock average has been determined, growers and advisors can use their preferred calculation method or decision support system (e.g. Yield Prophet®, 'N banks') to determine a 'base rate' which will act as the paddock average from which to vary N inputs (i.e. lower rates on high protein areas, higher rates on low protein areas). The increments of difference between rates will depend on; a) the spread of protein values, b) the spread of soil test results, and c) the grower's level of confidence/conservatism. A more conservative approach (smaller increments) will afford a lower level of risk when moving from blanket rate applications, however there will likely be a longer lead time in reducing within-paddock N variability.

Over a number of seasons, implementing this strategy should reduce the spatial variability of protein concentrations, ideally converging around 11.5 - 12.5% if the base rates chosen have been appropriate. It is likely that the most 'bang for buck' to be gained implementing this strategy will occur in the early stages, by eliminating very low (highly constrained) and very high N zones.

It is important to remember that in paddocks where yield potential varies greatly due to factors other than N (e.g., relatively fixed factors such as PAWC), a successful outcome will not be where yield becomes even, but rather where yield is optimised in all areas according to their site-specific yield potentials. In these instances, N rates will need to continue to be varied to match N supply with variable N demand. One option for achieving this may be to transition to a VR N strategy based on N removal patterns.

In all cases, ongoing monitoring of cereal protein% results and annual deep soil sampling should serve as a constant feedback to ensure N decision-making approaches are performing well.

Getting started

A protein based site-specific N strategy might be a good approach for a grower if they:

a. Are predominantly located on soil types not prone to losses (i.e., free draining with good nutrient holding capacity such as occurs across most of southern NSW), and
b. Have within-paddock variability in factors such as texture/CEC/OC%/PAWC, productivity (N removal) and/or management histories (e.g., amalgamated paddocks, previous inputs).

At present, the cost of a harvester mounted grain analyser is around AUD $25,000 + GST including installation (Next Instruments 'CropScan 3300H' unit). This cost will be spread over a number of seasons. The unit can also be removed and reinstalled if a new harvester is purchased. There will also be costs related to data management and interpretation if the grower cannot or does not wish to do this themselves.

After completing the first harvest, a good strategy is to pick a few of the most variable paddocks to focus on. If a grower isn't comfortable implementing a VR application straight away, they may prefer to use N-rich and/or N-poor strips to test the impact of variable N rates on their soils. If doing so, strips should be designed so they pass through several zones (e.g., low/high protein, soil types, management histories, etc.). Paddocks being cropped to a second cereal crop (e.g., wheat on wheat) will be of most value for reviewing the results of strip trials and/or the success of VR N applications.

Research results

A 2019/2020 research project undertaken in southern NSW by FarmLink Research in conjunction with Precision Agriculture sought to examine within-paddock N variability patterns and test assumptions around the correlation of SMN with various parameters, including protein concentration. Selected findings are presented below. The full research report can be accessed at http://www.farmlink.com.au/project/nitrogen-variability (Moffitt, 2021).

Aims

- Quantify levels of within-paddock SMN variability across five cropping paddocks (511.4 ha)
- Examine correlations between 2020 start-of-season SMN and various other parameters including 2019 yield, protein and N removal, ECa (via EM38), soil texture and OC% (via MIR)
- Comment on the effectiveness of each layer to inform site-specific inputs, and
- Develop grower and advisor capacities for VR N decision making.

Methodology

Georeferenced yield and grain quality data was collected during harvest 2019 by eight late model Case IH harvesters equipped with standard yield monitors and retrofitted CropScan 3000H grain analysers. All CropScan 3000H units were calibrated prior to harvest using a single set of certified reference samples for wheat, barley and canola (protein%, moisture% ± oil%).

Five paddocks (four wheat, one barley) were subsequently selected on the basis of having complete yield/protein datasets and some level of protein variability. Paddocks were all located within 100 km of Temora in southern NSW on predominantly red to grey sandy loam to clay loam topsoils overlying clay loam to clay subsoils (chiefly Chromosols/Sodosols). Paddock management has consisted of continuous cropping of cereals (wheat/barley), canola and occasional pulses, with some paddocks having histories of lucerne/clover phases. Annual rainfall across the five sites averages around 480-600 mm however in 2019 rainfall was very low, ranging from 160-310 mm (annual) and 64-142 mm (April-October). As a result, none of the five paddocks had any additional N applied throughout the 2019 season apart from low levels in MAP/DAP fertilisers applied at seeding.

