WEST WYALONG NSW
THURSDAY 18 FEBRUARY 2021

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

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GRDC 2021 Grains Research Update Welcome

If you are reading this, then chances are you are sitting in one of the GRDC's first face-to-face events since COVID-19 changed our lives.

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. This year our Updates will also be live streamed to ensure the information is available to all who need it.

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
WEST WYALONG

Thursday 18 February 2021

West Wyalong Services & Citizens Club, 100 Monash St, West Wyalong

Registration: 8:30am for a 9am start, finish 3:20pm

AGENDA Time	 Topic	 Speaker(s)
9:00 AM	**GRDC welcome**	
9:10 AM	**Strategies for longer term management of the soil N bank across the farming system.**	John Kirkegaard (CSIRO) & James Hunt (La Trobe University)
9:55 AM	**Integrating pulses into the farming system** - double breaks, fallow vs pulses and optimising crop sequence - a grower's perspective	John Stevenson, (Grower/manager Warakirri)
10:20 AM	**Adviser observations on key outcomes from the farming systems trial at Condobolin and local experience with double breaks.**	Chris Baker (Baker Ag Advantage)
10:35 AM	**Discussion session**	John Stevenson (Grower/manager Warakirri) and Chris Baker (Baker Ag Advantage)
10:45 AM	**Morning tea**	
11:15 AM	**Cereal disease bingo!** Learnings from 2020 and planning for 2021. Is stripe rust the death knock for some varieties?	Steven Simpfendorfer (NSW DPI)
11:50 AM	**Ryegrass - blowouts at seeding in 2020 and management for 2021.** o Causes of poor results - resistance vs environment/dose rate o Paraquat stewardship o Optimising glyphosate performance (tank mixes, AMS, formulation, resistance, adjuvants, timing, application, stress).	Peter Boutsalis (Plant Science Consulting) & John Broster (CSU)
12:20 PM	**Ryegrass - fitting new pre-emergent chemistries into the farming system.**	Greg Condon (Grassroots Agronomy/WeedSmart)
12:40 PM	**Weeds discussion** o Ryegrass blowouts in 2020 - what needs to change? o Issues fitting pre-ems into farming systems with disc seeders and stubble.	Led by Chris Baker (Baker Ag Advantage), Maurie Street (GOA), John Broster (CSU), Peter Boutsalis (Plant Science Consulting) and Greg Condon (Grassroots Agronomy/WeedSmart).
1:05 PM	**Lunch**	
1:45 PM	**Amelioration of hostile subsoils to improve crop productivity.**	Ehsan Tavakkoli (NSW DPI) & Peter Allen ("Carumbi")
2:20 PM	**Getting phenology right, what's next?** Project learnings from 2017-20, comparing wheat and barley responses and tactical agronomy to increase yield.	Felicity Harris (NSW DPI)
2:55 PM	**Are there economic benefits in control of foliar fungal disease in canola crops in the low to medium rainfall zones of NSW?**	Maurie Street (GOA)
3:20 PM	**Close**	

Contents

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Strategies for long term management of N across farming systems

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Key words

nitrogen, yield gap, Yield Prophet®, N bank, nitrogen deficiency

Take home message

- Maintain a neutral to slightly positive long-term N balance (as much N inputs from legumes and fertiliser as is removed in grain) to maximise profit and slow soil organic matter decline
- 'N bank' targets, Yield Prophet® and WUE tools and are all valid ways to manage N fertiliser and achieve potential yield without total soil N run-down
- Don't fear occasional overapplication of N - on most soils in southern NSW unused N carries over and is available to subsequent crops and to help maintain soil organic matter.

Background

Modelled data suggests Australian wheat yields are only half what they could be for the rainfall received (Hochman et al., 2017). Nitrogen (N) deficiency is the single biggest factor contributing to this yield gap (Collis, 2018; Hochman and Horan, 2018). This is also likely to be true for other non-legume crops (barley, canola and oats) which reduces farm profitability and global food security. Alleviating N deficiency economically could increase national wheat yields by 40 per cent (Hochman and Horan, 2018), and substantially improve farm profit.

On farms with no legume pastures, and with low levels of soil organic matter (SOM), most of the crop N supply must come from fertiliser. Grain legumes do not provide enough N to support yield of subsequent crops at the intensity (and targeted yield levels) at which they are currently grown. N fertiliser is a costly input and use of it increases cost of production and value-at-risk for growers. Growers fear that over-fertilisation will result in 'haying off', which reduces both yield and quality. There is also the concern that overapplied fertiliser that is not used by crops is lost to the environment by leaching, volatilisation and denitrification. Consequently, efforts continue to be made to match N fertiliser inputs to predicted seasonal yield potential. This is difficult in southern Australia due to the lack of accurate seasonal forecasts for rainfall.

The difficulty in matching N supply to crop demand and a tendency for growers to be conservative in their N inputs is responsible for a large proportion of the yield gap that can be explained by N deficiency. Chronic N deficiency has also caused soil organic matter to decline (Angus and Grace, 2017) and has driven a rise in the proportion of low protein grain produced in Australia (GrainCorp, 2016), which has eroded our standing as a producer of quality wheat in export markets.

What can we do about it?

We propose that the yield gaps due to N deficiency could be reduced if a longer-term approach to N management within farming systems is taken. This means recognising that on most soil types in southern NSW, environmental losses (volatilisation, denitrification, leaching, run-off/lateral flow) of N are low and episodic (Smith et al., 2019). The majority of fertiliser N that is applied in one season and not taken up by the crop is stored in the soil either in mineral or organic form and carries over for use by subsequent crops. This means N fertiliser applied that is surplus to crop requirements is not a lost cost but will be recouped in subsequent seasons and in fact can play a vital role replenishing soil organic N (Alvarez, 2005; Ladha et al., 2011).

How do we implement this?

The first step is using a valid method to ensure that enough fertiliser N is being applied to meet seasonal crop demand. The two key types of tools to do this are:

1. Those that try and match N inputs to seasonal demand such as WUE tools (e.g. Yield Prophet® Lite), Yield Prophet® and;
2. 'N bank' targets which maintain a base level of fertility.

Both are valid ways to calculate N supply to meet crop demand.

Yield Prophet® is still a highly effective tool to match N supply to seasonal demand. The downside of Yield Prophet® is that it is 'data-hungry' and requires experience to get it right. Yield Prophet Lite® and this simple spreadsheet tool (available here; https://www.bcg.org.au/understanding-crop-potential-and-calculating-nitrogen-to-improve-crop-biomass-workshop-recording/) requires less data but doesn't give probabilistic output or include seasonal forecasts.

'N banks' (Meier et al., 2021) are a strategy to manage N in crop production areas with low environmental losses (leaching, denitrification, volatilisation). Most of southern NSW has soils which are free-draining and hold a reasonable amount of water, receive low to medium rainfall and are generally acidic in the surface. Therefore, environmental losses of N are low, and N banks are likely to be an effective strategy to manage N in most of the region. Exceptions are areas prone to waterlogging or that have very sandy soils where leaching may occur. The advantages of N banks are that they are simple to calculate, crops are rarely N deficient, and if set at an appropriate level for the environment, the soil organic N is not mined but maintained. They also shift the cost of N fertiliser into years following a season of high production (when income is high), rather than within the current season of **possible** high production. Possible disadvantages include higher chance of N losses if the N is not used or immobilised, and haying-off (low yield, high protein) in low rainfall seasons. The risk of these are being experimentally evaluated at a BCG-La Trobe long term field experiment in the southern Mallee.

N banks require growers to set a locally relevant target for crop N supply (soil mineral N plus fertiliser N) that is enough to maximise yield in most seasons. Soil mineral N is then measured early in the growing season, and if less than the target N bank, is topped up to the target value with fertiliser N. A more detailed description of N banks and a long-term experiment investigating their effectiveness can be found here:
http://www.ausgrain.com.au/Back%20Issues/301mjgrn20/Grower%20group%20focus.pdf

The problem with Yield Prophet® and WUE tools is they require a forecast of the future (i.e. how much rain is going to fall between now and the end of the season). The N bank management strategy that is currently being developed does not even attempt to match crop N supply to seasonal demand, it simply makes sure that the crop has enough N supply (soil mineral N measured early in the season + fertiliser) to achieve water limited potential yield in most seasons. We do this by selecting an N bank yield target appropriate for the environment and apply N accordingly. A target of 125kg/ha N is proving most profitable in the southern Mallee (average wheat yield ~3.0 t/ha), but it is likely to be more like ~200 kg/ha N (average wheat yield >5 t/ha) at higher rainfall locations in south eastern NSW (Smith et al., 2019). We then use soil mineral N measurements from soil cores to work out how much mineral N the crop has available and top up the balance with fertiliser. For example:

Soil mineral N measured in soil cores (0-1 m) = 75kg/ha N

N bank target = 200kg/ha N

Fertiliser required to meet N bank target = 200 – 75 = 125kg/ha N (271kg/ha urea)

This system relies on having well drained loams or clay soils with low risks of leaching or denitrification losses associated with waterlogging, so that most surplus N applied carries over to the next season. Less N is needed following a low yielding year when a lot of mineral N is not used by the crop and carried over, and more N is required to be applied following a high yielding year when lots of N has been taken up by the crop and removed in grain.

How do the two different approaches stack up?

Three years of results from a BCG-La Trobe University long term experiment at Curyo indicate that an environmentally appropriate N bank strategy and Yield Prophet® (matching N to seasonal yield potential) use similar amounts of N and are equally profitable (Figure 1), and this is confirmed by simulation studies over many seasons (Meier et al., 2021). Modelling also suggests the strategy works in southern NSW across a rainfall gradient from Griffith to Young in free draining soils with at least 147 mm plant available water capacity (Smith et al., 2019).

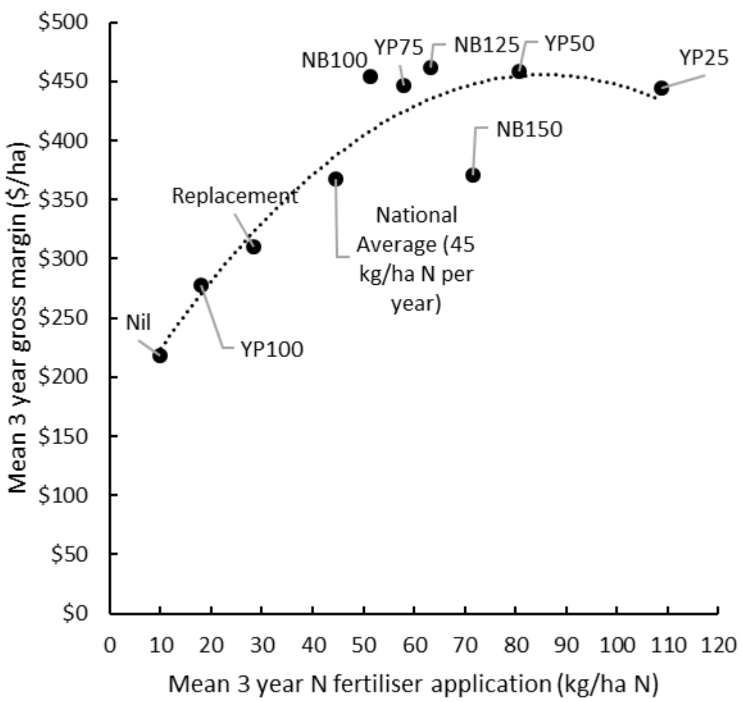

Figure 1. Mean fertiliser application and mean gross margin (2018-2020) for the BCG-La Trobe University long-term N management experiment at Curyo. For details of the experiment see http://www.ausgrain.com.au/Back%20Issues/301mjgrn20/Grower%20group%20focus.pdf. The number following 'N bank' treatments, is the N bank target in kg/ha. YP=Yield Prophet treatments at different levels of probability (YP100% targets yield assuming the worst season finish on record, YP50% targets yield assuming a median finish etc.).

Soil testing is essential

WUE tools, Yield Prophet® and the 'N bank' management system all rely on growers knowing how much mineral N (nitrate and ammonium) they have available to a crop early in the growing season.

In all these tools it is best not to include in-season mineralisation in the calculations, because mineralisation is cancelled out by immobilisation in systems where soil organic matter is being maintained (i.e. stubble retained systems with neutral to positive N balance). Consequently, for any rational decision to be made on N management, it is critical that paddocks are soil tested to measure mineral N at the start of the season. Assessment of the soil N bank is achieved by testing for nitrate and ammonium. This can be done any time from March through to June, but if done following sowing it is essential that samples are taken from the inter-row to avoid sampling any fertiliser N applied at sowing. Soil cores should be taken to at least 0.6m (ideally >1.0m) and segmented into different depths (e.g., 0-0.1 m, 0.1-0.3 m, 0.3-0.6 m). At least six cores need to be taken per paddock or production zone within a paddock, and bulked samples carefully mixed. Samples should be kept cool and sent to the laboratory as soon as possible after sampling. A good soil sampling contractor will do all these things for you!

Managing spatial variability

Soil mineral N varies a lot spatially, and this makes soil sampling difficult and prone to error. It can be beneficial to soil sample high and low yielding zones of paddocks independently to get a better picture of what is happening across the paddock. Some growers are making variable rate N applications based on protein maps from previous crops and are reporting a high level of success at achieving higher yield and protein in high performing areas of paddocks and avoiding chronic over-fertilisation in low yielding areas. Whilst protein maps are an effective way of informing how N is best allocated across a paddock, they can't help with estimating the base rate, with soil testing and the management systems described above necessary to achieve this.

Reviewing performance

N management performance should be reviewed over the longer term (>3 years), and there are two effective ways to do this and make sure growers are achieving your production goals. The first is by reviewing wheat grain protein. If growers are producing wheat with less than 10.5% protein (ASW), then yields are highly likely to be N limited, and profits will almost certainly be increased by increasing N application rates. If protein is between 10.5% and 11.5% (APW), yields are likely to be N limited and profits improved by increasing N application. If protein is between 11.5% and 13% (H2) yield is likely maximised and there will be no benefit from further N application. If protein is over 13% (APH) it is extremely unlikely that yields are N limited, and growers may be over applying N at the expense of some yield and perhaps profit, depending on whether they are attracting price premiums for high protein grain.

The second way to review N management is to calculate a long-term N balance for individual paddocks. N balance is the sum of N inputs from fertiliser and legumes minus the amount of N that has been exported in grain (a simple spreadsheet to calculate N balances is available here; https://www.bcg.org.au/understanding-crop-potential-and-calculating-nitrogen-to-improve-crop-biomass-workshop-recording/. N balance is a good indicator of levels of soil organic N mining. Paddocks with a neutral to positive N balance are unlikely to be mining soil organic N, and soil organic matter under cropping should be maintained. Paddocks with a negative N balance are mining soil organic N and soil organic matter will be declining. A very positive N balance indicates chronic over application, and whilst this might be building soil organic matter in stubble retained systems (soil organic matter contains C and N as well as P and S in constant ratios), profits might be increased by reducing N applications.

The BCG-La Trobe field experiment (Figure 2) and simulation studies (Meier et al., 2021; Smith et al., 2019) both indicate that profit is maximised at neutral to slightly positive N balances.

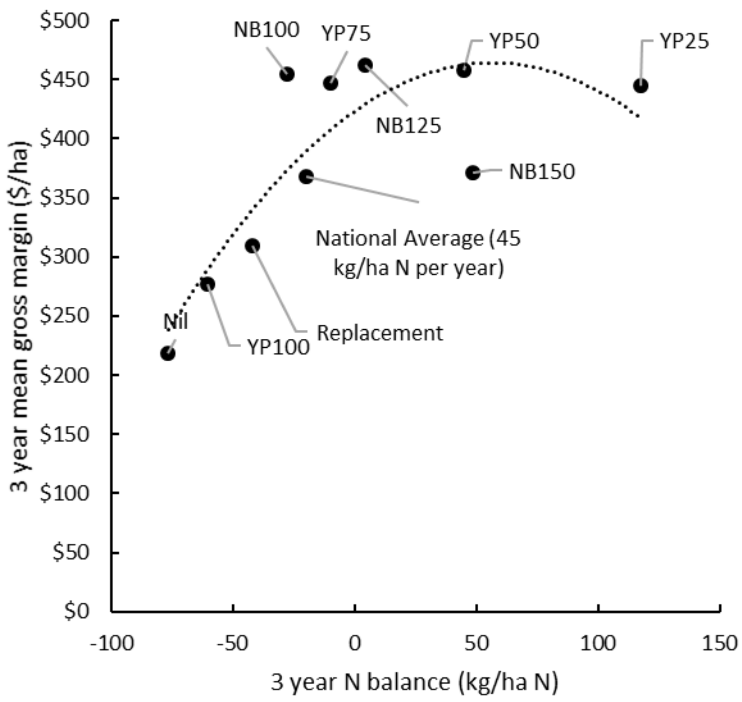

Figure 2. The BCG-La Trobe University long-term N management experiment at Curyo is showing that N management strategies that over-apply (i.e., have a neutral to positive N balance) are more profitable. These strategies will also reduce likelihood of mining soil mineral N and thus running down soil organic matter. For details of the experiment see: http://www.ausgrain.com.au/Back%20Issues/301mjgrn20/Grower%20group%20focus.pdf The number following 'N bank' treatments is the N bank target in kg/ha. YP=Yield Prophet treatments at different levels of probability (YP100% targets yield assuming the worst seasonal finish on record, YP50% targets yield assuming a median finish, etc.).

Recent farming systems experiments in southern NSW demonstrate the concept

GRDC funded farming systems experiments in southern NSW over the last 3 years have used different crop sequences and N strategies that exemplify the concept of taking a longer view with N management. The experiments included two N targets for topdressing decisions – one targeting Decile 2 conditions (conservative) and one targeting Decile 7 conditions (more akin to N-bank). The results during the two consecutive Decile 1 years of 2018 and 2019 tended to demonstrate that Decile 7 approach was less profitable in those years, however the record season of 2020 revealed significant responses to carry-over N that had been applied in previous years. At the time of writing the data for the full 3 years N balance was being reviewed and will be presented at the Update.

Conclusion

Nitrogen deficiency is the single biggest cause of the Australian wheat yield gap. Growers can easily reduce this yield gap, increase profit, and stop mining soil organic matter by taking a longer-term view of N management. Soil testing is essential to do this. N banks, Yield Prophet® or WUE tools are all equally effective at reducing N limitation and increasing profit. N management performance can be reviewed using wheat grain protein and calculating N balances for individual paddocks to make sure yields and profit are maximised and organic N is not being mined.

Acknowledgements

This project is funded by La Trobe University through the Securing Food, Water and the Environment Research Focus Area and the Mallee Catchment Management Authority, through funding from the Australian Government's National Landcare Program.

Useful resources

http://www.ausgrain.com.au/Back%20Issues/301mjgrn20/Grower%20group%20focus.pdf

https://www.bcg.org.au/managing-n-fertiliser-to-profitably-close-yield-gaps/

https://grdc.com.au/resources-and-publications/all-publications/publications/2020/a-nitrogen-reference-manual-for-the-southern-cropping-region

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Integrating pulses into the farming system - double breaks, fallow vs pulses and optimising crop sequence - a grower's perspective

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Notes:

Adviser observations on key outcomes from the farming systems trial at Condobolin and local experience with double breaks

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Notes:

NSW cereal diagnostics and enquiries – the 2020 winner is……?

Steven Simpfendorfer[1], Brad Baxter[2] and Andrew Milgate[2]

[1] *NSW DPI Tamworth*
[2] *NSW DPI Wagga Wagga*

Keywords

correct diagnosis, leaf diseases, soil-borne diseases, wheat, barley

GRDC code

DAN00213: Grains Agronomy & Pathology Partnership (GAPP) - A strategic partnership between GRDC and NSW DPI. Projects BLG208 and BLG207.

Take home messages

- Cereal diseases were prevalent in 2020 with favourable climatic conditions. Hence, in combination with increased cereal stubble loads, pathogen levels are likely to be elevated in 2021
- However, steps can be taken to minimise impacts which include:
  - Remember the basics of disease management – think disease triangle!
  - Know before you sow (e.g. PREDICTA®B or stubble tests) – inoculum levels
  - Varietal resistance – reduce host susceptibility
  - Manipulate canopy microclimate or stress during grain filling – environmental conditions
- NSW DPI plant pathologists can help with correct diagnosis and management options.

Introduction

A 'no-additional charge' cereal diagnostic service is provided to NSW cereal growers and their advisers under projects BLG207 and BLG208 as part of the GAPP co-investment. Evidence based methods are used to confirm diagnosis which include a combination of visual symptoms, crop management history, distribution in paddock and recovery/identification of the causal pathogens (microscopy, humid chamber or plating). Any suspect virus samples are confirmed using ELISA antibody testing at NSW DPI Elizabeth Macarthur Agricultural Institute at Menangle.

Wheat, barley and oat rust samples (stripe, leaf and stem) are sent to the Australia Cereal Rust Control Program (ACRCP). The submission of samples to ACRCP facilitates the tracking of pathotype populations and distribution across the cropping belt of NSW and Australia. This includes a new interactive map (Australian Cereal Rust Survey 2020 Sample Map - Google My Maps) regularly updated throughout the growing season by the ACRCP. Growers can access this resource to see which pathotypes dominate in their region. This can be very important to guide in-crop management decisions given five different stripe rust pathotypes were present at varying levels across NSW in 2020. Individual wheat varieties can have vastly different reactions to these pathotypes, so knowing which ones are dominant, where and when, can guide appropriate seasonal in-crop management.

The projects also record disease enquiries received and resulting management advice provided to growers and advisers throughout each season. These project activities support NSW cereal producers in correct diagnosis of diseases during the season with resulting independent advice on appropriate management strategies to limit economic impacts. This is assisting to limit the unnecessary application of in-crop fungicides by growers.

Which diseases dominated in 2019 and 2020?

Collation of this data across NSW provides an annual 'snapshot' of the key biotic and abiotic constraints to cereal production (Table 1).

Table 1. Cereal diagnostics and enquiries processed across NSW in 2019 and 2020. Disease/issues are ranked in order of frequency in 2020

Disease/issue	2020	2019
Stripe rust (wheat)	194	13
Spot form of net blotch	65	32
Physiological/melanism	65	10
Scald	65	4
Fusarium crown rot	61	14
Wheat powdery mildew	53	1
Frost damage	45	4
Leaf rust (wheat)	35	2
Other non-disease (e.g. soil constraint, leaf blotching)	34	24
Bacterial blight (other cereals)	30	0
Rusts crown and stem (oats)	29	4
Herbicide	28	6
Net form of net blotch	23	0
Bacterial blight (oats)	22	3
Barley grass stripe rust	20	1
Barley yellow dwarf virus	19	1
Septoria tritici blotch	17	13
Nutrition	16	2
Take-all	16	1
Rhizoctonia	12	7
Barley powdery mildew	12	0
Yellow leaf spot	10	4
Fusarium head blight	10	0
Loose smut	9	1
Seedling root disease complex (Pythium, crown rot, Rhizo,Take-all)	8	2
Septoria oats	3	2
Wheat streak mosaic virus	3	1
Common root rot	2	3
Rye grass rust	2	0
Ergot	1	0
Red leather leaf	1	7
Sclerotium rolfsii	1	2
Spot blotch	1	0
Ring spot	0	1
Total	**912**	**165**

Not surprisingly, individual seasons have a strong influence on the level of cereal diagnostic support provided to NSW growers/advisers, with over five-times the number of activities in the wetter 2020 season compared with much drier conditions experienced in 2019 (Table 1). This increase was primarily due to more conducive conditions for the development of a range of cereal leaf diseases (e.g. rusts, scald, net-blotches, Septoria) in 2020 (537 samples) compared with 2019 (77 samples).