Grid soil sampling plans were designed at resolutions of 1.17 ha (108 m x 108x m; 4x paddocks) and 1.44 ha (140 m x 140 m; 1x paddock), depending on the width of top-dressing operations. A total area of 511.4 ha (425 grid sites) was soil sampled in late February/March 2020 at 0-30 cm/30-60 cm intervals and analysed for nitrate (NO_3), ammonium (NH_4), MIR texture and MIR Organic Carbon% (OC%). Soil sampling occurred after opening rainfall in 2020 following extremely dry conditions for many months prior. EM38 and elevation mapping was conducted during January 2020 at 18 m/24 m swaths. Weighted averages for each grid cell location were determined for EM38/elevation and yield/protein data through various interpolation methods. The strength of the relationship between SMN and other attributes was analysed via linear regression at the grid resolution.

Grower-led VR N applications and post-harvest grid soil mapping were also conducted in 2020. These results will not be discussed in detail below however can be obtained in the full report.
http://www.farmlink.com.au/project/nitrogen-variability

Results and discussion

Considerable within-paddock variability of start-of-season (Feb/Mar 2020) SMN was observed at four of the five sites, where the range of values (max – min) was greater than 140 kg N/ha, and the standard deviation was greater than 20 kg N/ha (Table 2). At the fifth site (Ardlethan), where the average SMN was much lower (46 kg N/ha ± 11 kg N/ha SD), the range of SMN was 43 kg N/ha.

Table 2. Summary of 2020 start-of-season 0-60 cm SMN and 2019 harvest protein% results (grid n = 58 to 96)

		Ardlethan (83 ha)	Girral (103 ha)	Rannock (103 ha)	Temora (111 ha)	Thuddungra (112 ha)
Feb/Mar 2020 0-60 cm SMN (kg N/ha)	Mean	46	94	95	67	127
	Min	27	29	52	22	55
	Max	70	213	199	162	285
	SD	11	40	24	26	38
	CV	24%	43%	25%	39%	30%
2019 Protein %	Mean	8.3	17.4	11.7	13.4	15.3
	Min	6.7	15.9	10.0	10.1	14.0
	Max	11.9	18.4	13.5	15.4	16.8
	SD	1.2	0.7	0.8	1.3	0.6
	CV	14%	4%	7%	10%	4%

When examining the relationship between start-of-season (Feb/Mar 2020) SMN and various other attributes, 2019 grain protein% displayed the most consistent and strongest correlation compared to all other layers examined (Figure 2a; Table 3). This consistently positive relationship was significant at 4 out of 5 sites. The site that did not show a strong correlation (Ardlethan) was also the site of the lowest average SMN, lowest range of SMN and lowest average protein% levels (8.3%). Interestingly however, this site had one of the highest ranges of protein concentration (6.7% – 11.9%) in comparison to all others. This result will be discussed in more detail further below.

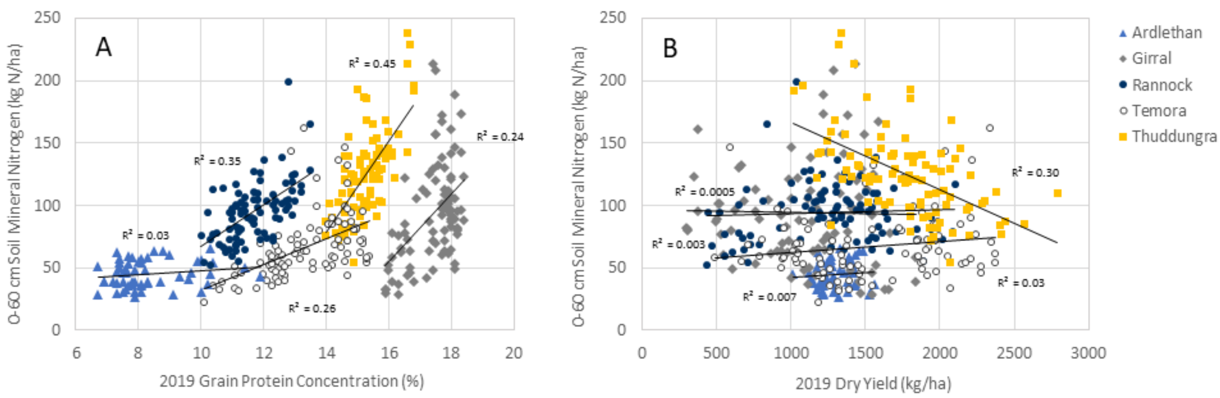

Figure 2. 0-60 cm Soil Mineral N (kg N/ha; sampled Feb-Mar 2020) versus 2019 cereal harvest results, (a) Grain Protein Concentration and (b) Dry Yield. (Girral = barley, rest = wheat). Each point represents one grid site (n = 425)

Table 3. Pearson correlation coefficients (r) for start-of-season (Feb/Mar 2020) 0-60 cm Soil Mineral N versus various attributes for each of the five trial paddocks. Values in bold are significant at $P < 0.0001$. *Variable rate chicken manure application performed pre-sowing 2019 at Thuddungra site only

Feb/Mar 2020 SMN versus:	Ardlethan	Girral	Rannock	Temora	Thuddungra
2019 Protein%	0.17	**0.49**	**0.59**	**0.51**	**0.67**
2019 Dry Yield	0.09	-0.02	0.05	0.16	**-0.55**
2019 N removal	0.22	0.06	0.16	0.32	**-0.47**
Elevation	0.11	-0.36	0.28	0.19	**-0.46**
ECa (0.5)	-0.32	0.17	-0.07	0.33	0.19
ECa (1.0)	-0.34	0.19	0.19	**0.41**	0.24
0-60 cm sand%	0.18	**-0.40**	-0.12	**-0.42**	-0.09
0-60 cm clay%	-0.20	0.36	-0.03	**0.50**	0.02
0-30 cm OC%	0.23	**0.47**	**0.44**	0.32	0.39
Manure rate*	-	-	-	-	**0.66**

Importantly, at each of the four significantly correlating sites, areas of the paddock with the lowest protein% coincided reasonably well with areas of low SMN (e.g., see Figure 3 and Figure 4 examples). This occurred both in paddocks of lower overall protein% (Rannock, Temora) and in those with very high protein% levels (Thuddungra, Girral). On the other end of the spectrum, areas within each paddock with the highest protein concentrations did not necessarily always coincide with the highest SMN values (e.g., northern zone in Figure 4). In the two main instances this occurred, these zones were in low lying areas with at least average SMN levels and it is likely they were impacted by frost, which was noted across these sites in 2019. These localised effects demonstrate the importance of paddock and seasonal knowledge when interpreting protein and other data patterns.

When comparing 2019 dry yield and N removal to patterns of 2020 start-of-season SMN there was a very poor relationship (non-significant) at four out of five sites (Figure 2b; Table 3). This result is not unexpected given that moisture supply was by far the most limiting factor to yield in 2019 (not N supply). At the fifth site (Thuddungra), SMN and yield correlated negatively, i.e., higher SMN coincided with lower yields. This is likely explained by a VR chicken manure application which was undertaken just prior to sowing in 2019, which increased the severity of ‘haying off’ where rates were highest. This interpretation is also supported by significant positive correlations found between manure rates and both 2020 start-of-season SMN (Table 3) and 2019 protein% ($r = 0.69$, $P < 0.0001$).

OC% consistently had a positive correlation with SMN, however the strength of the relationship was variable and not always significant (Table 3). It is possible that this relationship may have been stronger if soil sampling had been delayed until later in the season (following rainfall), however it is also worth considering that OC% is a bulked measurement of particulate, humus and recalcitrant (char-like) carbon fractionates, which vary in their ability to mineralise N (Baldock et al., 2013). Further research would ideally include the measurement of individual carbon fractionates and/or mineralisable N to better capture/understand the spatial patterns of mineralisation N supply.

Of the soil type proxy layers examined (ECa, sand%, clay%), there were no significant correlations with start-of-season SMN observed across all five sites, however two of the sites (Girral and Temora) had significant negative correlations between 0-60 cm sand% and SMN (i.e., sandier soils had lower SMN; Table 3). Along with Ardlethan, these sites were quite variable in soil type characteristics in comparison to Rannock and Thuddungra, where soil types were more consistent.

Previous management history also appeared to be a key driving factor of N variability for at least three sites, with noticeable differences observed between areas that were previously fenced separately, despite some of these changes being made up to 15 years prior.