The four main cereal diseases in 2020 were wheat stripe rust (widespread distribution of newer Yr198 pathotype), spot form of net blotch in barley, scald in barley and Fusarium crown rot in different winter cereal crops. In comparison, the four main cereal diseases in 2019 were spot form of net blotch, Fusarium crown rot, wheat stripe rust and Septoria tritici blotch (Table 1).

Interestingly, the levels of yellow leaf spot (*Pyrenophora tritici-repentis*) diagnosed in both seasons were relatively low. However, wheat samples with leaf blotches or mottling were submitted each year, suspected to be caused by yellow leaf spot. There is an ongoing difficulty with correct diagnosis of this particular leaf disease by growers and their advisers, often confused with Septoria tritici blotch (*Zymoseptoria tritici*), Septoria nodorum blotch (*Stagonospora nodorum*) and physiological responses to abiotic stress (e.g. frost yellowing, N mobilisation, herbicide damage).

The 2020 season also highlighted that root diseases like take-all, which have not been seen at damaging levels for many years can quickly re-emerge at significant levels when conducive conditions occur. Conversely, Fusarium crown rot remains a significant issue across seasons.

The number of rust and powdery mildew samples received from susceptible wheat varieties in 2020 highlights the importance of genetic resistance as a component of integrated disease management systems. Susceptible varieties are more reliant on fungicide applications to limit disease levels and associated yield loss, which can increase the risk of fungicide resistance developing. The resistance selected may not necessarily be in the main pathogen targeted by the fungicide applications. For example, reliance on fungicide applications in stripe rust susceptible varieties could inadvertently select for fungicide resistance in wheat powdery mildew populations when they co-infect plants. Preliminary research conducted in collaboration with Curtin University's Centre for Crop Disease Management (CCDM) in 2020, unfortunately indicates issues with reduced sensitivity to azoles (DMIs, Group 3) and resistance to strobilurin (QoIs, Group 11) fungicides are already widespread in wheat powdery mildew populations in NSW and Victoria.

Are you getting a correct diagnosis?

Importantly, 21% of activities in 2020 and 28% in 2019 were not related to disease. These samples were either diagnosed as being plant physiological responses to stress, frost damage, herbicide injury, related to crop nutritional issues or other non-disease issues. All of these samples were submitted as suspected of having disease issues. This highlights the ongoing importance of the diagnostic service provided by these projects to NSW growers and their advisers to support correct identification and implementation of appropriate management strategies. Never be afraid to get a second opinion from a plant pathologist, we are here to help (see contact details).

Management in 2021 – remember the basics!

Showing our ages here by referring back to the good old 'disease triangle', my mentors would be proud! Disease levels in 2021 will still be based around the disease triangle, which requires a combination of pathogen inoculum, susceptible host and environmental conditions conducive to disease development. Given the elevated incidence of a wide range of cereal diseases across NSW in 2020 (Table 1), inoculum levels of a range of cereal pathogens and hence disease risk in 2021 will be higher than previous seasons. Each of the three components of the disease triangle should be considered when implementing management strategies to minimise losses and determine if fungicide application is warranted in 2021.

1. Inoculum levels

The first step is 'know before you sow'. PREDICTA®B testing remains the gold standard for a quantitative assessment of a wide range of cereal pathogens and associated risk of both soil-borne and leaf diseases. Refer to the PREDICTA B sampling protocol (https://pir.sa.gov.au/__data/assets/pdf_file/0007/291247/Sampling_protocol_PreDicta_B_Northern_regions.pdf) . NSW DPI is alternatively offering a free cereal stubble testing service prior to sowing in 2021 (Jan-Apr) aimed primarily at determining Fusarium crown rot risk levels in cereal-on-cereal situations (contact Steven Simpfendorfer for details).

The disease risk associated with inoculum levels can be quite different with various pathogens depending on their capacity for wind dispersal. For example, stubble and soil borne pathogens which cause Fusarium crown rot, take-all and Rhizoctonia root rot are not dispersed by wind, hence risk from inoculum is confined to an individual paddock. Consequently, crop rotation to a non-host pulse or oilseed crop breaks the disease triangle. Stubble borne leaf pathogens, which cause net blotch or scald in barley, yellow spot or Septoria tritici blotch in wheat or powdery mildew, have limited wind dispersal (i.e. metres), so again crop rotation largely reduces disease risk and especially at early growth stages. Conversely, rusts are airborne (i.e. kilometres) so crop rotation is irrelevant to disease risk.

Seed borne infection should also be considered with some pathogens such as bacterial blights, scald, net-form of net blotch, smuts and bunts. Sourcing clean seed for sowing in 2021, that is, not from crops infected in 2020, is important to reduce risk of these diseases.

With stripe rust, reducing or delaying the onset of an epidemic significantly reduces disease pressure. Rust spores are readily wind borne and are commonly referred to as 'social diseases' (i.e. 'we are all in this together'). Hence, co-ordinated management across a region can have real benefits for all. Controlling volunteer wheat plants at least three weeks prior to first planting of crops limits the 'green bridge' survival and delays epidemic onset. In-furrow (e.g. flutriafol) and seed treatments (e.g. fluquinconazole) fungicides provide extended protection from stripe rust early in the season delaying epidemic onset. This can be particularly important when early sowing susceptible long season wheat varieties (e.g. DS Bennett⊕), which can place early disease pressure on later sown susceptible main season varieties.

Growers should also be aware that stubble management practices can also influence inoculum dispersal. For example, inter-row sowing between intact standing cereal stubble reduces the level of Fusarium crown rot infection. However, cultivating or mulching infected cereal stubble prior to sowing can spread Fusarium inoculum more evenly across a paddock and potentially into the surface layers of the soil where plant infection primarily occurs. Volunteer cereal plants and grass weeds over the summer fallow period can also be a major source of increased inoculum of Fusarium crown rot, take-all and Rhizoctonia leading into sowing in 2021.

2. Host susceptibility

Relatively self-explanatory? If you do not want cereal disease issues, then sow a non-host pulse or oilseed break crop. However, if considering cereal-on-cereal, key points are:

1. Make sure you are using the latest varietal resistance ratings especially to newer pathotypes of stripe rust. Many growers got caught out on this with durum wheats and DS Bennett in 2020. Improved levels of resistance to leaf diseases reduces reliance on foliar fungicides
2. If multiple pathogen risks then hedge towards improved resistance to the more yield limiting, harder to control and/or historically bigger issue in your area. This could be quite different between rainfall zones or dryland vs irrigated situations

3. Barley, bread wheat, durum, oats and triticale are NOT break crops for each other! They all host Fusarium crown rot, take-all and Rhizoctonia. Barley tends to be more susceptible to Rhizoctonia root rot, but its earlier maturity can provide an escape from late season stress which reduces yield loss to Fusarium crown rot
4. Rusts and necrotrophic leaf diseases (net blotches, yellow spot, Septoria) tend to be crop specific. However, note that in wetter seasonal finishes it appears that some of these necrotrophic leaf pathogens have the potential to saprophytically colonise other cereal species.

3. Environmental conditions

Largely in the 'lap of the gods'? Certainly more limited options here but growers should be aware that subtle microclimate differences within cereal canopies can have a large influence on cycling of leaf diseases. Crash grazing of dual purpose wheat varieties not only reduces any early stripe rust inoculum, but also opens the canopy to reduce the duration of leaf wetness and lowers humidity. This reduces conduciveness to leaf diseases. Higher nitrogen levels can also exacerbate rusts and powdery mildew through thicker canopies creating a more favourable microclimate for these pathogens. However, leaf nitrate also serves as a food source for these biotrophic leaf pathogens.

Yield loss from Fusarium crown rot infection, largely through the expression of the disease as whiteheads, is strongly related to moisture and temperature stress during grain filling. Although growers cannot control rainfall during this period, there is the potential to limit the probability of stress through earlier sowing (matched to varietal maturity and frost risk), maximising soil water storage during fallow periods (stubble cover + weed control), addressing other biotic (e.g. nematodes, Rhizoctonia) or abiotic (e.g. acidity, nutrition, residual herbicides etc.) constraints to root development and canopy management. Recent (last two weeks) and predicted weather conditions (next 2-4 weeks) should also be considered with in-crop leaf disease management decisions in susceptible varieties around key growth stages for fungicide application of GS30-32 (1st node), GS39 (flag leaf emergence) and GS61 (flowering).

Conclusions

Overall the 2020 season was fairly good across a large proportion of NSW with cereal diseases present at higher frequencies than recent seasons. Hopefully 2021 provides another favourable year for cereal production. Cereal disease risk is likely to be higher due to pathogen build-up in 2020 and the likely increased area of cereal-on-cereal in 2021. Calm considered and well planned management strategies in 2021 can minimise disease levels. NSW DPI is here to support correct diagnosis and discuss management options prior to sowing and as required throughout the season. Let's get back to cereal disease management basics in 2021 and leave any lingering 'pandemic panic' from 2020 behind.

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Causes of poor ryegrass results & paraquat & glyphosate resistance- 2020 season

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Keywords

multiple tactics, pre-emergence, glyphosate and paraquat resistance, annual ryegrass, optimising control, testing, random weed survey, double knock, high rainfall

GRDC code

UCS00020

Take home messages

- Ryegrass blowouts are a result of large seedbanks, insufficient weed control strategies and herbicide resistance
- Pre-emergence herbicides offer alternative modes of action to control multiple resistant ryegrass and extend the duration of activity
- Glyphosate resistance in annual ryegrass continues to increase whereas resistance to paraquat remains very low
- Improving herbicide efficacy by good application can reduce selection for herbicide resistance.

Ryegrass blowouts in 2020

The 2020 season saw the return of good rainfall across a large part of the NSW cropping zone. Ryegrass seed can survive in the seedbank for up to three years and longer if dry seasons prevail as occurred in the past few years in this region. Over the past few decades, controlling ryegrass with a single management practice is becoming increasingly difficult as the germination window of ryegrass has increased. Use of a single tactic can cause serious blowouts. Multiple tactics are often required to manage ryegrass particularly during a long season as in 2020 in NSW. Practices such as one or more double-knocks, a robust pre-emergence herbicide or herbicide mixture (Figure 1), in-crop effective post-emergent herbicides (if resistance testing has indicated susceptibility or low resistance), crop-topping if in a suitable crop and harvest weed seed control are necessary to combat ryegrass germinating during the growing season. A greater diversity of pre-emergence herbicides are becoming available with multiple modes of action providing greater benefits including duration of activity and control of multiple resistant ryegrass. It is important to introduce herbicides with alternative modes of action into cropping rotations to reduce herbicide resistance. Ultro® (Group E) and Overwatch® (Group Q) have been registered for the 2021 cropping season for use in pulses and wheat, barley and canola, respectively.

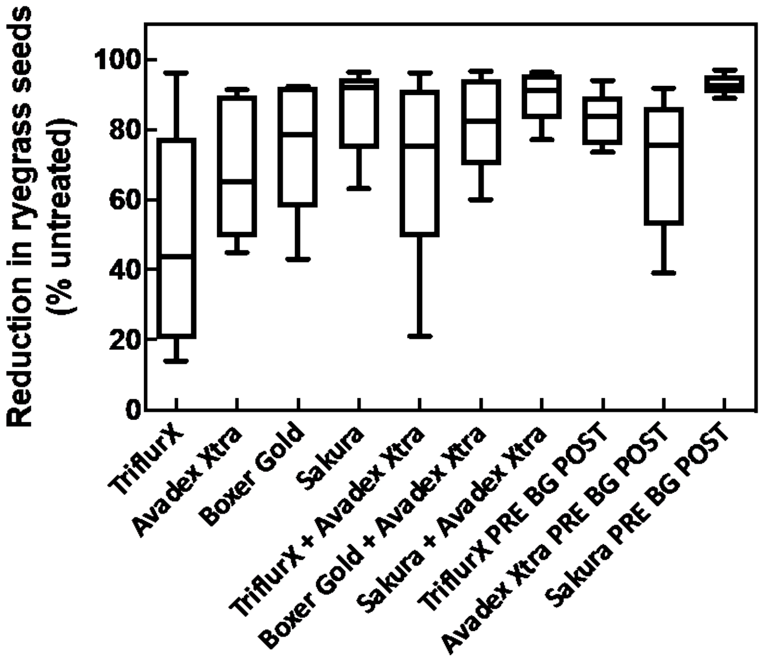

Figure 1. Averaged data showing efficacy of pre-emergence herbicide combinations from field trials in SA, Vic and NSW. As a standalone, Sakura® provided the best control. Tank-mixing or sequential applications improved control (Project code UA00113).

In addition to herbicide choice, there are several other factors such as using full label rates, good application techniques and spraying under ideal conditions that are required to optimise weed control. These are discussed for glyphosate below but are valid for most other herbicides. For pre-emergence herbicides specifically, the stubble load and rainfall prior and after sowing are two additional critical factors. Herbicides must wash off stubble and come into contact with the seed or in close proximity to be active. The germination phase of a seed is important for some herbicides. The mode of action of trifluralin is to prevent the first stage of germination with control reduced on seeds that have already started germinating (Figure 2) with Sakura and Boxer® Gold effective if sufficient moisture distributes the herbicide in close proximity to the seedling.

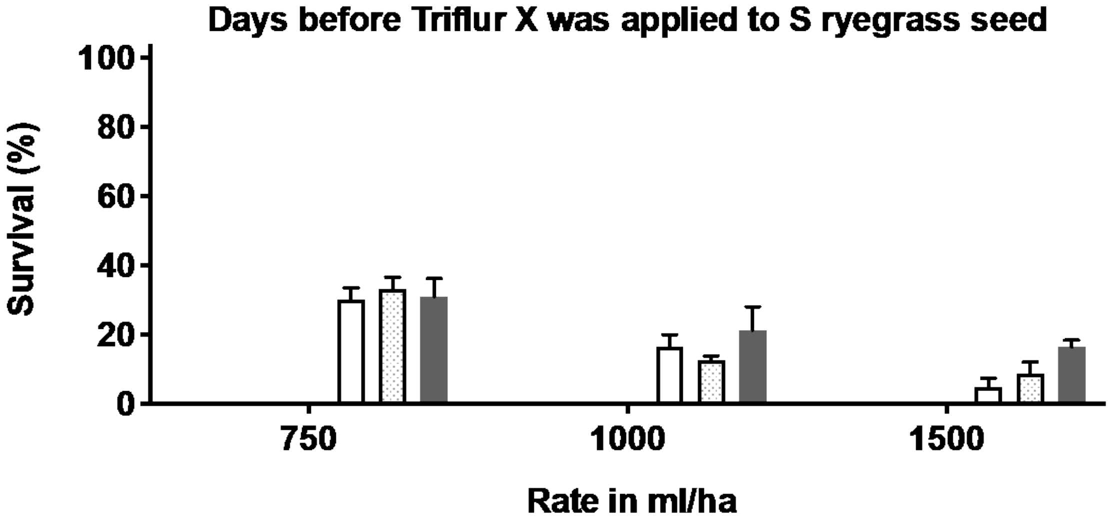

Figure 2. Percent survival of a herbicide susceptible ryegrass biotype measured 4 weeks after treatment. Three rates of Triflur X, Boxer Gold and Sakura were applied in pots. Product rates (mL/ha) are shown in the x-axis. Herbicides were applied on 13 July 2015 to seed that had been exposed to moisture 0, 3, 5, 7, 10, 12 and 14 days prior. Error bars indicate standard error of the means. No plots shown for Sakura and Boxer Gold as no survival was observed even at the lowest rate. As product is applied direct to seed, rates applied are lower or at the low end of label rates as this equates to robust field rates.

A long season can result in ryegrass germinating over an extended period. Whilst the competitive effects of later germinating ryegrass can be minimal on crop yield, the additional contribution of seed into the seedbank from these late germinators can be important for the following seasons. The presence of herbicide resistance can restrict the herbicide options available. Resistance testing can help in identifying herbicides to avoid if no longer effective.

Incidence of resistance in NSW

The GRDC continues to fund random weed surveys in cropping regions to monitor for changes in resistance levels in key weed species. The methodology involves collecting weed seeds from paddocks chosen randomly at pre-determined distances. Plants are tested in outdoor pot trials during the growing season. The majority of annual ryegrass populations in NSW are resistant to Group A 'fop' and Group B herbicides with some variability between the surveyed sub-regions (Table 1). No populations have been found that are resistant to the newer pre-emergent herbicides although this has been reported in other states. Of particular concern is the amount of populations resistant to glyphosate in some of the sub-regions.

Table 1. Extent (percentage) of herbicide resistance in annual ryegrass populations collected in NSW random surveys (resistance defined as populations with >20% survival)

	NSW (2015 - 2019)	2019 eastern NSW	2015 western NSW	2016 NSW northern	2016 NSW plains	2017 southern NSW	2018 NSW slopes
diclofop	59	92	16	32	65	84	77
clethodim	2	12	1	1	1	3	0
sulfometuron	50	82	30	22	35	74	70
imazamox/imazapyr	47	83	8	22	39	75	76
trifluralin	1	2	2	0	0	1	1
prosulfocarb + S-metolachlor	0	0	0	0	0	0	0
pyroxasulfone	0	0	0	0	0	0	0
glyphosate	5	14	6	5	0	7	3
Samples	608	53	117	94	111	128	105

Among the other species, resistance was much lower. 29% of wild oat populations across NSW were resistant to Group A ‘fop’ herbicides (Table 2). Group B ‘SU’ resistance was common for sow thistle (43%) and Indian hedge mustard (27%) across the state, with this rising to 75% of sow thistle populations in eastern NSW resistant (data not shown). Three populations (1%) of sow thistle from northern NSW were resistant to glyphosate. Of the wild radish populations surveyed, 38% were resistant to diflufenican and 23% to 2,4-D amine (Table 2)

Table 2. Extent (percentage) of herbicide resistance in populations of the other species collected in NSW random surveys (resistance >20% survival, * herbicide not tested or not applicable for species)

Herbicide group	Wild oats	Barley grass	Brome grass	Sow thistle	Wild radish	Indian hedge mustard
diclofop	29	0	0	*	*	*
clethodim	1	0	0	*	*	*
sulfometuron	4	1	7	43	4	27
imazamox/imazapyr	*	*	2	*	0	8
atrazine	*	*	*	*	4	0
diflufenican	*	*	*	*	38	4
2,4-D Amine	*	*	*	1	23	2
triallate	0	*	*	*	*	*
paraquat	*	3	*	*	*	*
glyphosate	0	*	0	1	0	0
Samples	511	133	110	202	28	71

Incidence of paraquat resistance

Resistance to paraquat has been detected in a few ryegrass populations from WA, SA, Vic. They have typically originated along fencelines, non-cropped farm areas, lucerne/clover seed production paddocks and vineyards (Figure 3). Detection has been via random weed surveys or samples sent to Plant Science Consulting and Charles Sturt University following reduced control in the field. While the number remains low it is important to use paraquat according to label recommendations with emphasis on rate, growth stage and population size. The first case of paraquat resistance in ryegrass detected globally was in South African orchards after decades of use on advanced growth stages resulting in sub-lethal effects (Yu *et. al.* 2004). More locally, a sample of perennial ryegrass was confirmed highly resistant to paraquat from a vineyard in the Adelaide Hills in 2019 following application of sublethal rates of paraquat for many years to keep the ryegrass suppressed but maintain ground cover (P. Boutsalis). This sample was also highly resistant to glyphosate.

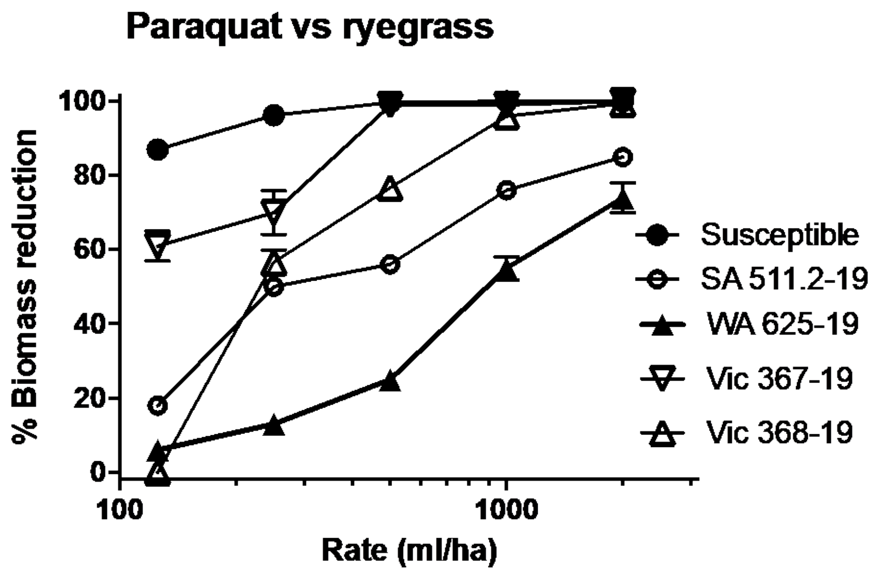

Figure 3. Efficacy of the first confirmed cases of paraquat resistance in annual ryegrass from SA, Vic and WA. Error bars indicate variation. Study conducted by Plant Science Consulting.

Additionally, two populations of barley grass resistant to paraquat and one developing resistance (10-20% survival) have been collected during the NSW random surveys.

Incidence of glyphosate resistance in NSW

Bayer CropScience provides free access to the Resistance Tracker website consisting of thousands of weed samples from resistance testing across Australia (https://www.crop.bayer.com.au/tools/mix-it-up/resistance-tracker). This website enables the searching of resistance according to weed species, mode of action herbicide, postcode and closest town with data presented from 2003 (Figure 4).