These results suggest that in any one paddock there are a great number of variables that may potentially (but not always) influence spatial patterns of SMN. This highlights the difficulty of creating accurate management zones to predict patterns of N supply in the absence of higher resolution data to test assumptions around zone homogeneity.

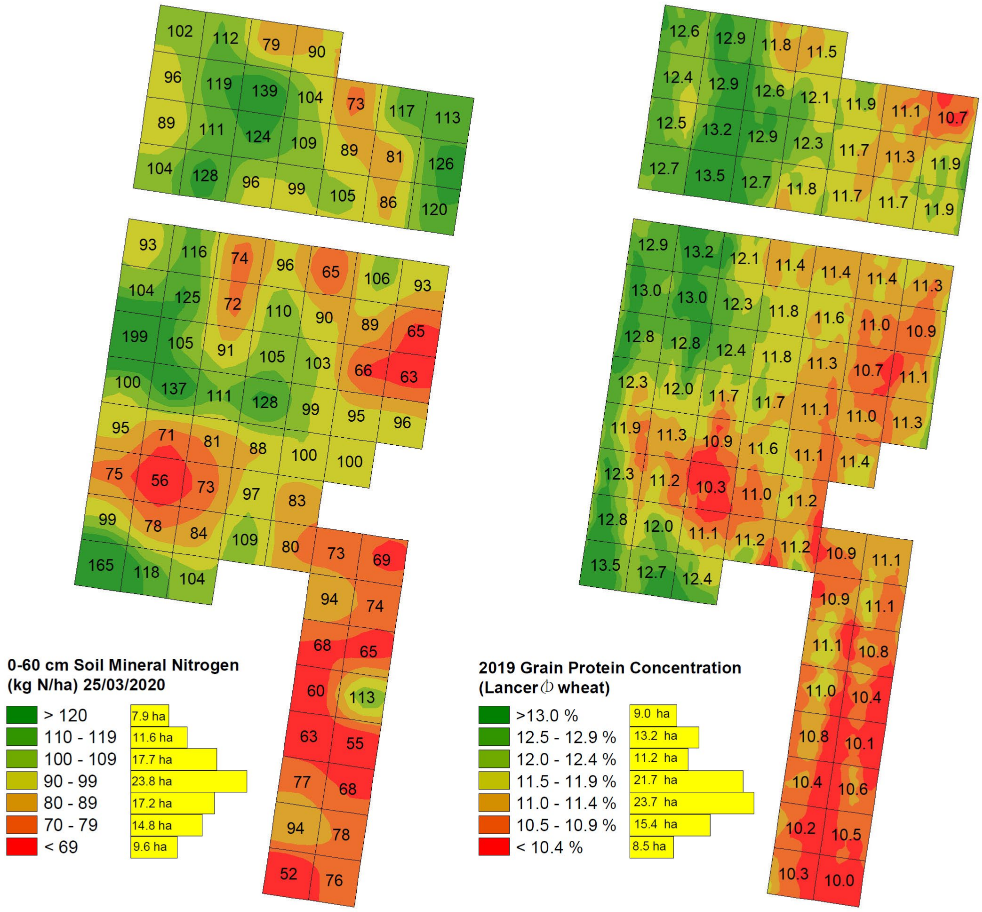

Figure 3. Rannock site 0-60 cm SMN (kg N/ha) sampled 25/03/2020 (left) and 2019 wheat protein% (right). Pearson correlation coefficient (r) = 0.59, P < 0.0001. The missing section between the two blocks is the location of an old fence line which was excluded from the sampling plan. Each cell size is 108 x 108 m, total area = 102.7 ha.