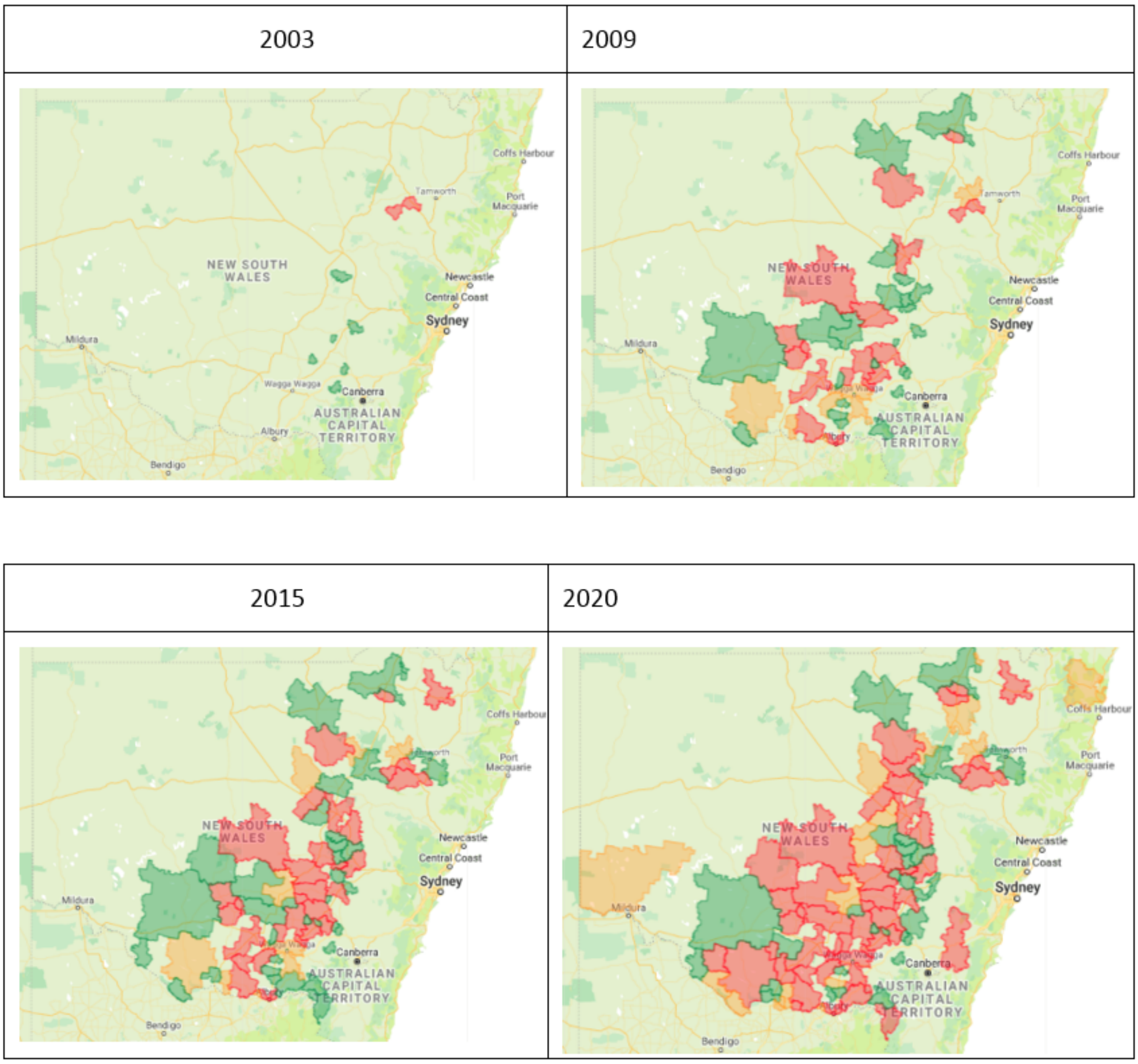

Figure 4. Occurrence of glyphosate resistance in annual ryegrass in NSW in 2003, 2009, 2015 and 2020. **Dark green shading** = postcode regions where testing has not detected glyphosate resistance in ryegrass, **orange shading** = postcodes where glyphosate resistance is developing and **red shading** = postcodes where resistance has been detected.

2020 season: The early break in 2020 across most southern cropping regions resulted in an opportunity for knockdown weed control. Multiple applications of glyphosate and paraquat were possibly targeting multiple flushes of weeds, in particular ryegrass from early autumn prior to sowing. Plants surviving glyphosate from WA, SA, Vic and NSW were sent to Plant Science Consulting for testing using the Quick-Test method to verify whether herbicide resistance had contributed to survival in the field. The data presented in Figure 5 indicates that 43%, 70% and 78% of ryegrass samples sent from SA, Vic and NSW in 2020 respectively, were confirmed resistant to glyphosate. This highlights that in a majority of cases, glyphosate resistance has contributed to reduced control in the paddock.

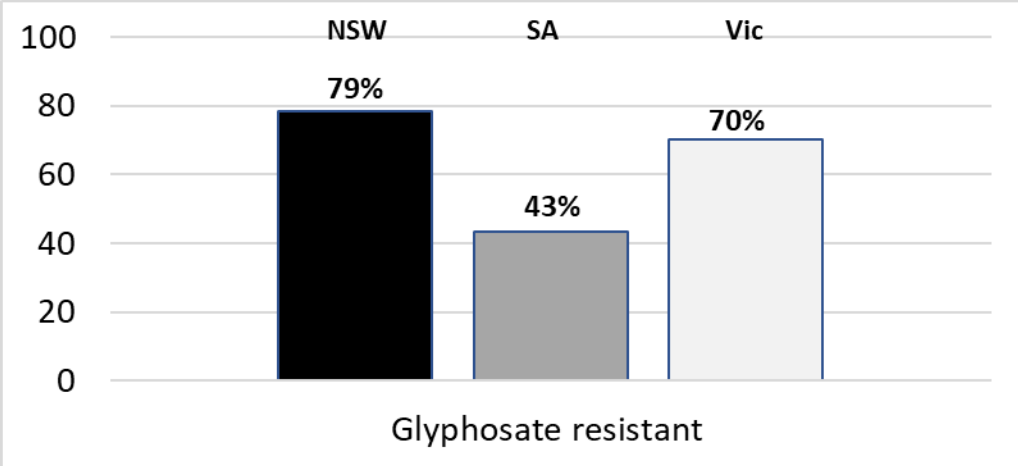

Figure 5. Percent (%) resistance to glyphosate confirmed in farmer ryegrass samples originating from 83 NSW, 37 SA and 74 Vic cropping paddocks treated with glyphosate in autumn 2020. Testing conducted by Plant Science Consulting using the Quick-Test.

Discrepancy between resistance testing and paddock failures to glyphosate

In some cases, plants that survived glyphosate in the paddock are not resistant. Reasons for the discrepancy between the paddock and a resistance test can include poor application or application onto stressed plants, incorrect timing, sampling plants that were not exposed to glyphosate, antagonistic tank mixes, inferior glyphosate formulation, poor water quality, incorrect adjuvants, or a combination of the above.

Evolution of glyphosate resistance

Glyphosate was first registered in the 1970s and rapidly became the benchmark herbicide for non-selective weed control. Resistance was not detected until 1996 in annual ryegrass in an orchard in southern NSW (Powles et. al. 1998). Only a few cases of resistance were detected in the following decade (refer to Bayer Resistance Tracker). The fact that it required decades of repeated use before resistance was confirmed indicated that the natural frequency of glyphosate resistance was extremely low.

There are several contributing factors for the increasing resistance in ryegrass to glyphosate with generally more than one factor responsible. Reducing rates can increase the development of resistance particularly in an obligate outcrossing species such as ryegrass, resulting in the accumulation of weak resistance mechanisms to generate individuals capable of surviving higher rates. This has been confirmed by Dr Chris Preston where ryegrass hybrids possessing multiple resistance mechanisms were generated by crossing parent plants with different resistance mechanisms. Other factors that can select for glyphosate resistance by reducing efficacy include:

1. Using low quality glyphosate products and surfactants
2. Mixing glyphosate with too many other active ingredients resulting in antagonism, particularly in low water volumes
3. Using low quality water, particularly hard water. Glyphosate is a weak acid and binds to positive cations (i.e. magnesium, calcium and bicarbonate) that are in high concentration in hard water (i.e. >200 ppm)
4. Applying glyphosate during periods of high temperature and low humidity, resulting in the rapid loss of glyphosate from solution on leaf surfaces thereby reducing absorption
5. Translocation of glyphosate in stressed plants can be reduced. Optimising glyphosate performance requires the translocation to the root and shoot tips. While this can occur readily in

small seedlings, in larger plants, glyphosate is required to translocate further to the root and shoot tips to maximise control
6. Shading effects reducing leaf coverage resulting in sub-lethal effects
7. Applying glyphosate onto plants covered with dust can result in reduced available product for absorption as glyphosate strongly binds to soil particles
8. Application factors such as speed and nozzle selection, boom height can reduce the amount of glyphosate coverage
9. A combination of the above factors can reduce control and increase selection for resistance.

Optimising glyphosate performance

The selection of glyphosate resistance can be minimised by considering the points above. A number of important pathways to improve glyphosate performance include:

Avoid applying glyphosate under hot conditions.

A trial spraying ryegrass during the end of a hot period and a following cool change was conducted in October 2019. Ryegrass growing in pots were sprayed at 8am, 1pm and 8pm with temperature and Delta T recorded prior to each application. Control of well hydrated plants ranged between 0% and 40% when glyphosate was applied during hot weather (30 to 32.5°C) and high Delta T (14 to 16.7) with the lowest control when glyphosate was applied at midday (Figure 6). In contrast, glyphosate applied under cool conditions just after a hot spell resulted in significantly greater control (65%-80%), indicating that plants can rapidly recover from temperature stress provided moisture is not limiting.

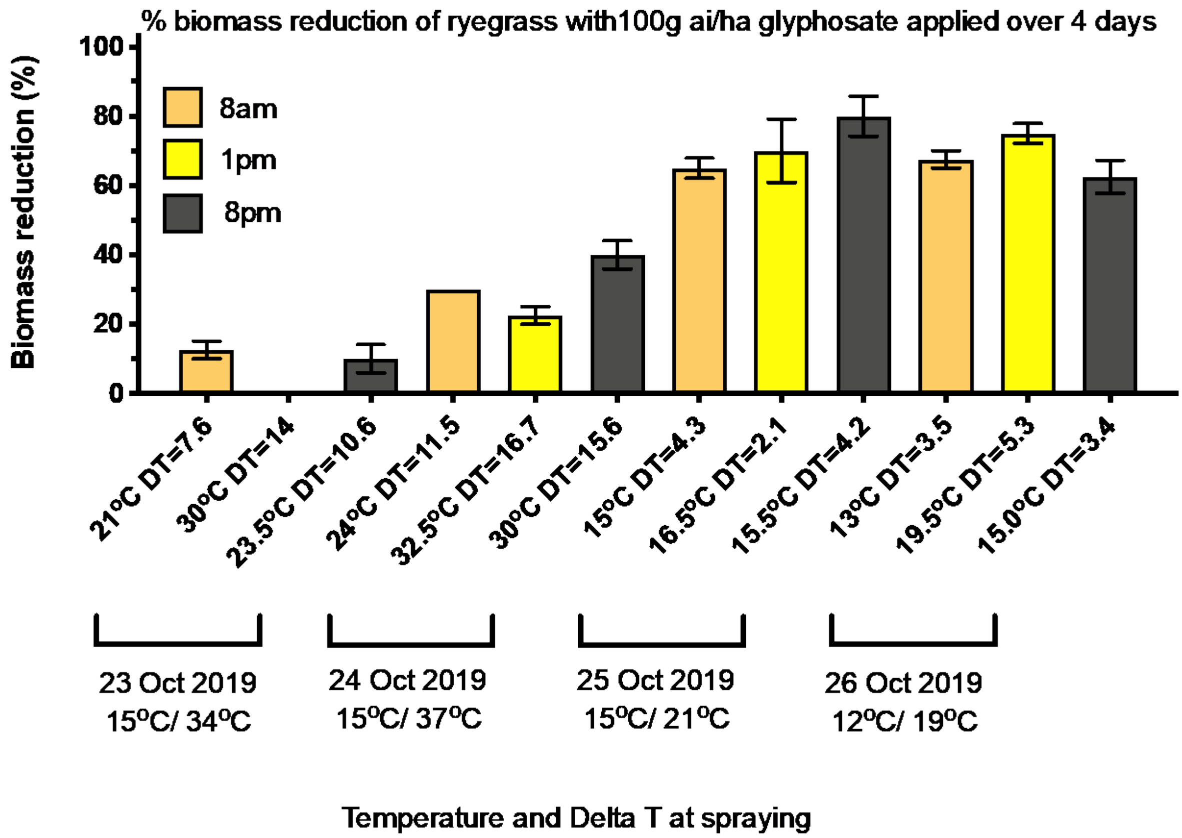

Figure 6. Effect of temperature & Delta T on glyphosate for ryegrass control

Improving water quality and glyphosate activity by using ammonium sulfate (AMS)

The addition of AMS has several functions. One is to soften water by combining to positively charged ions such as magnesium and calcium common in hard water. The negative charged sulfate ions combine with the positive cations preventing them from interacting with glyphosate and reducing glyphosate solubility and leaf penetration. Additionally, AMS has been shown to independently improve glyphosate performance, as the ammonium ions can work with glyphosate to assist cell entry, increasing uptake and activity. In a pot trial conducted with soft water, ammonium sulfate was shown to significantly improve control of ryegrass with 222mL/ha (100g ai/ha) of glyphosate 450 (Figure 7). As a general rule, growers using rainwater (soft) should consider 1% AMS, if using hardwater (i.e. bore, dam) 2% AMS is recommended. The addition of a wetter resulted in a further improvement of herbicide efficacy.

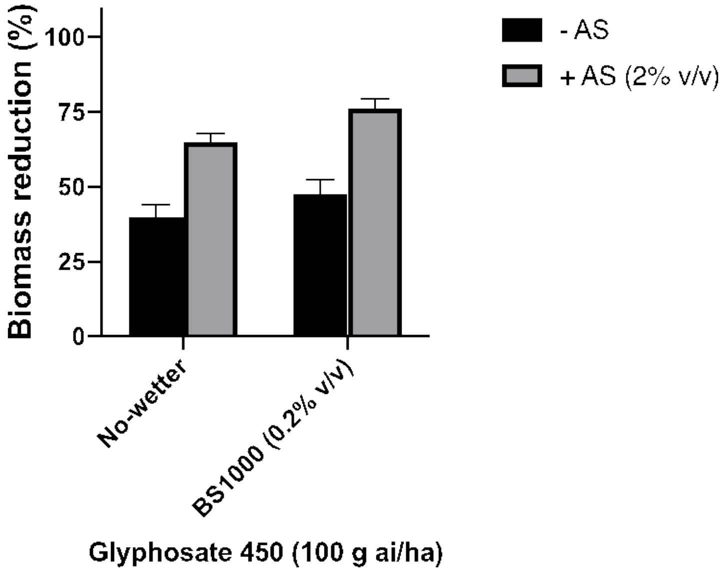

Figure 7. Effect of ammonium sulfate and wetter on glyphosate for ryegrass control

Herbicide activity can vary at different growth stages

In a pot trial investigating the effect of glyphosate at 4 ryegrass growth stages (1-leaf to 4-tiller), good control was achieved at the 3 older growth stages but not on small 1-leaf ryegrass (Figure 8). Most glyphosate labels do not recommend application of glyphosate on 1-leaf ryegrass seedlings. Very small seedlings (i.e. 1-leaf) are still growing on seed reserves and have not yet commenced sugar production via photosynthesis. As a consequence, little glyphosate is translocated downwards with the sugars to the growing point (meristem) of shoots and roots, thus reducing efficacy.

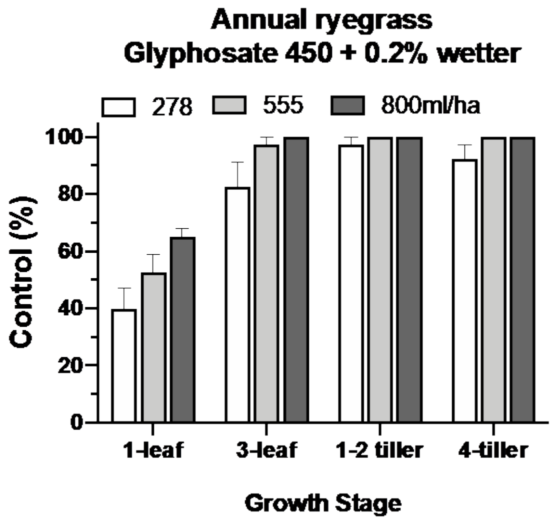

Figure 8. Effect of ryegrass growth stage on glyphosate activity

Double knock

A double knock strategy is defined as the sequential application of two weed control tactics directed at the same weed cohort (germination). The most common double knock strategy is glyphosate followed by paraquat. This has been widely adopted to prevent or combat glyphosate resistance in several weed species, including ryegrass. The first 'knock' with glyphosate controls the majority of the population, with the second 'knock' (paraquat) intended to kill any individuals that have survived glyphosate. Trial work conducted by Dr Christopher Preston (Figure 9) showed that control was optimised when the paraquat was applied 1-5 days after the glyphosate for two glyphosate resistant ryegrass populations. However optimal timing depends on weed size and growing conditions, with at least 3-5 days often being required for full glyphosate uptake and translocation, especially in larger plants. In this study, when the glyphosate resistant plants were left for 7 days before the paraquat application they can stress, resulting in the absorption of less paraquat, reducing control with the second tactic. If growing conditions are poor or plants large, the stress imposed by glyphosate maybe further delayed.

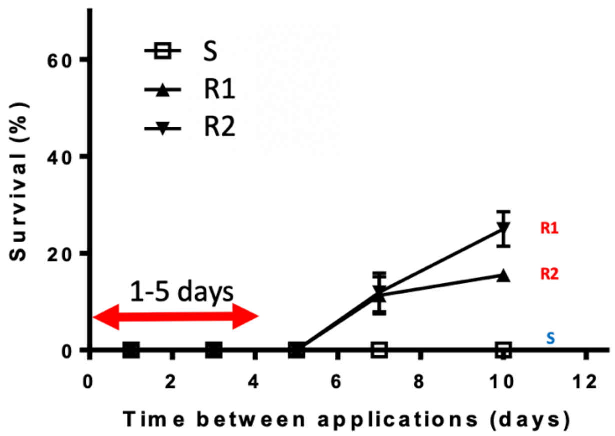

Figure 9. Double knock timing. Glyphosate applied onto a susceptible (S) and two glyphosate resistant ryegrass biotypes (R1 & R2) followed by paraquat 1, 3, 5, 7 and 10 DAA. Trial work conducted by Dr Christopher Preston (The University of Adelaide).

Summary

Ryegrass blowouts in 2020 were a result of large seedbanks, reduced weed control tactics and herbicide resistance. Using multiple tactics including new mode of action herbicides can improve ryegrass control. While paraquat resistance remains very low, glyphosate resistance in ryegrass is increasing at a rapid rate. The early break in autumn 2020 resulted in the testing of about 200 ryegrass populations prior to sowing with over half confirmed resistant to glyphosate. Decades of strong selection pressure resulting from repeated use coupled with application under suboptimum conditions has played a major role. More efficient use of glyphosate combined with effective IWM strategies is required to reduce further increases in resistance.

Acknowledgements

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Fitting new pre-emergent chemistries in the farming system and managing them for longevity

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Key words

pre-emergent herbicide, annual ryegrass, herbicide resistance, WeedSmart, Big Six

GRDC codes

UA00158, UQ00080, UWA00172

Take home message

- New pre-emergent herbicides are becoming available; however, it is vital that these are used appropriately to get the best results
- Choice of herbicide should consider soil type, seeding system, soil organic matter and likely rainfall after application
- Non-chemical tools such as crop competition, hay and harvest weed seed control are vital to protect the longevity of new and existing chemistry
- Ryegrass blowouts in 2020 will drive the adoption of WeedSmart Big 6 tactics to manage seedbanks over the medium to longer term.

Resistance to pre-emergent herbicides in south-eastern Australia

Pre-emergent herbicides have become more important for the control of grass weeds, particularly annual ryegrass, in the past decade as resistance to post-emergent herbicides has increased. Resistance to trifluralin is now common across many cropping regions of South Australia and Victoria, and is increasing in NSW. Worryingly, resistance to the Group J and K pre-emergent herbicides can also be detected in random weed surveys. In some parts of South Australia and Victoria, resistance to triallate is becoming common. It is likely resistance will further increase, making it more difficult to control annual ryegrass with the current suite of herbicides available. New pre-emergent herbicides offer an opportunity to expand the suite of products that can be rotated. However, it is important that these are used well to optimise performance while also maintaining their longevity.

New pre-emergent grass herbicides

Several new pre-emergent herbicides have recently been released or will be released in the next few years for grass weed control. The main characteristics of these herbicides are provided in Table 1. As with previous introductions of pre-emergent herbicides, it is important to understand their best use in different environments and farming systems. Some of these products will be new modes of action, which will provide an opportunity to manage weeds with resistance to existing herbicides. However, it will be important to rotate these new herbicide modes of action to delay resistance.

Table 1. Characteristics of new pre-emergent herbicides for grass weed control

Herbicide	Devrinol®-C	Luximax®	Overwatch®	Ultro®	Mateno® Complete[a]
Active ingredient	Napropamide	Cinmethylin	Bixlozone	Carbetamide	Aclonifen + pyroxasulfone + diflufenican
Mode of Action	K	T	Q	E	New + K + F
Solubility (mg L^{-1})	74	63	42	3270	1.4 (aclonifen) 3.5 (pyroxasulfone) 0.1 (diflufenican)
Binding K_{OC} (mL g^{-1})	839	6850	~400	89	7126 (aclonifen) 223 (pyroxasulfone) 5504 (diflufenican)
Crops	Canola	Wheat (not durum wheat)	Wheat Barley Canola	Pulses	Wheat

[a]Registration of Mateno Complete is expected in 2023

Devrinol-C is a Group K herbicide from UPL registered in 2019 for annual grass weed control in canola. Napropamide is not as water soluble as metazachlor (Butisan) and has less movement through the soil. Canola has much greater tolerance to napropamide compared to metazachlor, making it much safer under adverse conditions. Devrinol-C offers an alternative pre-emergent herbicide to propyzamide or trifluralin for canola.

Luximax is registered for annual ryegrass control in wheat, but not durum. It will provide some suppression of brome grass and wild oats. In our trials, control of ryegrass is as good as Sakura®. It has moderate water solubility and higher binding to organic matter in soils. It will move readily into the soil with rainfall events, but will be held up in soils with high organic matter. Persistence of Luximax is generally good, but it degrades sufficiently quickly that plant backs are 3 to 9 months. Wheat is not inherently tolerant of cinmethylin, so positional selectivity (keeping the herbicide and the crop seed separate) is important. Knife-points and press-wheels is the only safe seeding system and the crop seed needs to be sown 3 cm or deeper. Obtaining crop safety with Luximax will be challenging on light soils with low organic matter. Heavy rainfall after application can also see the herbicide move into the crop row and cause crop damage. Due to its behaviour, Luximax is not generally suitable for dry seeding conditions. Mixtures with trifluralin, triallate and prosulfocarb are good and can provide some additional ryegrass control; however, mixtures with Sakura, Boxer® Gold or Dual® Gold are likely to cause crop damage and need to be avoided.

Overwatch from FMC is a Group Q herbicide that should be available for 2021. Overwatch controls annual ryegrass and some broadleaf weeds and will be registered in wheat, barley and canola. Suppression of barley grass, brome grass and wild oats can occur. Wheat is most tolerant to bixlozone, followed by barley and then canola. The safest use pattern will be IBS with knife-points and press wheels to maximise positional selectivity, particularly with canola. Some bleaching of the emerging crop occurs often, but in our trials this has never resulted in yield loss. The behaviour of Overwatch in the soil appears to be similar to Sakura. It needs moisture to activate and has low to moderate water solubility. The level of ryegrass control in our trials has been just behind Sakura. Mixtures with other herbicides can increase control levels and in our trials in the high rainfall zones. The mixture of Overwatch plus Sakura has been very good.

Ultro from ADAMA is a Group E herbicide that will be available from 2021. Ultro will be registered for the control of annual ryegrass, barley grass and brome grass in all pulse crops. Chickpeas are the least tolerant pulse and rates are lower. Ultro provides the best control of annual ryegrass when used pre-emergent. Ultro has relatively high water solubility, so is more effective on weeds like brome grass that tend to bury themselves in the soil. Persistence of Ultro is shorter than Sakura. Knife-points and press-wheels are the preferred seeding system for IBS applications.

Mateno Complete from Bayer is likely to be available for 2023. It contains three modes of action including a new mode of action aclonifen. For ryegrass control, it will be similar to Sakura; however, it will provide more control of wild oats and brome grass and some broadleaf weed activity. It is planned to be registered for both IBS and early post-emergent use in wheat. The timing of the early post-emergent application will be similar to Boxer Gold, at the 1 to 2-leaf stage of annual ryegrass. It will require more rainfall after application than Boxer Gold does, so the post-emergent application will be more suited to higher rainfall regions.

New pre-emergent broadleaf weed herbicides

In addition to pre-emergent herbicides for grasses, there are also new pre-emergent herbicides for broadleaf weeds. The main characteristics of these herbicides are provided in Table 2.

Table 2. Characteristics of new pre-emergent herbicides for broadleaf weed control

Herbicide	Callisto®	Reflex®[a]	Voraxor®
Active ingredient	Mesotrione	Fomesafen	Trifludimoxazin + saflufenacil
Mode of Action	H	G	G
Solubility (mg L^{-1})	1500	50	1.8 (trifludimoxazin) 2100 (saflufenacil)
Binding K_{OC} (mL g^{-1})	122	50	~570 (trifludimoxazin) ~30 (saflufenacil)
Crops	Wheat Barley	Pulses	Wheat Barley

[a]Registration of Reflex is expected in 2021

Callisto is a pre-emergent Group H herbicide from Syngenta. It is registered in wheat and barley for use in IBS, knife-point press wheel seeding systems. It has strong activity on brassicas, legumes, capeweed and thistles. Wheat is more tolerant than barley and in both cases, positional selectivity is important for crop safety. Mesotrione has high water solubility and medium mobility in soils. High rainfall resulting in furrow wall collapse could result in crop damage. Callisto has moderate persistence with plant backs of only 9 months, provided 250 mm of rainfall has occurred. Callisto offers an alternative to post-emergent Group H herbicide mixtures, where early weed control is important.

Reflex is a Group G herbicide from Syngenta with expected registration in 2021. It will be registered pre-emergent and PSPE in pulse crops for control of broadleaf weeds; IBS only in lentils. It will have similar weed spectrum to Terrain®, but will likely provide better control of brassicas, sowthistle and prickly lettuce. Fomesafen has more water solubility than flumioxazin (Terrain), so will be more mobile in the soil. It does not bind tightly to organic matter. Lentils are the most sensitive pulse crop and separation of herbicide from the seed is important, particularly on light soils with low organic matter.

Voraxor, from BASF, contains the active ingredients trifludimoxazin and saflufenacil, which are both Group G herbicides. Voraxor provides broadleaf weed control and some annual ryegrass control as a pre-emergent herbicide in wheat, durum and barley. Voraxor is a little more mobile in the soil compared to Reflex and considerably more than Terrain. Voraxor will offer a broader spectrum of broadleaf weed control compared to Terrain and more annual ryegrass control. However, annual ryegrass control will not be as good as with current annual ryegrass pre-emergent standards. This means that it will be best used where broadleaf weeds are the main problem and annual ryegrass populations are very low. The mobility of the herbicide means crop damage may occur with heavy rainfall after application. This damage can be exacerbated if some grass pre-emergent herbicides are applied as a tank mix.

Mix and rotate in diverse farming systems

An expanded range of herbicides creates opportunities for the rotation of herbicide modes of action and the ability to mix with existing chemistry. Research by Pat Tranel from the University of Illinois, USA found that resistance can be mitigated by mixing herbicides at full rates. Pat is quoted saying ”rotating buys you time, mixing buys you shots”. Peter Newman from WeedSmart expanded on the concept to recommend that we mix herbicides and rotate modes of action so that we can ”buy time and shots”.

Research by Roberto Busi from AHRI found that rotating groups alone may not substantially delay resistance occuring. However *mixing* herbicide groups can be a highly effective tactic, even on resistant populations. Rygegrass from 140 fields across 58 farms in WA were tested for susceptibility to a range of pre- and post-emergent herbicides. The testing showed that a number of ryegrass populations were resistant to individual herbicides, for example 34% of the ryegrass populations were developing resistance to trifluralin and 11% developing resistance to triallate. Yet when these two herbicides were combined in a mix, full control was achieved.

For the other pre- and post-emergent mixtures that were tested: prosulfocarb + trifluralin, pyroxasulfone + trifluralin, triallate + trifluralin, prosulfocarb + trialliate, prosulfocarb + pyroxasulfone, triallate + pyroxasulfone and butroxydim + clethodim; there was consistently less resistance to the mixture, compared to the resistance levels of the individual herbicides when applied alone.

The mix and rotate strategy will not only provide improved weed control but more importantly aids in resistance management where unpredictable patterns of cross-resistance are evolving. Even the best pre-emergent herbicides can be broken by resistance if not managed wisely.

Populations of ryegrass from the Eyre Peninsula in South Australia have recently been confirmed as resistant to all of the pre-emergent herbicides – triallate (Avadex®), prosulfocarb (Arcade®), trifluralin, propyzamide and pyroxasulfone (Sakura). These findings by the University of Adelaide have huge implications for an industry now heavily dependent on pre-emergent herbicides in no-till systems, showing they can quickly break down in the face of metabolic cross-resistance.

Repeated applications of the same herbicides in simple canola-wheat rotations has allowed ryegrass to develop metabolic cross resistance. This is in the absence of alternative tactics such as croptopping, hay, harvest weed seed control or diverse rotations which create opportunities to run down the weed seedbank.

A heavy reliance on Groups J & K (eg Avadex®, Boxer Gold, Sakura) in no-till systems can be alleviated with the introduction of herbicides from Groups E, T and Q (eg Ultro, Luximax and Overwatch). The new chemistry used alone or in mixtures creates opportunities for targeting resistant weeds or managing resistance through alterntive use patterns.

The new Group E product Ultro (carbetamide) provides an alternative to trilflualin or propyzamide for pre-emergent grass weed control in pulses. Ultro will also reduce the heavy selection pressure on post emergent grass herbicides such as clethodim or clethodim + butroxydim (Factor) mixtures.

Crop rotation allows greater diversity with some of the new herbicide choices available. For example the new Group G product Reflex (fomesafen) has shown good control of broadleaf weeds such as sowthistle and prickly lettuce which are problematic in pulses. A heavy reliance on Imi chemistry in Clearfield® tolerant pulse crops has seen the development of resistance in brassica and thistle species. This new Group G product allows growers to relieve pressure on the Imi chemistry and strengthen the value of older herbicides such as simazine when used in a mixture.

Resistance stewardship – WeedSmart Big 6

As new chemistry becomes available it is crucial for all involved to protect the longevity of any new products and minimise the risk of resistance. The WeedSmart Big 6 brings together weed research data with grower experiences to create a set of practical guidelines focused on minimising the weed seedbank without compromising profit.

The WeedSmart Big 6:

1. rotate crops and pastures
2. double knock – to preserve glyphosate
3. test, mix and rotate herbicides
4. stop weed seed set
5. increase crop competition
6. adopt harvest weed seed control

Best practice agronomy is a key component of the Big 6 and pulls together all the aspects of profitable no-till cropping such as precision seeding, timely sowing, targeted nutrition, soil amelioration and crop competition so that crops have the edge over weeds. Tactics such as harvest weed seed control, cutting hay and diverse rotations are also essential to complement herbicide use including the mix and rotation of herbicides, double or triple knock and late season crop-topping.

Site specific applications such as shielded sprayers or optical spray technology are also effective at reducing herbicide inputs and introducing diverse chemistry. Application technology is now emerging as realistic option for controlling weeds and managing resistance. Optical spray technology is being developed for green on green scenarios where sensors detect weeds and activate the spraying of weeds only. Artificial intelligence and associated machine learning systems will reduce overall herbicide usage but also open up potential opportunities for high value chemistry or alternative site specific tools such as lasers.

Grower success in reducing weed seedbanks but staying profitable has been achieved through stacking Big 6 tactics over an extended period of time. For example, a diverse rotation with pulses, competitive barley and early sown hybrid canola combined with pre-emergent herbicides, opportunistic double knocks, croptopping and chaff decks has all the Big 6 tactics stacked together.

Harvest weed seed control – the mills are here

In 2020 the industry observed a surge in the adoption of weed seed impact mills for harvest weed seed control. Given a favourable season in the eastern states and moderate weed pressure, an increasing number of growers made the decision to invest between $60,000-$120,000 in one of the four impact mills available. These include the: Seed Terminator, iHSD – Harrington Seed Destructor, Redekop Seed Control Unit and Techfarm WeedHOG. With approximately 500 units now in use across Australia, growers are beginning to understand the strengths and weaknesses associated with the technology.

The objective of an impact mill is to grind, shear and crush the weed seeds contained in the chaff fraction of harvest residue. The objective is to get as many weed seeds into the header in order for the mill to destroy the viability of seed and reduce the seedbank. On average, a harvester cutting low can capture 70% of the seeds prior to shedding or lodging and then destroy 98-99% of these weed seeds that enter the header. Overall the feedback has been positive especially those committed to making the system work over the long term, but a number of growers expressed concern with several issues. This included exorbitant running costs, mill wear, belt alignment and excessive heating, fuel use and loss of capacity. In a big season such as 2020 where crop yields were generally above average, the power requirements to harvest the crop are already significant, and a mill then adds more load on the machine. This in turn reduced operator output and subsequently increased costs which was frustrating during a wet harvest.

Not every harvest will be as slow and challenging as 2020 and all impact mill owners are encouraged to assess the true cost of the machine over a number of seasons. All systems involve compromise and the processing of weed seeds with an impact mill is no different. Working with the mill manufacturer and local dealer to review the strengths and weaknesses of the unit, and then following up in the paddock to see how well the machine worked is vital. Harvest weed seed control is a part of a long term commitment to controlling weeds. Like herbicides it requires ongoing learning and attention to detail to achieve success.

Summary

New chemistry is providing opportuntites for growers to manage resistant weeds using a broad range of herbicides. In order to protect these new products, the industry needs to continue working together to ensure farming practices include both chemical and cultural weed control options to keep seedbanks low and minimise the risk of resistance.

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Amelioration of hostile subsoils via incorporation of organic and inorganic amendments and subsequent changes in soil properties, crop water use and improved yield, in a medium rainfall zone of south-eastern Australia

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Key words

dispersive alkaline subsoils, amendments, soil pH, exchangeable sodium percentage, root growth, grain yield

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DAV00149 & UA00159

Take home messages

- Deep placement of organic and inorganic amendments increased grain yield in the order of 20 to 50% for four successive years on an alkaline dispersive subsoil at Rand
- Deep placement of organic and inorganic amendments increased root growth, and crop water use from the deeper clay layers during the critical reproductive stages of crop development
- Improvements in grain yield with deep placement of organic and inorganic amendments were associated with a reduction in subsoil pH and improvement in soil aggregation
- Genotypic variability in grain yield response of wheat cultivars grown on alkaline dispersive subsoils has identified varieties and associated traits for enhanced performance and future breeding.

Background

Sodicity, salinity and acidity are significant surface and subsoil constraints that reduce crop productivity throughout the cropping regions of Australia (Sale et al., 2021). The majority of cropping soils contain at minimum one, but more multiple constraints (McDonald et al., 2013). The economic impact to Australian agriculture, expressed by the 'yield gap' between actual and potential yield, attributable to subsoil constraints was estimated to be more than A$1.3 billion annually by Rengasamy (2002), and as much A$2.8 billion by Hajkowicz and Young (2005). Of the 'three', sodicity is thought to be the most detrimental to productivity, resulting in the greatest yield gap. In Australian wheat-cropping regions alone, this 'gap' was estimated to be worth A$1.3 billion per annum in lost income (Orton et al., 2018), while close to 20% of Australia's land area is thought to be sodic.

Sodic soils, which are characterised by an excess of sodium (Na^+) ions, and classified as those with an exchangeable sodium percentage (ESP) greater than 6% (Northcote and Skene, 1972), are often poorly structured, have a high clay content, high bulk density, and are dispersive. These factors result in poor subsoil structure that can impede drainage, promote waterlogging (low water infiltration), and increase de-nitrification (nutrient imbalance), and soil strength (Orton et al., 2018). These properties also impede the infiltration of water into and within the soil, reduce water and nutrient storage capacity, and ultimately the plant available water (PAW) content of the soil. Subsequently, root growth and rooting depth are impeded, as is crop ability to access and extract deeper stored water and nutrients (Passioura and Angus, 2010). Thisis particularly problematic in environments characterised by a dry spring, where the reproductive phase often coincides with periods of water stress, and when the conversion of water to grain has the greatest effect both on yield (Kirkegaard et al., 2007), and the likelihood and magnitude of a yield gap (Adcock et al., 2007).

In southern NSW, winter crops commonly have sufficient water supply either from stored soil water or rainfall during the early growth stages. However, the reproductive phase is often affected by water stress or terminal drought and this is thought to be the major cause of variable grain yield (Farooq et al., 2014). The effect of water stress in the reproductive phase is further impacted by shallow root depth induced by subsoil sodicity. Under such conditions, a key to improving crop productivity is to improve root growth in and through sodic subsoils to enable use of deep subsoil water later in the growing season. Water use at this late stage has a 2 to 3 fold greater conversion efficiency into grain yield (Kirkegaard et al., 2007) than seasonal average based conversions efficiencies (e.g. 20 – 25 kg/mm verses 50 – 60 kg/mm).

While there are large advantages to be gained by improving the soil environment of sodic subsoils, the various amelioration approaches (deep ripping, subsoil manuring, applying gypsum, improved nutrition and use of ‘primer-crops’) have produced variable results (Adcock et al., 2007; Gill et al., 2008). Furthermore the use of subsoil organic material is also impacted by limited local availability, the high cost of suitable organic ameliorants delivered in-paddock, the sometimes large quantities required, the lack of suitable commercial-scale machinery and the poor predictability of when and where the amelioration will benefit crop productivity (Gill et al., 2008; Sale et al., 2019).

Gypsum application has been the most widespread traditional approach used to correct subsoil sodicity. However, problems have included; surface application when the problem is evident in the subsoil, the large quantities of gypsum required to displace significant amounts of sodium and the somewhat low solubility of gypsum.

Genetic improvement is also frequently advocated as an avenue for improving crop productivity and adaptation under different hostile soil conditions (McDonald et al., 2012; Nuttall et al., 2010). Little is known about genetic variation for tolerance of subsoil constraints and how they relate to different plant traits such as elemental toxicity tolerance, canopy cover, rooting depth and harvest index and the integration of these factors in yield response of different genotypes. This limited knowledge is also due to the practical difficulties in measuring dynamic and variable soil constraints under field conditions.

This paper reports on the performance of a barley-wheat-canola-wheat rotation on a Sodosol (Isbell, 2002) soil at a site in the Riverina town of Rand in southern New South Wales in the four years immediately following incorporation of a range of subsoil amendments, and the residual effects of ‘subsoil manuring’ on crop performance, soil physical properties, and access to PAW stored in the soil profile over subsequent seasons. A range of treatments comprising deep-ripping and subsoil incorporation of organic and inorganic amendments at a depth of 20–40cm were compared to, and contrasted with, surface applications, ripping-only and untreated controls. Amendments that could be easily procured or produced as part of a farming system were used in the trial. It is hypothesised that subsoil incorporation of organic or inorganic amendments will provide significant improvements in grain yield, which are associated with changes in the physical properties of the subsoil that result in improved root growth, and access to, and use of, deep soil water.

Method

Rand amendment site

The trial site was located at Rand, in the Riverina region of southern New South Wales in a paddock that had been under a continuous cropping (cereal-canola) for more than 50 years. The soil was a Sodosol with a texture-contrast profile increasing in clay content at depth, and with physical and chemical properties (Table 1.) unfavourable for root growth, including a high bulk density and low hydraulic conductivity.

Table 1. Chemical and physical properties of the soils at different depths at the trial site.

Depth (cm)	pH (H_20)	EC (1:5) (µS/cm)	Nitrate N (mg/kg)	Exchangeable cations (cmol/kg)	Exchangeable sodium percentage (%)	Bulk density (g/cm^3)	Volumetric water content (θv)
0–10	6.6	132.1	20.6	16.1	3.8	1.40	0.120
10–20	7.8	104.0	5.8	22.6	7.3	1.52	0.163
20–40	9.0	201.5	4.1	26.7	12.5	1.50	0.196
40–50	9.4	300.5	3.0	27.5	18.1	1.48	0.232
50–60	9.5	401.3	3.0	28.8	21.8	1.53	0.237
60–100	9.4	645.0	2.9	29.7	26.4	1.55	0.218

The trial was established in February 2017 as a randomized complete block with 13 treatments (Table 2) and four replicates. Experimental plots were arranged in two blocks (ranges) of 26 plots, separated by a 36m cropped buffer. Individual plots within each block were 2.5m wide (South-North) × 20m long (East-West), separated on their long sides by 2m buffers of uncultivated ground. Plots were ripped to a depth of 40cm, and amendments incorporated into the soil via a custom built 3-D ripping machine (NSW DPI), comprising a “Jack” GM77-04 5-tyne ripper (Grizzly Engineering Pty Ltd, Swan Hill, VIC, Australia), configured to 500mm tyne spacings, and topped with a custom designed frame supporting two purpose built discharge hoppers (bins) and a 300L liquid cartage tank. The larger, ~1.6 cubic meter-capacity hopper was designed to deliver organic materials, and can accommodate approximately 1000 kg of material, roughly equivalent to a standard ‘spout top, spout bottom’ bulk bag. The organic amendments were obtained in pellet form for ease of application and consisted of dried pea straw pellets (1.13% N, 0.05% P, 1.34% K; extrusion diam. 7–10mm, length 6–35mm), wheat stubble pellets (0.34% N, 0.15% P, 1.59% K; diam. 7–10mm, length 6–35mm), and dried poultry manure pellets marketed as Dynamic Lifter® (3% N, 2% P, 1.7% K; diam. 7–10mm, length 6–35mm). The amendments were applied three months prior to sowing the first season.

In 2017, experimental plots were sown to Barley (cv. LaTrobe⦇) on the 11th of May at a seeding rate of 70 kg/ha (target plant density 100 plants/m^2). Monoammonium phosphate (MAP) was applied at 80 kg/ha as a starter fertiliser at sowing. The crop was sown after spraying with Boxer Gold® (800 g/L prosulfocarb + 120 g/L S-metolachlor), Spray.Seed® (135 g/L paraquat dichloride + 115 g/L diquat dibromide) and Treflan® (480 g/L trifluralin). The crop was harvested on the 21st of November.

In 2018, Wheat (cv. Lancer⦇) was sown on the 15th of May at a seeding rate of 80 kg/ha (target plant density 150 plants/m^2). MAP was applied at 80 kg/ha as a starter fertiliser at the time of sowing. The crop was sown after spraying with Spray.Seed, Sakura® (850 g/kg pyroxasulfone), Logran® (750 g/kg triasulfuron) and Treflan. Urea (46% N) at 110 kg/ha (50.6 kg/ha N) was applied at 106 DAS. The crop was harvested on the 6th of December.

In 2019, Canola (Pioneer® 45Y92CL) was sown on the 10th of April at a seeding rate of 4.4kg/ha (target plant density 40 plants/m^2). MAP was applied at 90 kg/ha (9 kg/ha N, 19.8 kg/ha P) as a starter fertiliser at the time of sowing. The crop was sown after spraying with a knockdown mixture of herbicides. Urea at 220 kg/ha (101.2 kg/ha N) was applied as a top-dressing at 119 DAS, and Prosaro® (210 g/L prothioconazole + 210 g/L tebuconazole) at 50% bloom as a preventative for Sclerotinia stem rot (132 DAS). The crop was harvested on the 30th of October.

In 2020, wheat (cv. Scepter) was sown on the 16th of May at a seeding rate of 63 kg/ha (target plant density of 120 plants/m^2). Diammonium phosphate (DAP) was applied at 78 kg/ha as a starter fertiliser at the time of sowing. The crop was sown after spraying with Spray.Seed, Roundup, Sakura and Treflan. Urea at 150 kg/ha (69 kg/ha N) was applied as a top-dressing 7 DAS prior to rain. The crop was harvested on the 7th of December.

The long-term average annual rainfall at the site is 553mm with a reasonably uniform average monthly rainfall. In 2017, in-season rainfall (April-November) totalled 329mm, while 244mm and 242mm, respectively, were recorded for the same period in 2018 and 2019. Rainfall in both 2018 and 2019 was approximately 25% less than that recorded for 2017, and approximately 65% of the long-term average seasonal rainfall. The long-term average monthly rainfall, and average monthly maximum and minimum temperatures, daily (bars) rainfall events and monthly rainfall at the Rand experimental site for the period 2017–2020 (Figure 1).

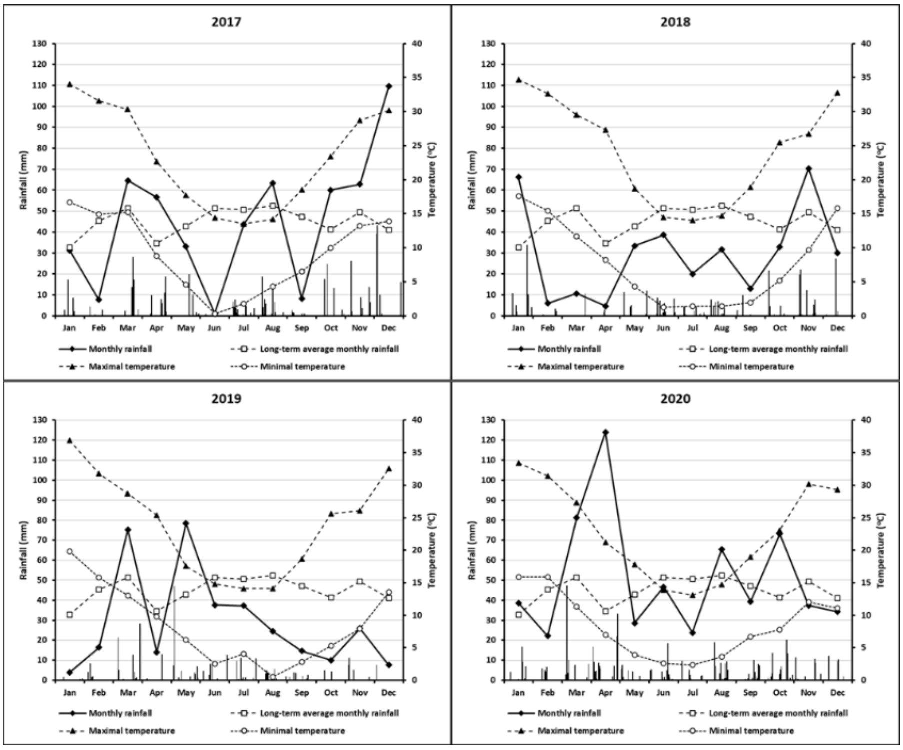

Figure 1. Long-term average monthly rainfall, and average monthly maximum and minimum temperatures, daily (bars) rainfall events and monthly rainfall at the Rand experimental site located at Urangeline East, NSW.

Table 2. Description of the treatments and organic and inorganic amendments used in the trial.