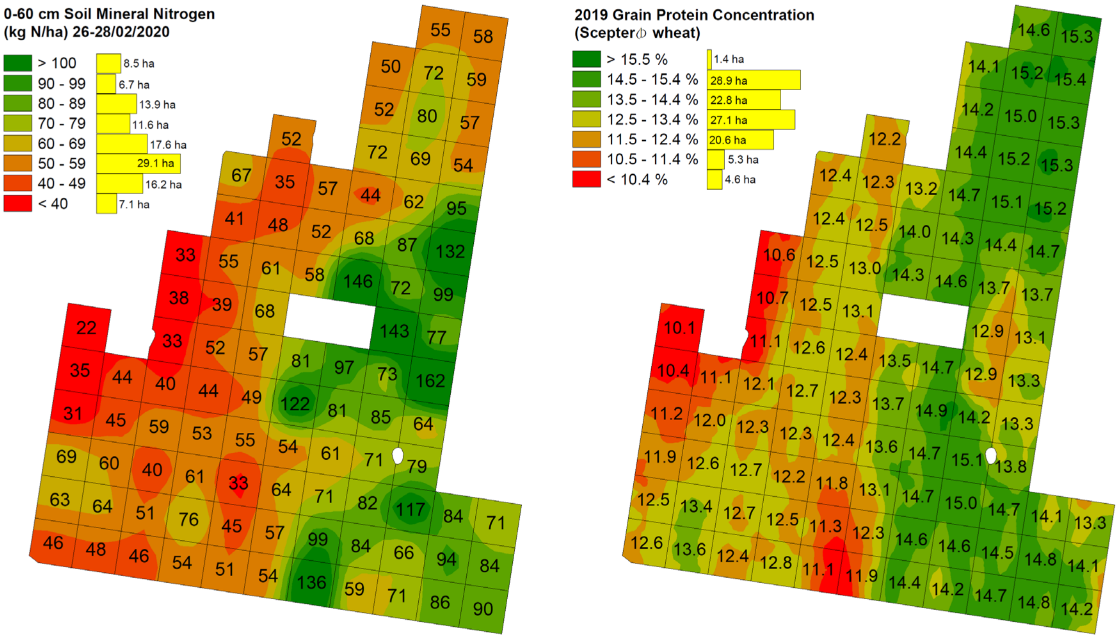

Figure 4. Temora site 0-60 cm SMN (kg N/ha) sampled 26-28/02/2020 (left) and 2019 wheat protein% (right). Pearson correlation coefficient (r) = 0.51, P < 0.0001. The far north of the paddock is a low-lying area that yielded poorly and was most likely severely impacted by both moisture stress and frost in 2019. Each cell size is 108 x 108 m, total area 110.7 ha.

Across the five sites, there was a general trend of increasing strength of correlation between SMN and protein% as the average SMN level increased. This may be explained by considering that N supply levels have to be high in comparison to N demand in order for there to be substantial residual (carryover) SMN. If crop demand is much higher than supply, SMN may be drawn down across the paddock and residual N will be correspondingly low. In this situation, protein% may still vary, as overall N supply may have differed spatially throughout the season. In this situation, it will be necessary to consider if the factors that caused variability in protein% are likely to be present in the following season or if they were a ‘one-off’. For example, differences in mineralisation occurring due to soil type or long-term management practices are likely to reoccur while differences in carryover N patterns from the previous year may or may not reoccur.

This interpretation may explain the observations at the Ardlethan site, where 2019 protein variability was still quite high (6.7 – 11.9%) despite reasonably low 0-60 cm 2020 start-of-season SMN levels across the paddock (average 46 kg N/ha, Table 2). This suggests that N deficiency occurred across most of the paddock in 2019 (drawing SMN to very low levels), however the magnitude of N deficiency varied. When examining the patterns of protein variability, higher protein levels coincided with lighter textured soils on the eastern third of the paddock while lower protein levels coincided with heavier soils on the western two-thirds of the paddock. One possible explanation is that 2019 start-of-season (carryover) SMN levels differed between these two zones. This explanation is supported by a review of 2018 canola yields which were higher on the heavier soil type (i.e., more N removal occurred). A second explanation may be that additional N was accessed on the lighter soil type below 60 cm depth (i.e., below the depth of sampling). This may have occurred if sub 60 cm N reserves were variable OR if the less hostile subsoil conditions (lower CEC/EC/Cl/Na%) on the lighter soil type allowed greater root penetration during the very dry 2019 season.

Due to the uncertainty around this result, a strip trial experiment was implemented in 2020 to explore whether the grid soil mapping results or 2019 protein% layer would have been the best basis for site-specific N in 2020. The site was grown to a second season of wheat, with 80 kg/ha urea applied as a flat rate and two 160 kg/ha urea N-rich strips applied at 140 m width.

Results demonstrated a significant positive correlation between 2019 protein% and 2020 protein% for both the N-rich strip areas ($n = 15$, $r = 0.81$, $P < 0.001$) and non N-rich strip areas ($n = 40$, $r = 0.73$, $P < 0.0001$; Figure 5a). A significant positive correlation was also observed between 2019 protein% and 2020 yield for the non N-rich strip areas ($r = 0.83$, $P < 0.0001$; Figure 5b) while no significant correlations were observed between 2020 start-of-season SMN and 2020 yield or protein.