Treatment	Description	Amount of amendment added
1	Control	Direct sowing
2	Deep gypsum	5 t/ha, incorporated to depth of 20-40 cm
3	Deep liquid NPK	Incorporated to depth of 20-40 cm, N to match chicken manure
4	Deep chicken manure	8 t/ha, incorporated to depth of 20-40 cm
5	Deep pea straw	15 t/ha, incorporated to depth of 20-40 cm
6	Deep pea straw +gypsum+NPK	12 t/ha, 2.5 t/ha, incorporated to depth of 20-40 cm,
7	Deep pea straw+NPK	15 t/ha, incorporated to depth of 20-40 cm
8	Deep wheat stubble	15 t/ha, incorporated to depth of 20-40 cm
9	Deep wheat stubble +NPK	15 t/ha, incorporated to depth of 20-40 cm
10	Ripping only	To depth of 40cm
11	Surface gypsum	5 t/ha, applied at soil surface
12	Surface chicken manure	8 t/ha, applied at soil surface
13	Surface pea straw	15 t/ha, applied at soil surface

At late flowering soil coring was completed using a tractor-mounted hydraulic soil-coring rig and 45 mm diameter soil cores. The break core method was used to estimate rooting depth and exposed roots were recorded at the following depths 0 - 10, 10 - 20, 20 - 40, 40 - 60, and 60 – 100 cm. Quadrat samples of $2m^2$ were taken at physiological maturity to measure plant biomass and grain yield.

Grogan genotypes screening experiment

In 2019 an experiment was conducted near the township of Grogan in southern NSW, which included 17 commercial wheat genotypes in a row column design with four replicates. The soil profile was slightly acidic in the top 10cm ($pH_{1:5\ water}$ 5.9) and pH dramatically increases with depth (Table 1). The changes in soil sodicity (exchangeable sodium percentage, ESP) followed a similar trend of soil pH with ESP at 10.5% in the topsoil and increasing up to 40% in the subsoil (Table 1).

Table 3. Site characterisation for the Grogan experimental site. Values are means (n=5).

Soil depths (cm)	EC (µs/cm)	pH (1:5 water)	Colwell-P (µg/g)	CEC (cmol(+)/kg)	Exchangeable sodium percentage
0-10	309.40	5.87	58.80	16.66	10.53
10-20	133.00	7.65	7.40	22.06	11.97
20-30	136.90	8.76	2.62	24.53	15.94
30-40	207.66	9.12	2.50	25.55	20.12
40-60	338.94	9.60	1.34	27.17	26.27
60-80	530.40	9.53	1.00	31.63	36.68
80-100	897.20	9.43	1.48	34.07	40.25
100-120	1148.20	9.38	1.50	35.28	40.35

The experiment was sown on 17 May 2019 using a direct sown drill with DBS tynes spaced at 25cm. At sowing 90 kg MAP (20kg P/ha and 9kg N/ha) was drilled in all plots and 75 kg N/ha was surface applied just prior to stem elongation. Mean plant density as measured by seedling counts at four weeks after sowing was 116 ± 1.6 (mean ± SE of 68 plots) plants m^{-2}. At different growth stages multispectral images (MicaSense RedEdge-MX) were collected using drone technology to determine different vegetation indices such as normalised differences in vegetation index (NDVI) and leaf chlorophyll index (LCI) as a surrogate of canopy attributes and plant physiological processes (Liu et al., 2019; Satir and Berberoglu, 2016; Zhang et al., 2019). Quadrat samples of $1m^2$ area were taken at physiological maturity to measure plant biomass and grain yield. Harvest index was calculated as grain yield divided by biomass.

Results

Rand amendment trial

The one-off application of various amendments (Table 2) significantly affected the crop grain yield over 4 consecutive years. For example, in 2020, wheat grain yield (relative to control) increased following the deep placement of wheat stubble, wheat stubble + nutrient and gypsum by 21%, 20 and 18% respectively ($P < 0.001$) (Figure 2). The variations in yield in response to surface application of amendments or ripping only was not significantly different from the control. A multi-year cumulative analysis of grain yield response (2017-2020) indicated that deep placement of plant-based stubble, gypsum and their combination resulted in significant and consistent improvements in crop yield (Table 4). A preliminary cumulative gross return is also presented in Table 4.

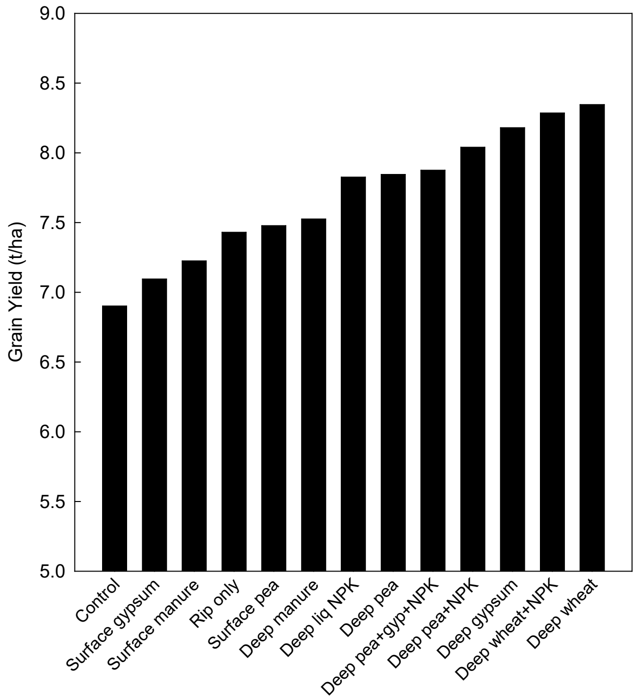

Figure 2. The mean effect of surface or deep-placed amendments on grain yield of wheat (cv. Scepter⁽ᴰ⁾) grown in an alkaline dispersive subsoil in Rand, SNSW in 2020. Values are mean (n=4). $LSD_{0.05}$ = 0.67.

Table 4. Cumulative grain yield (2017-2020) and cumulative gross return ($) for barley (2017; $220/t), wheat (2018; $250/t), canola (2019; $600/t) and wheat (2020; $250/t) at Rand.

Treat	Yield (t/ha)		$	
Control	15.3	a	4517	a
Surface gypsum	15.5	a	4576	a
Rip only	15.9	ab	4737	ab
Surface pea	16.00	ab	4817	ab
Deep liq NPK	17.1	bc	4847	ab
Surface manure	17.1	bc	5104	bc
Deep wheat	18.2	cd	5388	cd
Deep manure	18.3	cd	5428	cd
Deep pea+NPK	18.4	cd	5557	d
Deep wheat+NPK	18.5	d	5383	cd
Deep pea	18.7	d	5507	d
Deep gypsum	18.9	d	5684	d
Deep pea+gyp+NPK	19.4	d	5699	d

Over the course of this study several key measurements of soil and crop parameters were made to investigate the impact of various amendments on soil:plant interactions.

The number of visible roots in the amended subsoil layer (20 – 40cm depth) were significantly (P < 0.05) affected by different amendments (Figure 3). Deep placement of both manure and pea hay increased the number of visible roots by more than 3-fold. Neutron probe readings taken in September also indicate that the highest root counts were associated with the driest soil water profile (Figure 4). Variation in soil pH measured at the amended layer is shown in Table 5. Compared to the control, deep placement of gypsum reduced the soil pH by 0.86 units (8.99 to 8.13) at 20 – 40cm depth. However, pH was not affected by other treatments.

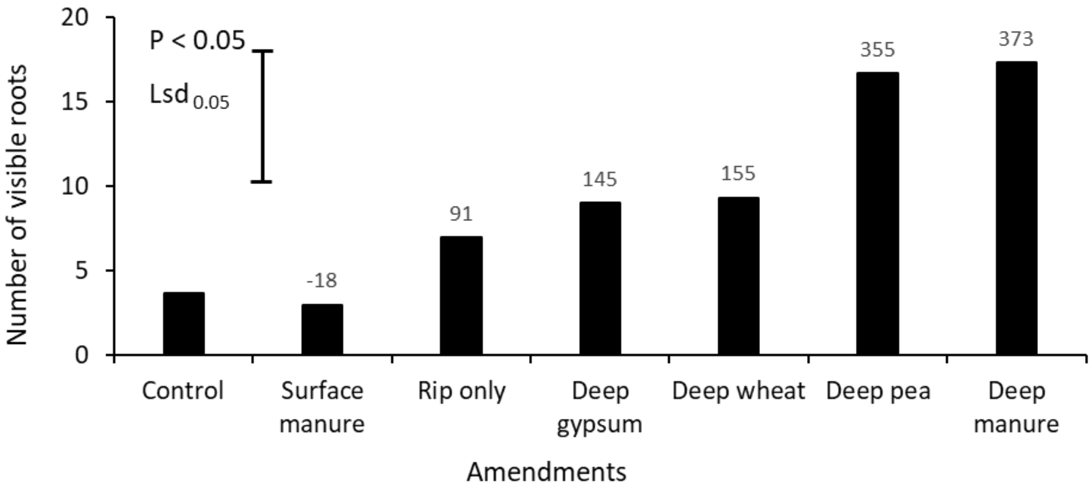

Figure 3. The mean effect of surface or deep-placed amendments on the number of visible roots at 30cm at late flowering of canola (cv. Pioneer® 45Y91CL) grown in alkaline dispersive subsoil in Rand, SNSW in 2019. Values on the top of each bar is representing percent change of visible roots compared to control.

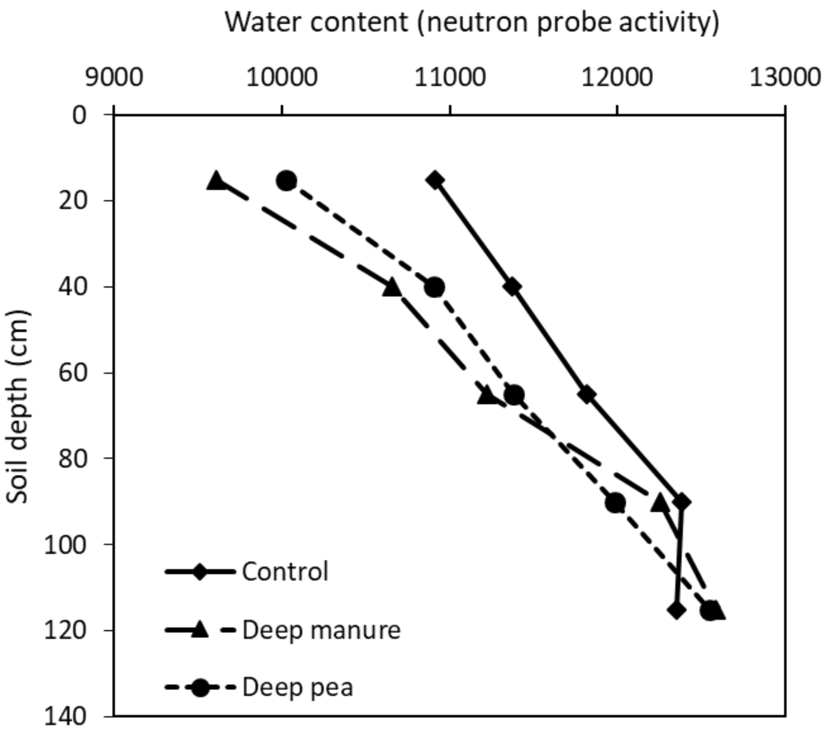

Figure 4. Neutron probe readings taken in September at the Rand amendment site for contrasting treatment comparisons. Results are based on the neutron activity (raw data) where higher values represent higher water content in the soil profile. Values are averages (n = 4).

Table 5. The changes in soil pH (20-40 cm) in selected treatments at the Rand site. Samples were collected in May 2020. $LSD_{0.05} = 0.27$.

Amendment	Predicted mean	Group
Control	8.99	a
Deep liq NPK	8.96	a
Rip only	8.94	a
Deep wheat+NPK	8.93	ab
Surface gypsum	8.92	ab
Deep pea	8.87	ab
Deep wheat	8.83	ab
Deep manure	8.60	bc
Deep pea+gyp+NPK	8.52	c
Deep gypsum	8.13	d

Grogan genotypes screening trial

Significant ($P < 0.001$) genotypic variation occurred in grain yield among the genotypes and ranged from only 0.57 t/ha (Gregory⦇) to 2.0 t/ha (Scepter⦇, Emu Rock⦇ and Mace⦇; Figure 5). Biomass at final harvest did not significantly differ among the genotypes (data not shown; $P = 0.11$) and there was no significant ($P = 0.09$) correlation between grain yield and biomass at final harvest (Figure 6).

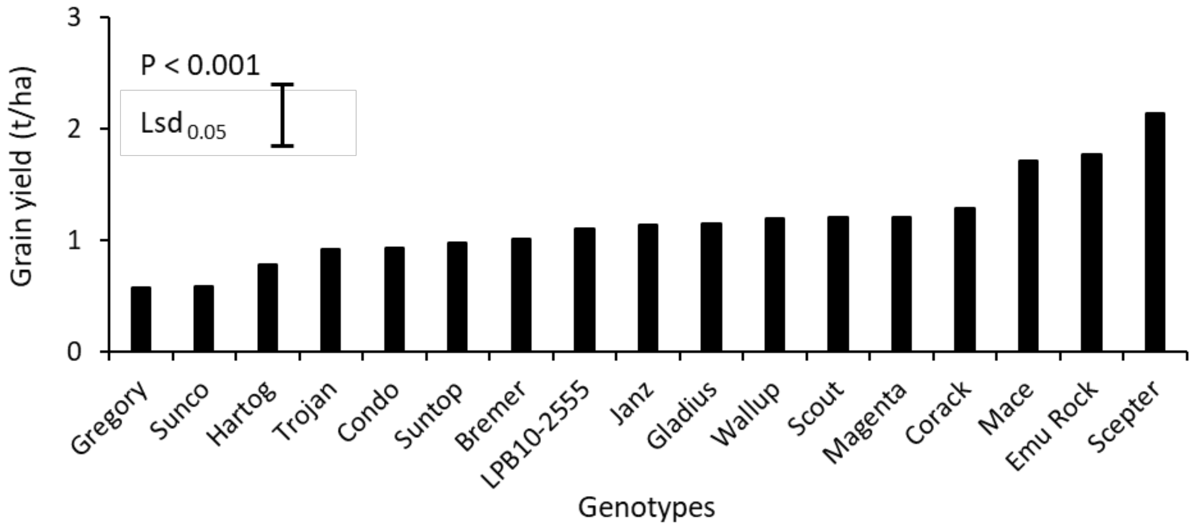

Figure 5. Variations in grain yield of 17 wheat genotypes grown in alkaline sodic dispersive subsoil in Grogan, SNSW in 2019. Each data point is mean values of n = 4.
(Varieties Gregory, Trojan, Condo, Suntop, Bremer, Gladius, Wallup, Scout, Magenta, Corack, Mace, Emu Rock and Scepter are protected under the Plant Breeders Rights Act 1994)

Significant variation was observed in harvest index (data not shown; $P < 0.001$), which ranged from 0.08 (Gregory⦇) to 0.26 (Scepter⦇). A significant ($P < 0.001$) and positive correlation between harvest index and grain yield is observed among the studied genotypes (Figure 6).

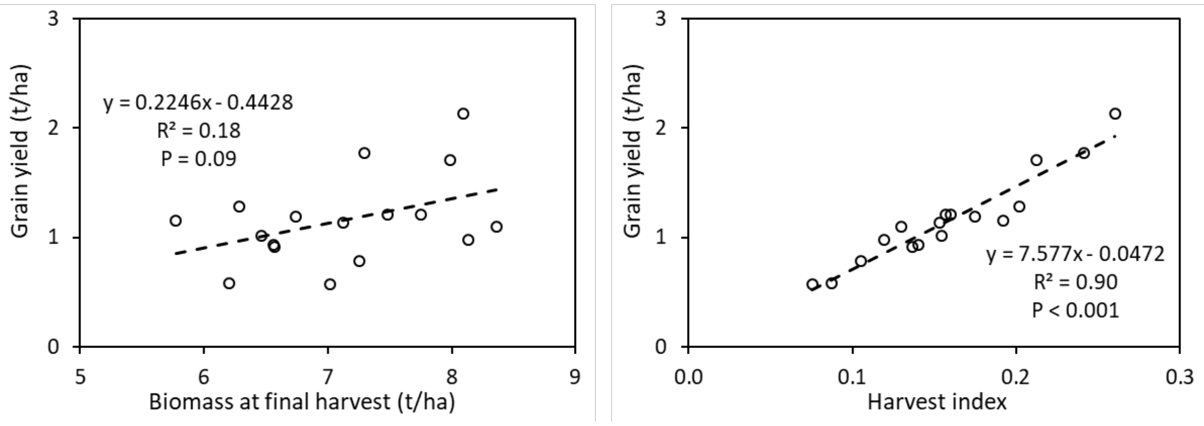

Figure 6. Linear regressions between grain yield and biomass at final harvest (left) and harvest index (right) of 17 wheat genotypes grown in alkaline sodic dispersive subsoil at Grogan, SNSW in 2019.

All the non-destructive vegetation indices, i.e. NDVI ($P < 0.01$), NDRE ($P < 0.001$) and LCI ($P < 0.001$) measured at stem elongation showed significant and positive correlation with biomass at anthesis (Figure 7).

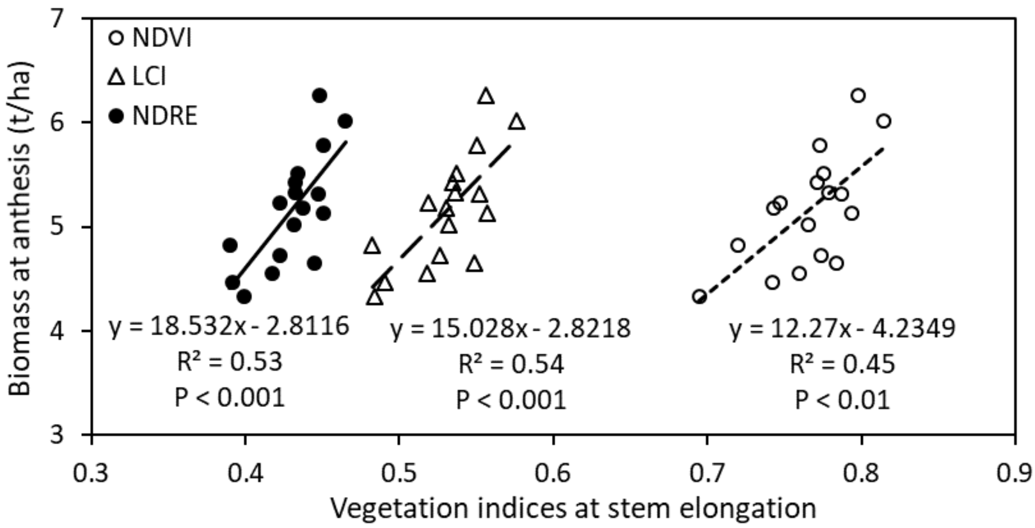

Figure 7. Linear regressions between vegetation indices (measured at stem-elongation) and anthesis biomass of 17 wheat genotypes grown in alkaline sodic dispersive subsoil at Grogan, SNSW in 2019. NDVI = normalised differences in vegetation index; LCI = Leaf chlorophyll index; NDRE = Normalised difference red edge.

Discussion

In Alkaline dispersive soils, several properties of subsoils including, high pH, high levels of soluble carbonate species, poorly structured dense clay, and dispersion together with overall poor chemical fertility, represent a hostile environment for crop roots. Here we demonstrate the impact of various amendments on these properties and the potential to re-engineer these hostile subsoils for improved crop performance.

Barley, wheat, canola and wheat were grown in 2017–2020, respectively, under increasingly dry conditions. Growing season rainfall (April to November total) was average in 2017 (decile 5), and declined in 2018 (decile 1.5), with still drier conditions in 2019 (decile 1.0), when only 45 mm of rain (decile 0) fell during the spring months from September to November. This improved in 2020 where the trial received 401 mm during growing the season. The amendments that consistently resulted in significant yield increases above the control, were the deep-placed combination of pea straw pellets, gypsum and liquid fertilizer nutrients, and the deep-placed gypsum and deep placed pea straw (Table 4). Improvements in subsoil structure were measured in the winter of 2019. The deep crop residue amendments significantly increased macro aggregation, as measured on the rip-line at a depth of 20-40 cm. Similarly, deep gypsum and the deep gypsum/pea straw/nutrient combination markedly increased water infiltration into the soil profile, with higher saturated hydraulic conductivities measured on the rip-line. Our results to date indicate that independent modes of action of various amendments (e.g. crop residue vs gypsum) are required in the amendment mix, in order to ameliorate these subsoils. For example, adding gypsum reduced pH in the amended subsoil to below 8.5 (Table 5). This indicates that significant changes in soil pH can occur with realistic application rates of gypsum in subsoil. Given high alkalinity also increases negative charges on the surfaces of clay particles (Rengasamy et al., 2016), which increases clay dispersion, a reduction in pH following gypsum application also resulted in significant improvement (reduction) in soil dispersion (Tavakkoli et al., 2015). In alkaline sodic soils, high ESP and high pH are always linked together and it is difficult to apportion their effects on the resulting poor soil physicochemical conditions and consequently on crop growth.

The addition of pea straw and nutrients provides substrate for enhanced biological activity resulting in increased macro aggregation and improved subsoil structure. When combined together, organic and inorganic amendments may result in additive effects to improve soil physical and chemical properties (Fang et al., 2020a; Fang et al., 2020b).

In a year of intensive drought like 2019, the grain yield improvements at Rand may be attributed to the additional root growth in the amended subsoil layer (Figure 3), which facilitated the use of extra subsoil water (Tavakkoli et al., 2019 and Figure 4). Under dryland conditions, water captured by roots in the subsoil layer is extremely valuable as its availability coincides with the grain filling period and has a very high conversion efficiency into grain yield (Kirkegaard et al., 2007; Wasson et al., 2012). A major focus of this current research is to understand the amelioration processes of the subsoil application of organic and inorganic amendments. A tentative, but promising, finding from our field and controlled environment trials, is that farm grown products like wheat and pea stubbles when mixed with nutrients improve soil aggregation, root growth, water extraction and grain yield and these treatments are comparable to animal manures and gypsum. If confirmed, this means that grain growers have a potentially large supply of relatively inexpensive organic ameliorants already available in their paddocks, which will increase the application options and viability of correcting subsoil sodicity.

Despite, demonstrating significant improvement in grain yield with subsoil incorporation of organic and inorganic amendments, the widespread adoption of these practices are still limited by their cost effectiveness. Identifying traits associated with the superior tolerance to different soil constraints may be a low cost technique to tackle this issue (McDonald et al., 2012). Given the intensive drought condition in the study year, considerable genotypic variation was observed with some varieties having 3- fold higher grain yield than other varieties. Based on controlled-environment studies, the high yielding varieties at Grogan, 'Mace⁽ᴾ⁾ and Emu Rock⁽ᴾ⁾,' are moderately tolerant to tolerant to high pH and have roots that can grow relatively well through soils of high bulk density, whereas low yielding varieties such as Gregory⁽ᴾ⁾, Hartog and Sunco, are more sensitive to one or both of these stresses. The very low harvest index in the trial suggests that there was severe stress around flowering to reduce grain set, as well as during grain filling. Results suggest that the ability to maintain root growth hay have helped to alleviate stress in varieties like Emu Rock⁽ᴾ⁾ and Mace⁽ᴾ⁾. Furthermore, different traits associated with this greater yield performance of wheat genotypes are crucial aspects of future breeding programs.

Conclusions

The findings from the current field studies demonstrate initial but promising results of ameliorating alkaline dispersive subsoils in medium and high rainfall zones of southern NSW. Deep placement of organic and inorganic amendments resulted in significant yield improvement in four successive years at Rand where subsoil water was present. This yield improvement was facilitated by a reduction in soil pH and ESP% and increased microbial activity that can lead to improved soil aggregation. Furthermore, deep placement of organic and inorganic amendments increased root growth, which in turn increased soil water use from the deeper clay layers during the critical reproductive stages of crop development, thereby increasing grain yield. In addition to soil management, genotypic variability in grain yield of wheat cultivars observed and their associated traits identified in the current study can be used for improving wheat germplasm through future breeding programs.

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On farm financial implications of research into varieties and deep soil amelioration

Peter and Hazel McInerney, 3D-Ag, Wagga Wagga

Keywords

cost benefit, varieties, deep-soil-amelioration

Take home messages

- Know what is happening to depth, in the soil under your feet
- Grow varieties adapted to the soil type and landscape
- Deep placement of ameliorants has good potential to significantly improve yield and therefore revenue in tough seasons
- Deep placement of ameliorants is very likely to be commercially viable on responsive soils.

Introduction

This paper should be read in conjunction with the research papers produced from GRDC projects DAV00149 & UA00159.

The purpose of this paper is to examine those results for the financial implications to the farmer of two aspects of the above projects, with reference to the farm at Rand hosting the trial site regarding: 1 varietal choice specific to soil type; 2 the potential of deep soil amendment.

With the ever-present cost price squeeze and land prices increasing rapidly, all things that might improve productivity and returns need to be examined carefully in terms of a specific farm and circumstances. Any activity that improves soil condition and resilience can help mitigate production and therefore business risk, leading to more capacity to deal with seasonal volatility. For example; being able to sustain profit even in tough years is a measure of a sustainable farm business.

Varietal screening trial results are a readily available means for farmers to help identify potentially superior varieties to test on their own farms against currently used varieties. Buying the most appropriate variety is a very low cost means of improving potential outcomes.

Deep placement of ameliorants is an emerging technology where the financial implications could have great relevance to farm businesses going forward.

These aspects are ultimately reviewed from the broader farm perspective.

Background

From 2015 to 2017 Dr Tavakkoli and associates conducted a variety screening trial (GRDC project UA00159) at Rand. From 2017 to 2020 this same site hosted the deep soil amelioration experiments (GRDC project DAV00149). Data from these trials is reviewed below and examined in terms of the financial implications to the farmer regarding variety choice and the potential of deep soil amelioration.

On the farm where the trial site is located, the farmer/co-operator has invested in understanding his soil by having the entire property zoned and soil sampled to depth to identify areas most in need of remediation. The soil is sodic with dispersion issues from the surface to depth. In the past, gypsum, lime and animal manures have been applied to improve surface conditions.

Until recently little could be done to address issues deeper (>15cm) in the soil, however this research and the construction of a machine capable of the deep placement of ameliorants will see the research tested at paddock scale in 2021.

Discussion

1. Varietal choice

Variety screening for acid soil tolerance has been routine for over 40 years with the very successful variety Dollarbird, followed by Diamond bird released in the 1980's, with other varieties since. No such program existed for sodic or alkaline subsoils, which occupy a large area of the southern wheat belt. McDonald (2012) was among those suggesting that some varieties might possess genetic traits that were more tolerant of hostile subsoil. In 2015 Project UA00159 began with a site at Rand, NSW, and others subsequently.

The trial at Rand showed spectacular results, with the variety Mace⦶ averaging 5.5 t/ha over the three years, almost 0.75 t/ha more than any other variety (Tavakkoli E., pers.comm.). In 2018 AGT donated 1.0 tonne of Scepter⦶ (variety A in Figure 1), a new variety of a genetically similar line to Mace⦶ for the farmer to try as a commercial comparison. One tonne of Beckom⦶ (variety B in Figure 1) was purchased to include in the comparison.

Both varieties performed well and were incorporated in the farm program in 2019. Figure 1 shows the results achieved in 2019 and 2020. In the very dry 2019 season Scepter⦶ was harvested, while the Beckom⦶ was 'salvaged' as silage and hay. Given the season, both varieties were successful in producing revenue for the business. In 2020 both varieties again did well, although Scepter⦶ is clearly well ahead and much more profitable at the Rand site. While Scepter⦶ out-performed Beckom⦶ *at this site,* Beckom⦶ is still an excellent variety.

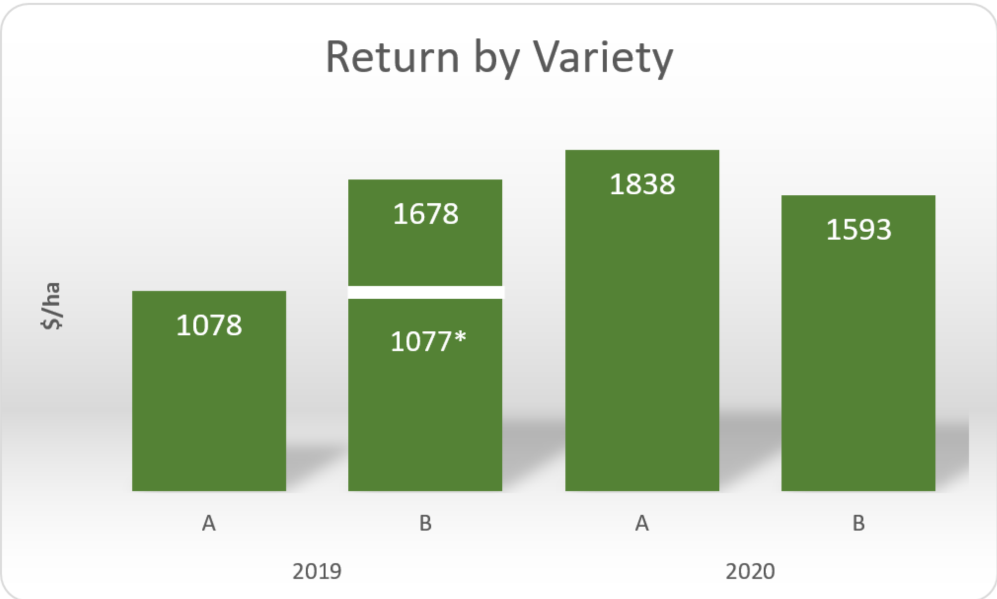

Figure 1. Return by variety 2019-20 (Variety A = Scepter⦶, Variety B = Beckom⦶)

**Note: The return of Variety B in 2019 after deduction of contracting costs for silage and hay making and the estimated loss of nutrients by product removal is reduced from $1678 to $1077/ha.*

Making the most of available information, plus small scale on farm comparative trials to identify superior varieties is an obvious and low cost means of optimising productive potential and profit.

2. Deep soil amendments

Out of twelve different amendments, both surface and deep applied, from the Rand trial, five deep treatments are reviewed below, namely

- *Treatment 1* - Deep pea straw + gypsum + [Nitrogen - Phosphorus – Potassium] (NPK)
- *Treatment 2* - Deep ripping
- *Treatment 3* - Deep placement of pelletised wheat straw
- *Treatment 4* - Deep gypsum and
- *Treatment 5* - Deep placement of pea straw.

In viewing the data, consideration needs to be given to crop type and seasonal conditions. In terms of rainfall, 2017 was a decile 5 or median year, 2018 and 2019 were both decile 1 years (i.e., in the lowest 10% of annual rainfall records for Walbundrie since 1880), while 2020 was a decile 7.

Figure 2 shows the percentage yield change from the control treatment in 2017 through to 2020 and Figure 3 shows the $/ha impact over the same sequence of years and crops. The prices used are the actual price the farmer received in the year concerned.

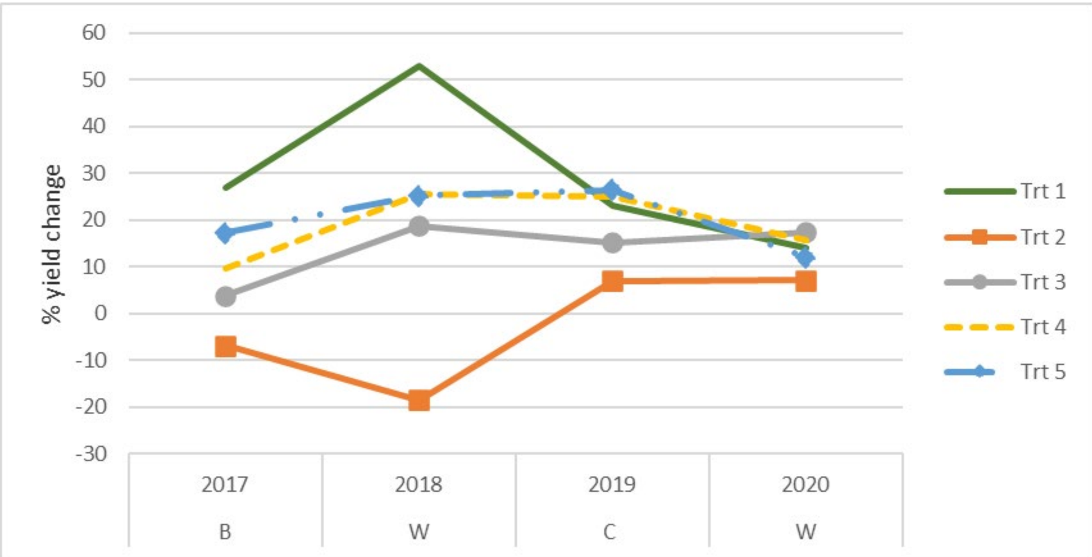

Figure 2. % yield change of each treatment

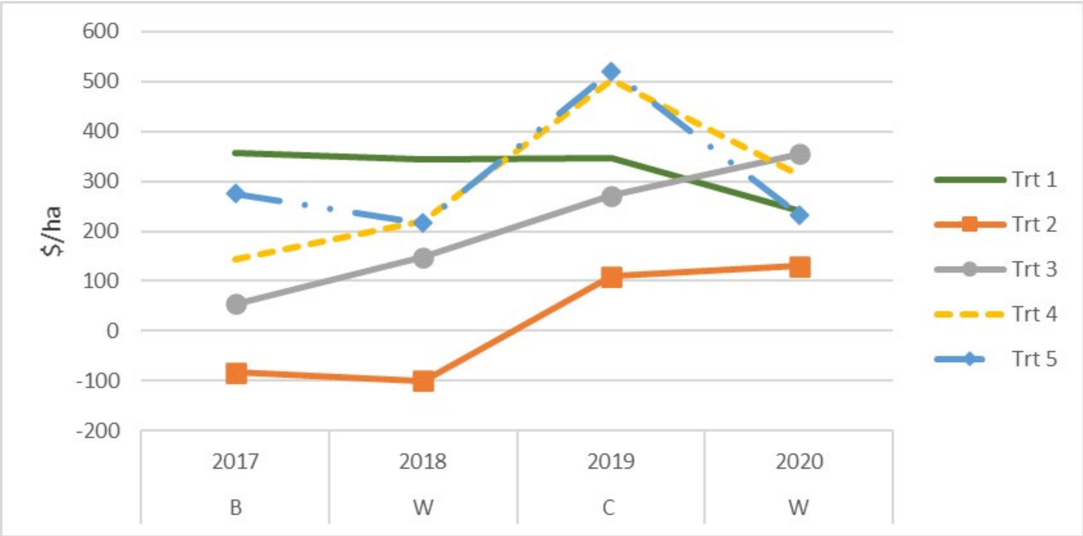

Figure 3. The financial impact of each treatment

Results

From the research outcomes, of note is some strong positive responses in the decile 1 seasons (2018 and 2019) which ultimately translates to an enormous financial benefit to a farm business' bottom line. Specifically;

Treatment 1

Deep pea straw + gypsum + NPK - showed outstanding results in the first three years of the trial and a solid performance in the high yielding decile 7 year of 2020. Although this treatment ranked best on a dollar basis, out all the treatments (not just the deep treatments) it may not be easy to replicate on a commercial basis.

Treatment 2

Deep ripping is included because it is still practiced at an industry level, although most evidence points to it being ineffective in sodic soils. It does however still have a place in removing compaction. This highlights the need to ensure a thorough understanding of the physical and chemical properties of a soil to depth *before* deciding on a course of remediation.

At the sodic Rand site, deep ripping shows a negative response in the first two seasons and every dollar lost hurts the bottom line, particularly in a tough decile 1 season such as 2018. Ranked last of the five deep treatments reviewed.

Treatment 3

Deep placement of pelletised wheat straw. Pelletising this resource for use on farm for deep amelioration has potential. In Figure 3 this treatment shows the $/ha trend line increasing in each of the four seasons of data available, however is overall ranked 4th of the five treatments reviewed.

Treatment 4

Deep gypsum is included as it is commercially available and is used successfully in surface amelioration, in appropriate soil types.

At the Rand site the deep gypsum seems to be producing good yield increases at least initially. Ranked 3/5.

Treatment 5

Deep placement of pea straw - while peas will not be grown on all farms, other pulse crop residue may be able to be substituted, for example in the case of the farmer/co-operator the pulse residue is likely to be faba bean stubble. Pellets of pulse, as with cereal stubble is promising by virtue of its availability and relative simplicity to prepare and use. Ranked 2/5

To draw out the financial impacts for the farmer, the following discussion will be about *money*, not economic theory. In economics, the utility value of a dollar, is almost always a dollar. In farming, the dollar that helps the business scrape into profit in a tough year assumes near magical properties.

Remembering profitability on farm is largely driven by YIELD x PRICE and the factor that the farmer has the greatest capacity to manipulate is yield potential. This means that every opportunity to increase yield, cost effectively, should be examined and the cost:benefit tested on farm.

Table 1 below contains four years of yield data from the trial, derived by averaging the results of the four replicates. The financial outcomes (price per tonne) are based on the grain price achieved by the co-operating farmer for the year concerned.

Table 1. Yield and grain prices over the four years of the trial

Year	2017	**2018**	2019	2020
Crop	Barley	**Wheat**	Canola	Wheat
Yield of control t/ha	4.89	**1.6**	2.38	6.9
Yield of Trt 1	6.21	**2.46**	2.92	7.88
Price $/t	$270	**$385**	$605	$245

Calculations based on this information show that in the Decile 1 season of 2018 Treatment 1 yielded 53% higher than the control treatment. In dollars this means the control treatment generated $640/ha while Treatment 1 generated $948/ha. For such a severe drought year many would consider $640/ha to be a good result, however $948/ha is a profit worthy of any year.

Resilience to drought is something that good farmers are always trying to achieve, and this work shows some very promising results. While the revenue increases look promising, the cost of achieving them can be significant and every farmer should do some on farm investigation and trial work before committing their whole program.

The costs associated with implementing Treatment 1 for example: The machine developed by the co-operating farmer and his engineer colleague, for the deep placement of ameliorants will cost around $200/ha to use. The pelletised straw, for example costs approximately $50 /t to produce and at a rate of 10 t/ha the cost is about $700/ha of upfront investment. Added to this is the cost of the NPK and gypsum if used, approximately another $200/ha.

Regarding the opportunity cost of materials, it is my view that, if the pelletised material is harvest residue from the same paddock, or the same farm, then all that is happening is that the residue is being used in a more effective way and the opportunity cost is zero.

At farm scale

Extrapolating from the research data to what might happen at farm scale - the paddock adjacent to the trial site is used to model two treatments from the trial i.e., Treatments 1 and 5 using the farmer's actual rotation. The farmer's actual yields for the paddock are considered as the 'control, then using the percent increase achieved by the respective treatment and relevant year in the trial, the 'new' yield potential is generated. The grain prices used are the actual prices achieved by the farmer.

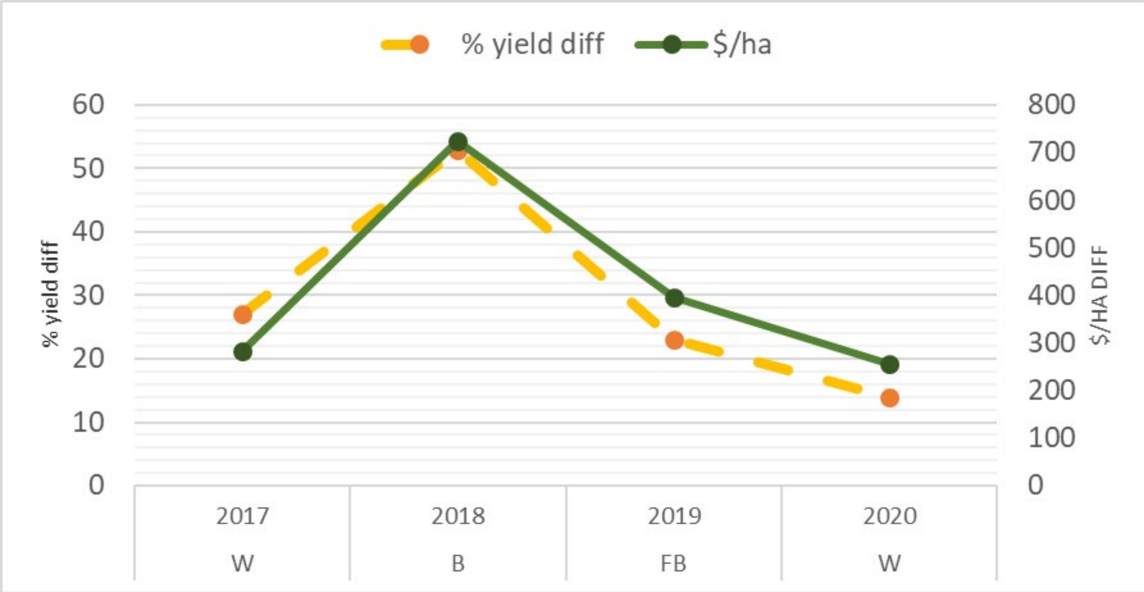

Figure 4. Estimated impact of using Trt 1 (deep placement of pea straw + gypsum + NPK) as the % change in yield and gross margin ($/ha) when compared to grower standard practice

Benefit: The modelled revenue outcome shows a positive return to the farmer and a cumulative additional revenue stream of $1663 over the four years, with outstanding results in 2018 and 2019, which were the toughest years.

Cost: Blending and applying pea straw, gypsum and NPK, would cost approximately $900/ha producing a net benefit of $773 over the four years. It is unclear however how easily this treatment could be done on farm and additional equipment and/or time might add to the cost.

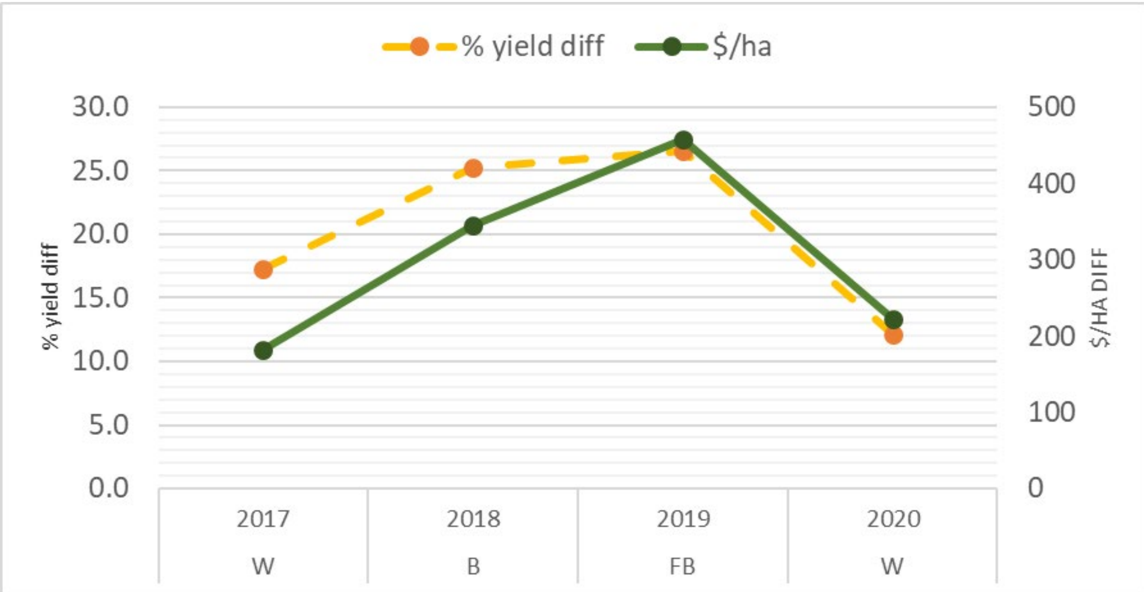

Figure 5. Estimated impact of using Trt 5 (deep placement of pea straw) as the % change in yield and gross margin ($/ha) when compared to grower standard practice

Figure 5 models pelletised pulse straw alone which should be easier for most farmers to make.

Benefit: A cumulative benefit of $1207 over the four years.

Cost: Projected as approximately $700/ha producing a gross surplus of $507/ha.

While only four years of trial data have been collected, we expect yield benefits to continue for several years into the future, making deep soil amelioration financially viable on responsive soils.

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Phenology is FUNdamental – applying key project learnings to optimise grain yield

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Keywords

optimal flowering period, frost, heat stress, risk

GRDC code

DAN00213 (Grains Agronomy and Pathology Partnership, GRDC and NSW DPI)

Take home messages

- Aim to target the optimal flowering period (OFP) for your growing environment – know your risk
- Match varietal phenology and sowing time – use the right variety for the right sowing date
- Remain disciplined with sowing dates – don't sow too early!

Background

The 'Optimising yield potential of winter cereals in the Northern Grains Region' project has been a co-investment by GRDC and NSW DPI under the Grains Agronomy and Pathology Partnership (GAPP) in collaboration with QDAF. From 2017-2020, field experiments were sown across ten locations in New South Wales and Queensland where annual rainfall ranged from 184 to 853 mm and grain yields ranged from 0.2-10 t/ha. The project aimed to provide a better understanding of wheat phenology and yield responses across different environments to refine sowing recommendations and improve yield stability and profitability of growers in the northern grains region (NGR).

The consistent messages presented from the project to date have centered around synchronising crop development (phenology) with seasonal conditions to ensure that the optimal flowering period (OFP) is matched to the growing environment. In previous GRDC Update papers, we combined model simulation and field validation to determine OFPs across locations in the NGR, whereby the OFP varied in timing and duration, as well as for different yield levels (Harris *et al.* 2019, 2020). As flowering time is a function of the interaction between variety, management and environment, the two primary management levers growers can pull to ensure flowering occurs at the optimal time and yield is maximised are *time of sowing* and *variety selection*.

Apply these key project findings to reduce risk and optimise grain yield:

Understand differences in phenology of commercial wheat varieties

In wheat, flowering is generally accelerated under long-day photoperiods and varieties can be broadly classified into two main types: *winter* or *spring*, distinguished by their response to vernalisation and their adaptation to different sowing dates. Winter types can be sown early and will remain vegetative for an extended period (e.g. DS Bennett⁽ᴾ⁾, LRPB Kittyhawk⁽ᴾ⁾). This extended vegetative period arises from a genetic requirement of the plant to experience prolonged cold temperatures to trigger flowering (vernalisation). This delays cold-sensitive reproductive stages to ensure flowering coincides with optimal seasonal conditions in spring.

In contrast, spring types generally do not require a period of cold temperature to initiate flowering. However, they can vary in their responses whereby exposure to cold temperatures can hasten their development (e.g. LRPB Nighthawk⦶) or have no effect on development (e.g. Dart⦶, Sunprime⦶). There are multiple combinations of vernalisation and photoperiod genes which influence phenology responses, as such we have observed significant variation in flowering response among both winter and spring types across environments and in response to sowing time. The figures below present the range in flowering date responses across years and sowing dates for two sites and highlights the risk of precocious flowering in quicker spring types.