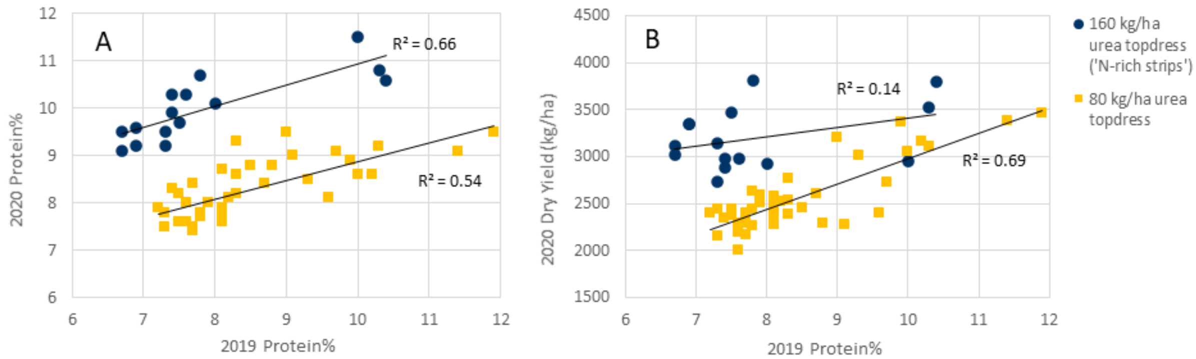

Figure 5. 2019 wheat (cv. Lancer⒫) protein% versus 2020 wheat (cv. Spitfire⒫) a) protein% and b) grain yield at the Ardlethan site. Each point represents one 120 x 120 m grid cell. N-rich strips n = 15, non N-rich strips n = 40.

The consistency of protein patterns observed between the 2019 and 2020 seasons despite a lack of correlation with grid soil sampling results suggests there may be either differences in deeper SMN that has not been captured by 0-60 cm soil sampling, differences in the plant accessibility of N present below 60 cm or differences in mineralisation N supply between the two soil zones. The latter explanation appears less likely given that OC% levels were found to be lower on the lighter textured (high protein%) soil zone.

An average yield increase of 564 kg/ha and protein increase of 1.7% was observed for the N-rich strip cells when compared to their immediately adjacent non N-rich cells. A negative relationship was found between 2019 protein% and 2020 yield response, i.e., lower protein% areas had the largest yield response to additional N ($r = -0.56$, $P < 0.01$; Figure 5b, Figure 6). There was no significant relationship between yield response and start-of-season SMN ($r = -0.04$, ns).

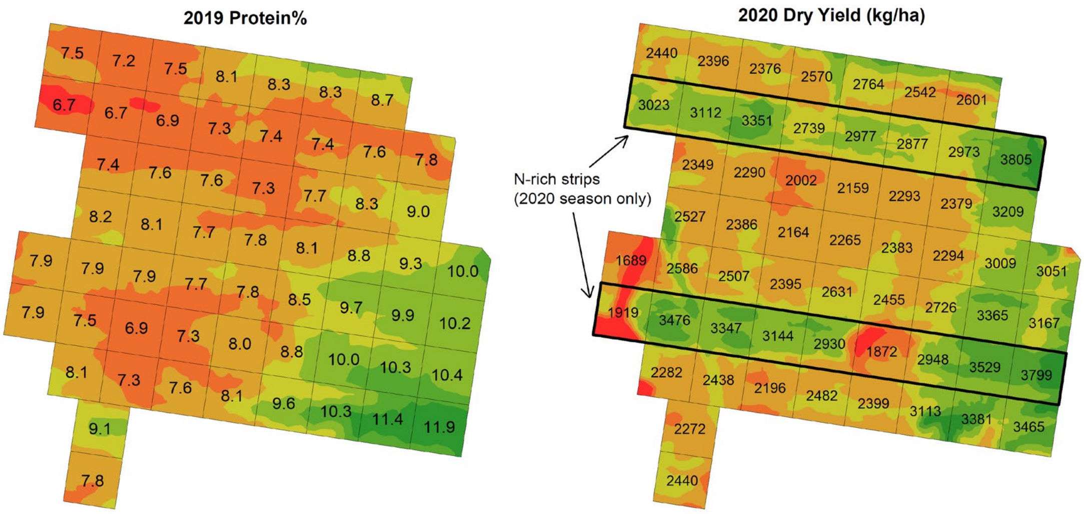

Figure 6. 2019 wheat (cv. Lancer⊕) grain protein (left) and 2020 wheat (cv. Spitfire⊕) dry yield at Ardlethan, with locations of N-rich strips shown. Note the greater yield response to additional N in areas of lower 2019 protein%.

These results suggest that given a fixed N budget, applying additional fertiliser to the lowest protein% areas of the paddock would have produced the greatest overall yield increase. Therefore, it appears that the adoption of a VR N strategy in 2020 based on the 2019 protein% pattern would likely have resulted in a more profitable outcome at this site than using grid soil mapping results or management zones where soil tests were used to directly determine rates.

Conclusions, challenges and further research required

The results of this project and experiences working with growers collecting and utilising harvester protein data have demonstrated that considerable potential exists for protein-based site-specific N strategies to drastically improve N management in our cropping systems, when used in conjunction with annual soil sampling and an appropriate N rate calculation method.

Research results suggested that at higher background SMN levels (where N supply is not drastically exceeded by demand), it is likely that a good relationship will exist between protein% and residual (carryover) N. Even at low (constraining) SMN levels, results showed that protein% patterns may still give a good indication of spatial patterns of N requirements. It is further worth considering that in these instances, considerably higher N rates are probably required in an overall sense, therefore any method that encourages more considered N management (e.g., through reviewing protein levels and undertaking basic ground-truth soil testing) is likely to have a positive impact on profitability.

The success of protein-based site-specific N strategies appears to be linked to the major advantage of this approach whereby the crop itself indicates the N adequacy it experienced over the sum of the whole season. This circumvents many of the challenges of site-specific N management which have either limited the quality/efficacy of some VR N approaches (that attempt to provide simple solutions to a complex problem) or have limited the uptake of other VR N approaches (that are too complex/laborious to be practical). The high spatial resolution of this data and relatively low cost when compared to alternative approaches (e.g., intensive soil sampling) is another major advantage.

While protein maps cannot be used to guide N management decisions in the season of their collection, this method should be considered more of a 'whole-system' approach to N management, with the aim of incrementally building (and/or mining) background SMN levels to match site-specific yield potentials across the farming operation over a number of seasons. This approach has considerable synergy with the concept of 'N banking' (Hunt et al., 2021; Meier et al., 2021) which aims to decouple N input decisions from seasonal demand by 'topping up' N levels each year to a pre-defined target that would be considered non-limiting in most seasons.

By using these two methods in conjunction (on soils that are not prone to losses), growers are armed with a simple, yet targeted strategy to both reduce/eliminate areas of yield loss due to N deficiency and reduce instances of N oversupply which are environmentally, agronomically and economically undesirable. This approach also has logistical benefits in that N rates and VR input maps can be determined/created quite early in the season (following the return of deep N soil test results). This has obvious benefits for financial budgeting and planning however also means that these decisions can be made well ahead of time rather than at a potentially stressful period before a rain event if relying on mid-season remotely sensed imagery, for example.

For this approach to be widely implemented, additional work is required to determine how to bridge the data gap that occurs in seasons where non-cereal crops are grown. Although not discussed in the current paper, results at the four project sites that grew canola in 2020 did not suggest that their protein patterns were as closely related to N supply as those observed in wheat. This may be due to the sensitivity of canola oil/protein concentrations to late seasonal climatic conditions (Walton et al., 1999; Uppal et al., 2019), however additional research is required to further explore this issue (see the full research report for 2020 trial results and a discussion around canola oil/protein drivers - http://www.farmlink.com.au/project/nitrogen-variability).

Another area for further research is examining the impact of frost during grain filling, which can result in elevated grain protein concentrations by curtailing the deposition of starch (Allen et al., 2001). While this may serve to 'artificially' elevate grain protein concentrations, it is possible that this effect is counteracted by reduced yields (N removal) and higher N concentrations of residues.