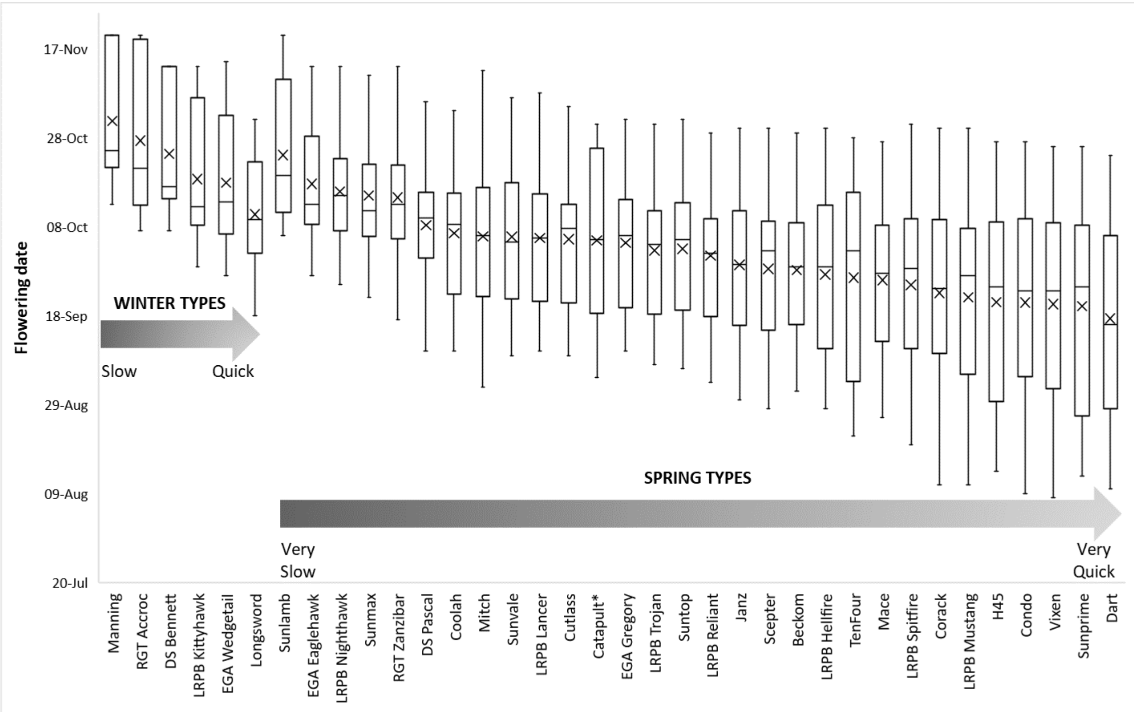

Figure 1. Flowering date responses of genotypes across four sowing dates from early-April to late-May for Wagga Wagga (2018), Marrar (2019) and Harefield (2020) experiments. Asterisk indicates Catapult⦶ only evaluated in 2019, 2020 seasons.

(Varieties Manning, Bennett, Kittyhawk, Wedgetail, Longsword, Sunlamb, Nighthawk, Sunmax, Zanzibar, Pascal, Coolah, Mitch, Lancer, Cutlass, Catapult, Gregory, Trojan, Suntop, Reliant, Scepter, Beckom, Hellfire, TenFour, Mace, Spitfire, Corack, Mustang, Condo, Vixen, Sunprime and Dart are varieties protected under the Plant Breeders Rights Act 1994.)

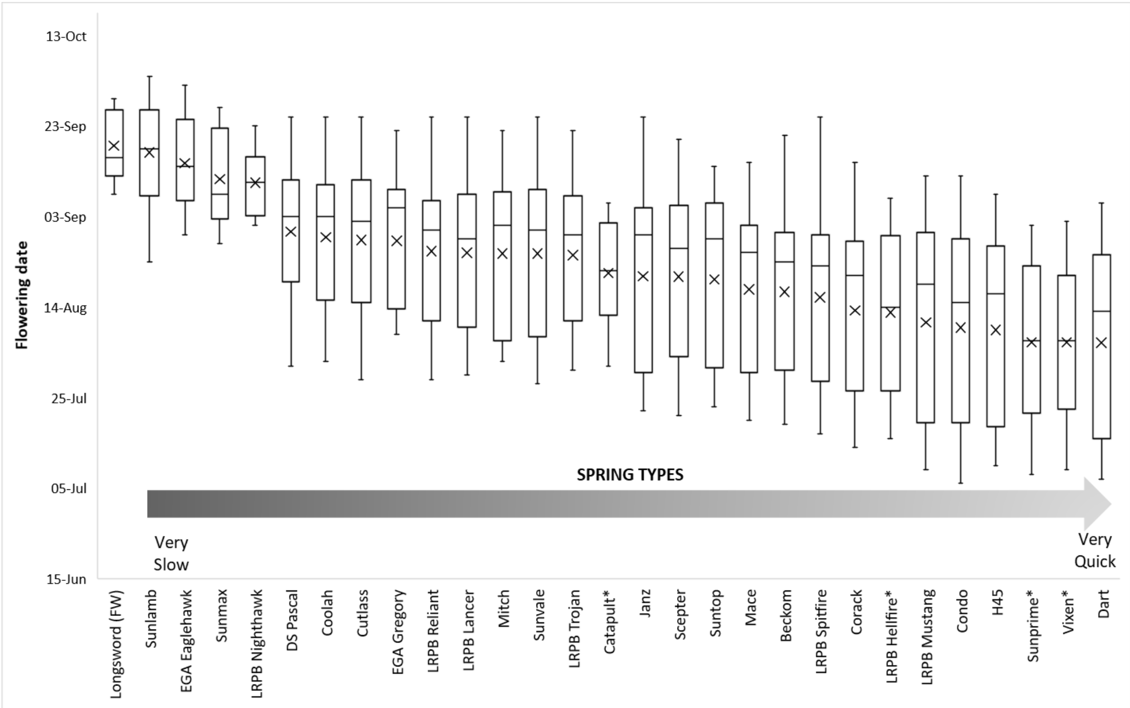

Figure 2. Flowering date responses of genotypes across three sowing dates from mid-April to late-May for Edgeroi (2017) and Narrabri (2019, 2020) experiments. FW – Fast winter type, asterisk indicates genotype only evaluated in two years at Narrabri (2019, 2020).
(Varieties Longsword, Sunlamb, Sunmax, Nighthawk, Pascal, Coolah Cutlass, Gregory, Reliant, Lancer, Mitch, Trojan, Catapult, Scepter, Suntop, Mace, Beckom, Spitfire, Corack, Hellfire, Mustang, Condo, Sunprime, Vixen and Dart are varieties protected under the Plant Breeders Rights Act 1994.)

Need to match varietal phenology and sowing time with environment

Generally, slower developing winter types are more suited to cooler, medium-high rainfall environments in southern NSW which have a longer growing season and increased risk of frost. Winter types when sown early are capable of high water-limited yields, can spread sowing risk and also be a useful frost mitigation tool. However, the vernalisation requirement of these winter types makes them less suited to warmer environments of northern NSW and QLD, where we observed flowering dates later than the OFP and often significant yield penalties in comparison to more adapted mid-quick spring types sown within their recommended window.

In contrast, quicker developing spring types are better adapted to regions with shorter growing seasons, and in environments or later sowing scenarios where frost and heat stress occur in close proximity to each other. Despite the variability across environments and seasons, we were able to identify varieties which were able to maintain relatively stable grain yields across many sowing dates at some sites and which may offer more flexibility to growers.

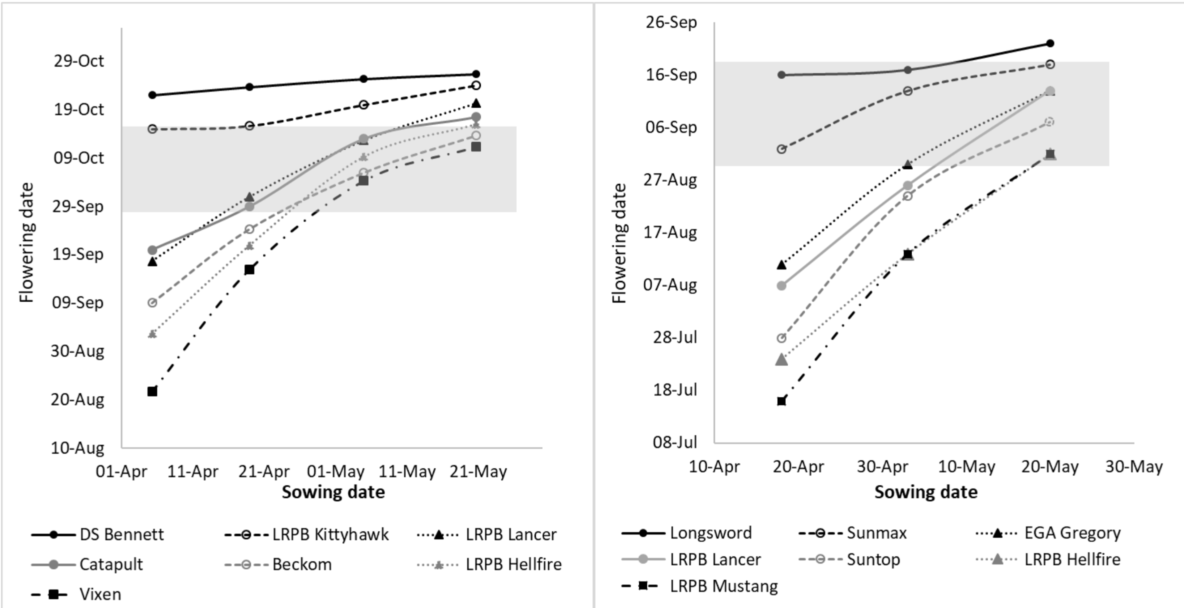

Figure 3. Mean flowering date responses of selected genotypes at a) Wagga Wagga (2018), Marrar (2019) and Harefield (2020) and b) Edgeroi (2017) and Narrabri (2019, 2020) across sowing dates. Shaded box indicates optimal flowering period for each location.

(All the varieties mentioned in the figure above are varieties protected under the Plant Breeders Rights Act 1994.)

Know the risk of getting it wrong - #SowSlowEarly

Winter types – we have observed a yield penalty in many mid-fast winter types when sown prior to early April. This is often due to difficulties establishing crops when soil temperatures are high and there is rapid drying of the seed bed following a rain event. The vernalisation response of some winter varieties has also been observed to be less stable when sown very early, which can result in stem elongation occurring earlier and an increased risk of frost damage. Unless grazing is the primary purpose, sowing prior to early April can increase crop water use under warm temperatures. This can lead to increased likelihood of excessive vegetative growth, taller crop heights and lodging, as well as increased disease pressure.

Spring types – although we have observed significant variation in phenology responses to sowing date amongst spring types, when sown early (when temperatures are warmer and days longer) flowering behaviour is unpredictable and varies substantially across seasons (Figure 1, Figure 2). As such there is increased risk of spring types flowering earlier than the OFP and grain yield penalties due to frost damage or insufficient accumulation of biomass when sown earlier than their recommended windows.

Key recommendation is to remain disciplined with sowing dates – don't sow too early!

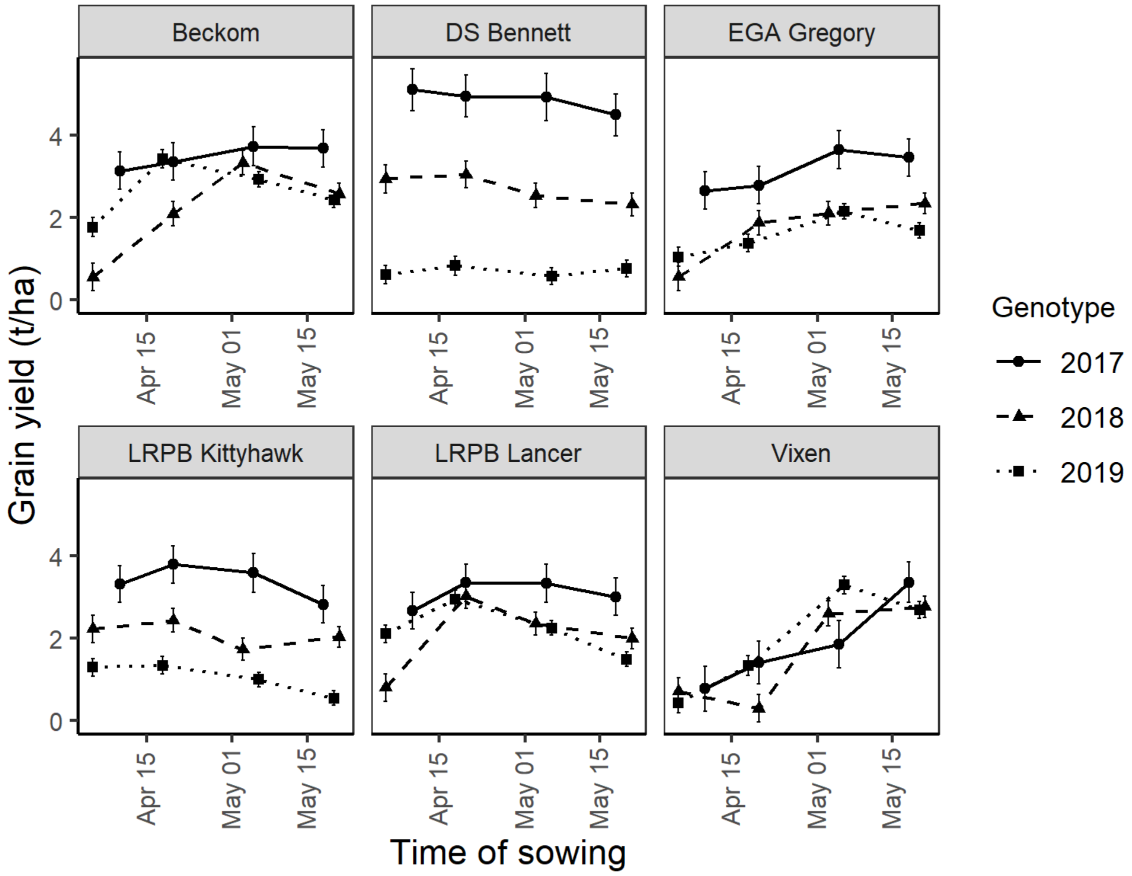

Figure 4. Yield response to sowing time predictions (BLUPs) for a subset of six genotypes for Wagga Wagga in 2017 and 2018 and Marrar in 2019. Vertical error bars denote the 95% confidence interval.
(All the varieties mentioned in the figure above are varieties protected under the Plant Breeders Rights Act 1994.)

Comparing wheat and barley - watch this space...

Compared to wheat, barley is considered to be more widely adapted, have superior frost tolerance and offer higher yield potential across environments in southern Australia. A comparative analysis of the best performing barley and wheat genotypes (defined as the highest yielding treatment) where experiments were co-located across production environments at eight sites in NSW from 2015-2020 is presented in Figure 5. The OFP where yield was maximised for barley was found to be 10-14 days earlier than for wheat, and barley maintained a yield advantage over wheat at yield levels ranging from 1.5-9.6 t/ha. Our understanding of the specific interactions between phenology and environment in barley and the differences in yield physiology between the cereals species is limited. In 2020, a new project was initiated to quantify the flowering time, yield and quality responses of barley, relative to wheat across a range of sowing times. *Preliminary data from 2020 will be presented at the updates.*

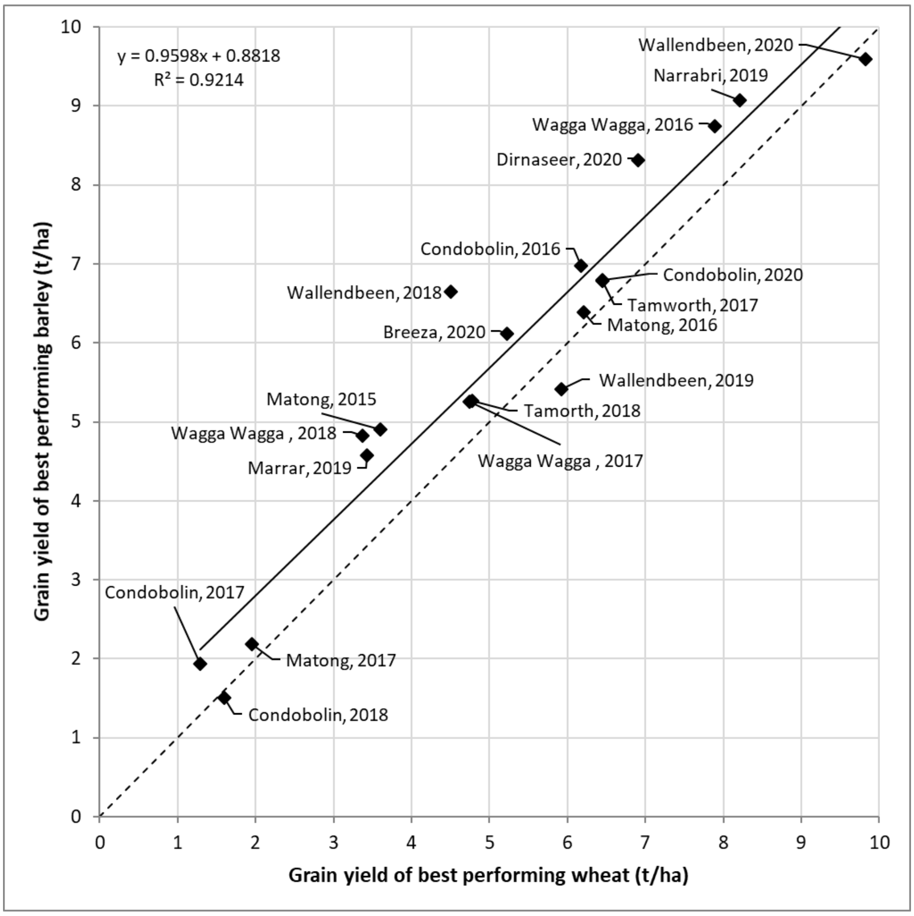

Figure 5. The relationship between the best performing wheat and barley genotypes (sown at optimal time for each environment from mid-April to late-May) at nine sites in NSW from 2015-20. Dotted line indicates 1:1 relationship.

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Harris, F, Graham, R, Burch, D, Brooke, G, Matthews, P, Xing, H (2019) Hot vs Cold: balancing the risks associated with abiotic stresses in wheat. Proceedings of the GRDC Grains Research Updates, presented at Dubbo and Spring Plains, 2019.

Useful resources

https://grdc.com.au/ten-tips-for-early-sown-wheat

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

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[2] *Grain Orana Alliance*

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.

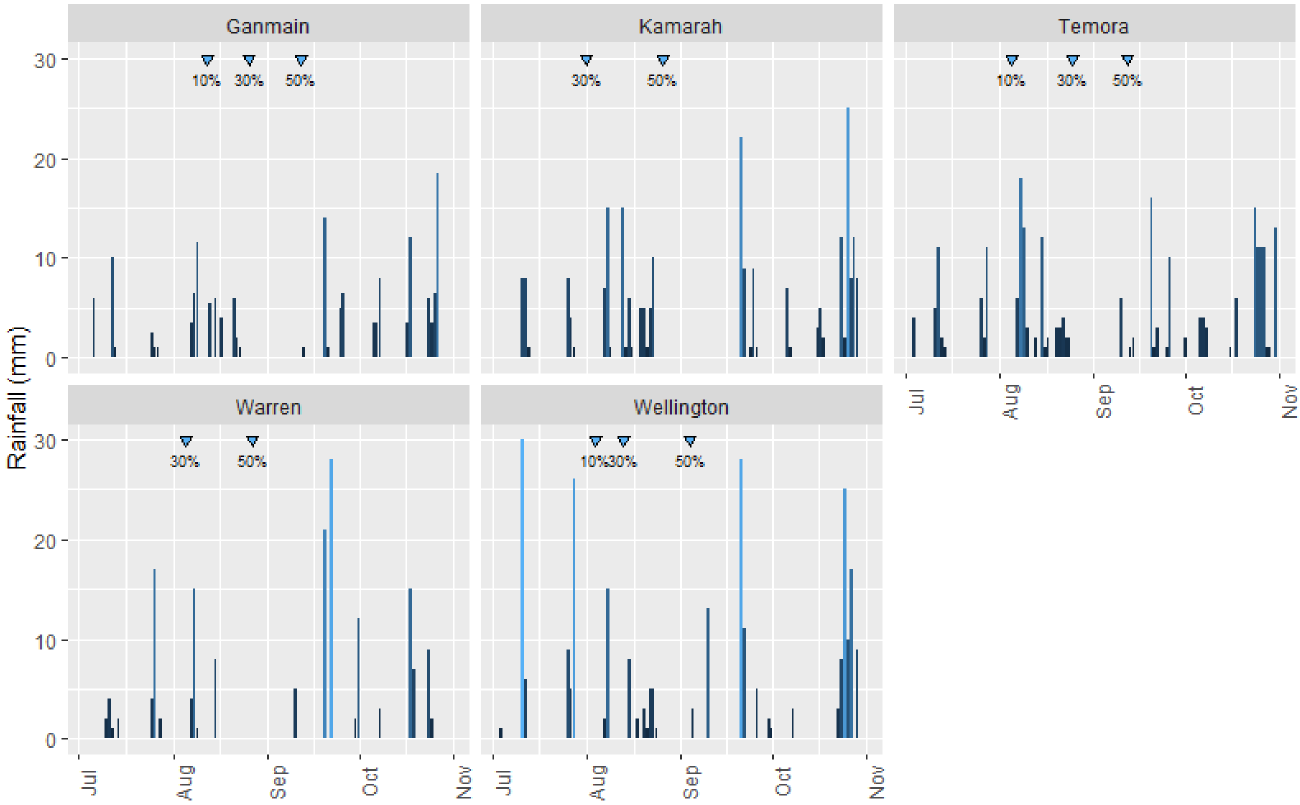

Figure 1. Daily rainfall received (vertical columns) and spray timings (inverted triangles) for five canola fungicide response trials conducted in NSW, 2020. Timings are bloom stage timing, e.g., 10% is 10% bloom stage.

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.

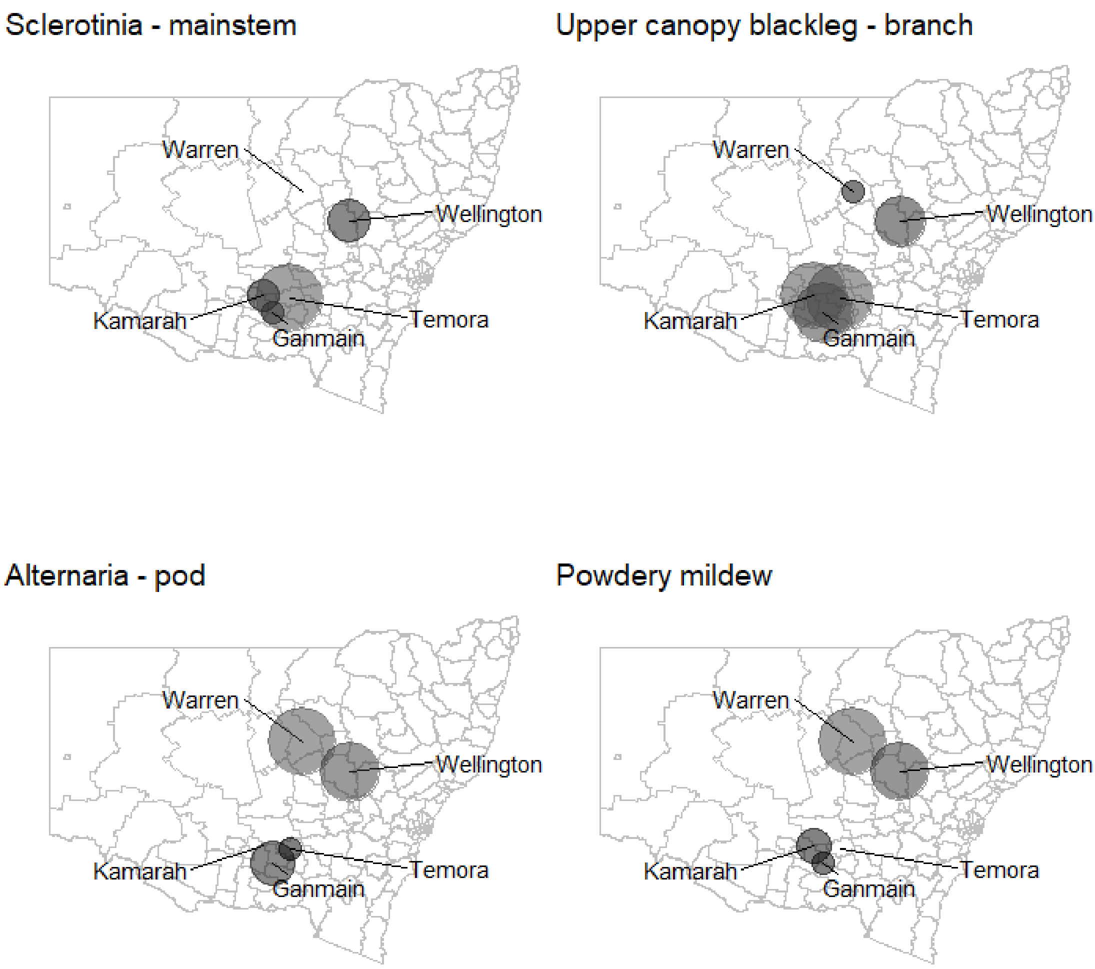

Figure 2. Severity of the diseases Sclerotinia stem rot (main stem), upper canopy blackleg (branch), Alternaria (pod) and powdery mildew across five canola fungicide response trials in NSW in 2020. Larger circles represent greater infection levels (data presented from untreated control). Data presented 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.

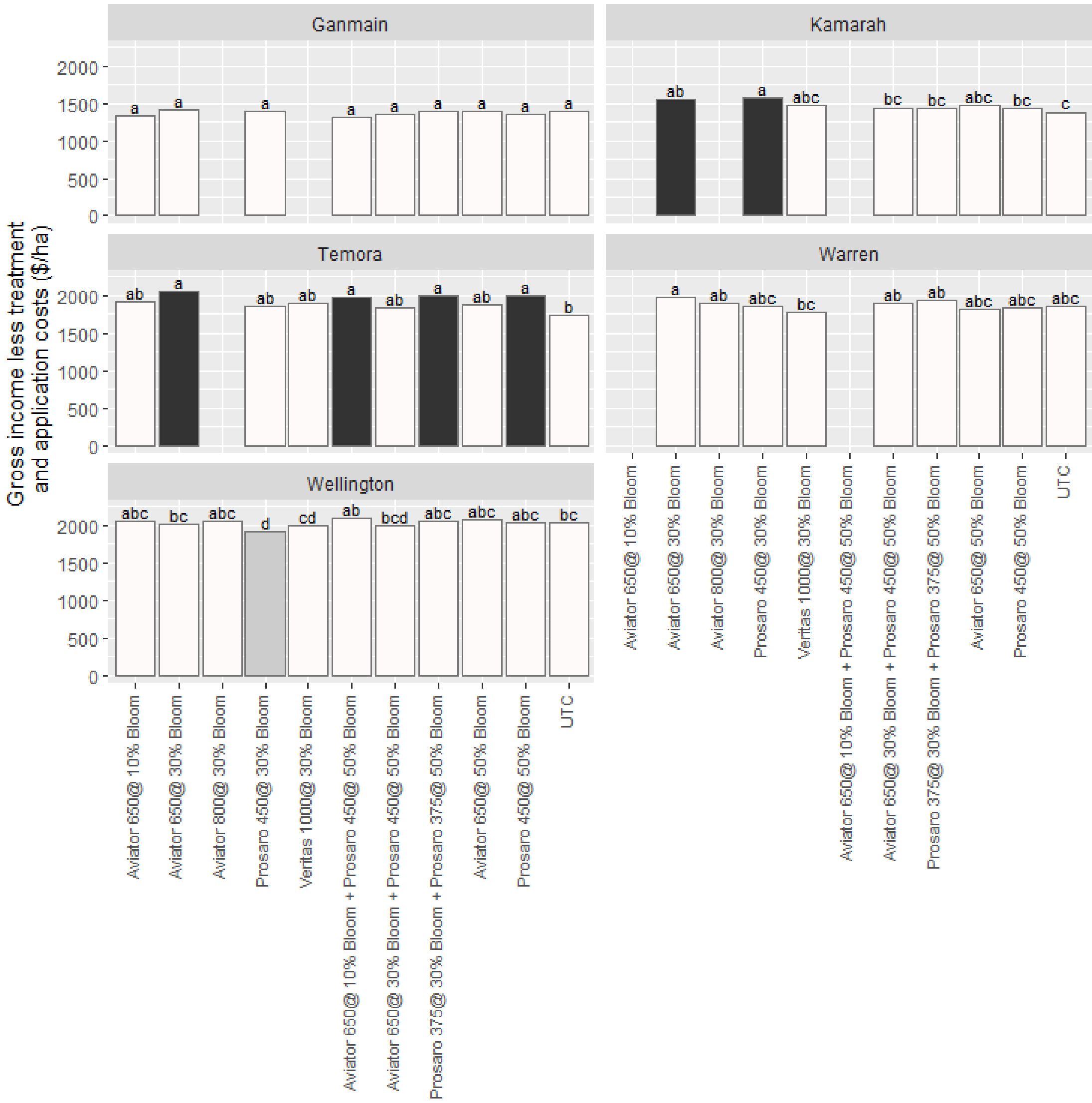

Figure 3. Partial gross margin (gross income less fungicide product and application costs) of fungicide treatments across five sites in NSW in 2020. Treatments with the same letter are not significantly different at p=0.05. Treatments in black are significantly higher than untreated control (UTC) and 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.
    - One example promoted by Bayer can be found at- https://www.crop.bayer.com.au/-/media/bcs-inter/ws_australia/use-our-products/product-resources/prosaro/prosaro_420_sc-factsheet-sclerotinia_control.pdf
    - 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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Diseases in pulses and canola – the watchouts and implications for 2021

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Take home messages

- Changes in farming practice in the last 15 years have increased disease pressure on cropping rotations in southern NSW
- In 2020, exceptional conditions for crop production also increased the incidence and severity of disease in broadleaf crops in the region. This will have implications for disease management in crops in 2021
- Annual crop surveys are an important means of monitoring disease incidence and severity between districts and between years. Surveys enable the identification of emerging disease issues and forewarning of potential problems
- Sclerotinia diseases were widespread in broadleaf crops across the region in 2020, especially narrowleaf lupin and canola. This will have implications in 2021 and beyond
- Blackleg was observed in every canola crop assessed as part of the IDM crop survey
- Canola sown into a double break scenario will potentially require pre-emptive management to minimise disease risk
- The decision to use fungicides is not always clear and should be assessed every year, depending on the disease risk profile of your crop
- Other significant diseases this season included virus diseases and Botrytis grey mould (especially in narrowleaf lupin).

Introduction

In the last 20 years, grains production in southern NSW has changed significantly. Many landholders have moved entirely into grain production enterprises, removing livestock and pastures from their farming system. Agronomic practices have changed including stubble retention, minimum tillage and crop sequences. These changes have increased the disease burden across the farming system. Management of disease in the cropping system is now an important and annual consideration for many grain producers in southern NSW.

In 2020, sowing conditions were considered ideal across many districts, and crops were sown on time. Rainfall patterns and mild temperatures across the south provided ideal conditions for developing crops and resulted in some of the best crop yields seen for many years. These ideal conditions also allowed development of root and foliar diseases in broadleaf crops across the region. In many instances, even low levels of pathogens were able to develop into epidemic levels, despite the dry conditions in 2018 and 2019. In general, disease management practices across the region were very good, but there will be disease implications to consider moving into 2021.

Crop surveys have been undertaken for several years in southern NSW to monitor changes in disease prevalence, distribution and impact across farming systems and districts. Surveys are a valuable tool in the identification of emerging disease threats, monitoring IDM strategies, guide priorities for future research effort, and provide a mechanism for industry awareness and preparedness.

This paper discusses the priority diseases identified in 2020 crop surveys and implications for grains producers in 2021.

Methodology

With the assistance of local agribusiness, 45 pulse crops and 30 canola crops were sampled in 2020 at the early flowering to early pod filling stage (early August to late September). Crops details were collected including GPS location, previous cropping history and herbicide use. Crop locations were restricted to the southern half of NSW, that is south of Dubbo to the Victorian border.

Six pulse crop species were surveyed (albus lupin, narrowleaf (NL) lupin, faba bean, field pea, lentil and chickpea) and one oilseed crop (canola). There were no targets set for each species, but rather the number of crops sampled reflected the frequency of crops across the region.

At each crop a diagonal transect was followed starting at least 25m into the crop from the edge, to avoid any double sown areas, roadsides, dam or trees. At 10 locations at least 25 m apart along the transect, a row of 10 random plants was assessed for symptoms of foliar disease and any other abiotic issues present. At five locations (every second assessment point), five random whole plants along a row were collected for detailed assessment of disease and root health. The samples were prepared for assessment of fungal DNA concentrations at SARDI.

Table 1. The breakdown of commercial crops assessed and sampled as part of the 2020 IDM crop survey.

Region	NL lupin	Albus lupin	Chickpea	Field pea	Faba bean	Lentil	Canola	Total
Riverina	6	2	4	5	4	2	9	32
SW Slopes	8	3	2	2	3	2	16	36
CW Slopes and Plains	2						6	8
Total	***16***	***5***	***6***	***7***	***7***	***4***	***31***	***76***

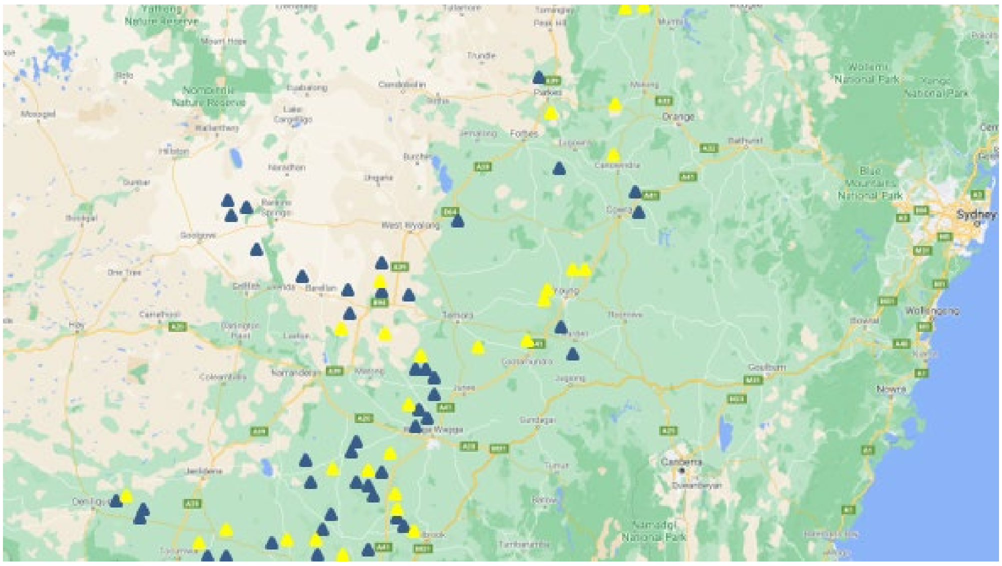

Figure 1. Distribution of pulse and canola paddocks assessed as part of the 2020 IDM crop survey. 45 pulse crops (blue triangles) and 30 canola crops (yellow triangles) were sampled for the presence of foliar and root disease.

What did the survey find?

Sclerotinia (all pulses)

Sclerotinia diseases (stem rot and white mould) were the most prevalent diseases found across all pulses in this season's survey. A combination of exceptional crop growth and frequent rain periods during late winter and spring provided ideal conditions for this pathogen to develop across a wide region of southern NSW and range of broadleaf crops in the rotation.

Symptoms of the disease included basal infections, stem lesions and pod infections. Basal infections are the result of direct infection of plants by mycelium from germinating sclerotia. As sclerotia in the soil soften in winter from wet soil conditions, mycelium is produced that grows along or just under the soil surface. Once this mycelium encounters a plant stem, direct infection occurs that can kill the plant completely. Symptoms appear as a fluffy white collar that occurs around the stem base at soil level (often referred to as collar rot). Newly formed sclerotia will also be produced in this tissue. Stem and pod lesions are the result of infection via ascospores, in a similar way to the infection process in canola. Apothecia (flattened golf tee like fruiting structures of the Sclerotinia fungus) germinate from sclerotia in the soil. The apothecia produce and release airborne ascospores that land on and infect suitable plant tissues, often old senescent leaf and flower tissue or pods. Symptoms appear as fluffy white mycelium on the outside of stems and on pods (particularly lupin), often killing the plant above the lesion. Newly formed sclerotia often develop either within infected stems or on the outside, if conditions are favourable.

Table 2. Proportion of pulse crops inspected and found to have Sclerotinia spp. present as part of the 2020 IDM crop survey.

	NL Lupin	Albus lupin	Chickpea	Field pea	Faba bean	Lentil
No. of crops sampled	16	5	6	7	7	4
No. of crops with Sclerotinia	13	3	3	3	5	1
% of crops infected	81%	60%	50%	43%	71%	25%

Implications for 2021: Sclerotia produced by infected crops in 2020 pose a significant disease threat in 2021 and beyond. Many of the crops detected with the disease in 2020 had been sown to successive cereal crops in 2018 and 2019, meaning the sclerotia responsible for the disease in 2020 were most likely formed prior to these cereal crops, therefore in 2017 or 2016. It is well known that sclerotia are long lived. The majority of sclerotia can survive for up to 5 years in the top five centimetres of soil, however this can increase up to 10 years if buried deeper and not exposed to microbial activity. Growers, agronomists and advisers should pay attention to crop choice and management for the next few seasons, especially those growers following 'double break' cropping systems. Sowing canola or pulses into paddocks known to have outbreaks of Sclerotinia in 2020 face a significant disease risk, especially in medium to high rainfall districts.

Blackleg (canola)

Blackleg, caused by the fungus *Leptosphaeria maculans*, was the most common disease observed in canola in the 2020 crop survey. Each of the 31 crops inspected had symptoms of the disease present at varying levels of severity. Symptoms ranged from leaf infection to stem cankered plants.

The high incidence of blackleg in commercial canola crops is not surprising in 2020 given the conducive conditions for the disease to develop this year. Differences in severity could be attributed to crop variety, fungicide use and proximity to old canola stubble. Frequent wet days throughout winter and spring provided multiple leaf wetness periods for infections to occur and proliferate. At the time of observation (mid-August to early September), those leaf infections that had developed towards the top of the crop canopy had potential to develop into upper canopy infection (UCI).

Implications for 2021: The large area sown to canola in central and southern NSW means there will be large areas of canola stubble in 2021 producing blackleg inoculum. Disease management in canola changes seasonally depending on the variety, seasonal conditions and frequency of canola in the rotation.

Consideration also must be given to disease risk factors impacting on the new season crop; is seedling protection important, do I need to apply fungicides for UCI, or are there diseases other than blackleg to consider? Often these risk factors cannot be addressed at the start of the season and require on-going crop monitoring and scouting for disease symptoms to make decisions that are cost effective. Scouting for symptoms is a powerful way to keep abreast of blackleg development within crops and make decisions around fungicide applications. Scouting is particularly important in the management of UCI.

More than ever, blackleg management in medium to high rainfall zones relies on fungicides as cultural practices become difficult to implement. With a suite of new fungicides and fungicide actives on the market, it is strongly recommended to rotate actives where possible to avoid the development of resistance in the pathogen population. CropLife Australia has on-line resources available for rotating fungicides in canola:
(https://www.croplife.org.au/resources/programs/resistance-management/canola-blackleg/)

Another useful resource is the BlacklegCM app. Prior to sowing, use the BlacklegCM decision support tool to identify high risk paddocks and explore management strategies to reduce yield loss due to disease.

Botrytis grey mould (narrowleaf lupin)

Botrytis grey mould (BGM), caused by the fungus *Botrytis cinerea*, is a disease normally associated with lentil, chickpea, vetch and faba bean production. Crop surveys in 2020 also observed this disease in narrowleaf lupin crops, with 43% of crops infected. Outbreaks of BGM are initiated on senescent plant tissues, such as old leaves and flower parts before developing into larger, more damaging lesions. The large, dense crop canopies produced by narrowleaf lupin crops in 2020 favoured the development of senescent tissue following canopy closure and when light penetration into the canopy was hindered.

Symptoms of the disease included stem and leaf infections, and infections of old flower parts and pods. Whilst the disease can be confused with Sclerotinia white mould, the fluffy mycelium produced by the fungus is grey rather than white and no sclerotia are produced. Outbreaks of BGM are considered rare in narrowleaf lupin, but the causal fungus is ubiquitous. Extraordinary seasonal conditions in 2020 favoured development of this disease.

Implications for 2021: Old lupin stubbles affected by BGM present a significant inoculum source in 2021. The BGM fungus can infect other pulses including chickpea, lentil and faba bean. Spores of the BGM pathogen are airborne and will form readily on old infected stubble and be blown into surrounding crops. Care should be taken to avoid growing pulse crops (especially chickpea, lentil and faba bean) adjacent to old narrowleaf lupin stubbles in 2021. If this cannot be avoided, the crop should be managed as a medium to high disease risk and considerations made for foliar fungicide use where economically justified.

Virus (all pulses)

Virus diseases were evident in many pulse crops across central and southern NSW in 2020. All major pulse viruses require an aphid vector to infect host plants and the severity of virus diseases depends on the movement of aphids through a crop. Aphids require a living host plant to survive crop-free periods (‘green bridge’). For the 2020 season, good summer and autumn rainfall, and mild winter temperatures allowed for the build-up and maintenance of aphid activity across the region. This resulted in the appearance of virus symptoms in many pulse crops by late winter and early spring. Within the survey, virus symptoms were most noticeable in narrowleaf lupin and lentil crops.

Symptoms in narrowleaf lupin ranged from plants with shortened internodes and bunchy tops (typical for cucumber mosaic virus, CMV), to plants with a withered top, bright yellow leaves and premature death (typical for bean yellow mosaic virus, BYMV). Lentil crops featured shortened plants, bunchy growth and premature yellowing. Virus diseases in southern NSW during 2020 were not as severe as in northern NSW, where BYMV resulted in serious yield losses in a large number of faba bean crops. A number of narrow-leafed lupin crops in central NSW also suffered severe yield losses caused by CMV and Alfalfa mosaic virus (AMV).

Yield loss due to virus is not always easy to estimate compared to a fungal disease. Early virus infections tend to result in greater yield loss and subsequent plant death compared to infections later in the season when plants are more developed.

Implications for 2021: The occurrence of virus in pulse crops in 2020 demonstrated how dynamic virus diseases can be within the cropping system, and the influence of environmental conditions on the build-up and movement of virus vectors. The use of virus-free seed is of particular importance for narrow-leafed lupins, as CMV can be transmitted at high levels in narrow-leafed lupins. Sowing crops with virus infected seed can result in poor establishment and seedling vigour, in addition to becoming a source of virus infection throughout the crop. Following the agronomic recommendations of sowing into cereal stubble and sowing at the recommended sowing rate to avoid having thin or poorly established crops can also discourage aphid landings within crops and slow down virus spread.

Department of Primary Industries and Rural Development (DPIRD) in Western Australia offer commercial tesing of pulse seed for virus, for more details on the diagnostic services provided contact DDLS Specimen Reception +61 (0)8 9368 3351 or DDLS@dpird.wa.gov.au for .

Other diseases

Ascochyta blight: The most serious disease of chickpea in Australia was recorded in 30% of chickpea crops surveyed in 2020, however, reports of damaging levels of the disease in southern NSW were minimal. Strategic use of fungicides is highly effective at managing the disease which is spread through rain splash of spores. Be aware of the significant inoculum sources in 2021, as the pathogen survives on old infected chickpea stubble and seed.

Blackspot: The most common disease of field pea in Australia and most damaging in paddocks with a high frequency of field pea production. Spores of the fungus survive on old field pea stubble and in soil. Whilst blackspot was observed in 71% of field pea crops surveyed, only a single crop developed the disease at a damaging level. Avoid sowing next season's crop adjacent to last year's stubble and observe a four-year break between field pea crops in the same paddock.

Chocolate spot: Potentially the most damaging disease of faba bean and responsible for the nickname 'failure beans' in the 1990's. The 2020 crop survey observed the disease in 43% of crops at low to moderate levels. Improvements in variety resistance and the range of foliar fungicide options available have significantly improved disease management and reduced potential for yield loss.

Bacterial blight: Mild winter conditions and few damaging frost events resulted in limited outbreaks of this disease compared to 2018 and 2019. Bacterial blight was observed in 28% of field pea crops inspected in the survey. The disease generally appears in low lying areas of field pea crops, which are most prone to frost and freezing injury. The disease is challenging and relies on pre-emptive disease management strategies such as maintaining at least a 3-year rotation between field pea crops and sowing disease-free seed. There are no post emergent disease management options. The bacterial pathogens survive on old field pea stubble and seed.

Phomopsis stem blight: Whilst this disease does not cause significant yield loss, presence of the disease within lupin crops poses a significant risk to livestock health. The causal fungus, *Diaporthe toxica*, produces a toxin as it grows within lupins that can kill grazing livestock, especially young sheep. Care should be taken when grazing lupin stubbles following harvest and especially following summer rain which stimulates growth of the fungus within stubble. It is rare to observe the disease whilst lupin plants are still green, but a single narrowleaf and a single albus lupin crop were observed with the disease during the survey. Typically, growth of the fungus becomes most apparent following harvest and after rain when fruiting structures of the fungus develop on lupin stubbles.

Conclusions

The results from the survey this year demonstrate the ability of pathogens to persist between years, even when conditions are unfavourable. Environmental conditions in 2020 allowed what were considered to be low levels of disease to build up quickly and becoming potentially damaging in broadleaf crops across the region. No new emerging disease threats were identified in 2020 from surveys, but several common diseases occurred at significant levels that will potentially impact for the next few seasons including Sclerotinia stem rot, blackleg and Botrytis grey mould.

Where possible an integrated approach should be used to manage disease in grains crops. More than ever we are becoming reliant on fungicides to maintain tight cropping rotations and high yields. The loss of fungicides from the system due to the development of resistance or detection of residues in end products will quickly remove these valuable tools from the system.

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