These challenges highlight that the most successful site-specific N management strategies will probably use a number of data layers and grower knowledge in conjunction with protein mapping and targeted deep N sampling to devise effective N input maps over the whole rotation. Such data layers that were identified by the current study to be potentially useful indicators of N variability included soil type parameters (e.g., ECa, CEC or texture mapping, subsoil health tests), long-term productivity (e.g., stacked yield or biomass maps), landscape features (e.g., elevation) and previous management history information (e.g., locations of amalgamated paddocks and their histories).

Given the immense potential productivity and environmental benefits of improved site-specific N management, considerable scope exists for follow up research to address the abovementioned challenges and explore the applicability of these methods in other regions and soil types.

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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

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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.

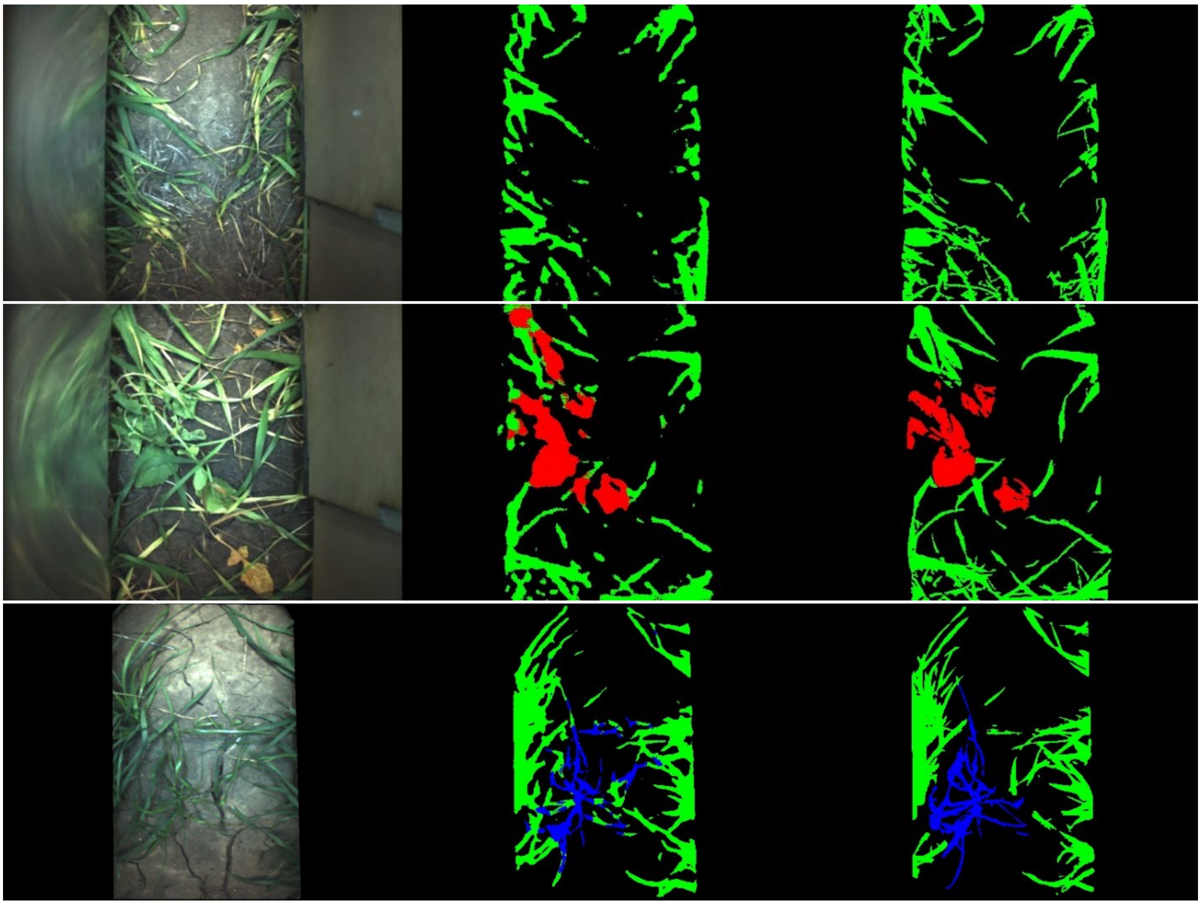

Figure 3. Sample images of image segmentation. Each row is a different example. Images from the left to right columns are: the input RGB image, segmentation results from the ML algorithm, and pixelwise manually segmented 'ground-truth' training data. In the segmented images, green pixels are wheat, red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