TOTTENHAM
NSW
TUESDAY 23
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
TOTTENHAM

Tuesday 23 February 2021

Tottenham War Memorial Hall, Bulbodney St, Tottenham

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

AGENDA

Time	Topic	Speaker(s)
9:00 AM	**GRDC welcome**	
9:10 AM	**Cereal disease bingo!** Learnings from 2020 and planning for 2021. Is stripe rust the death knock for some varieties?	Steven Simpfendorfer (NSW DPI)
9:45 AM	**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)
10:10 AM	**Canola phenology** - targeting varieties to flowering dates in different environments	Danielle Malcolm (NSW DPI)
10:40 AM	**Morning tea**	
11:10 AM	**Optimising P nutrition and canola establishment**	Maurie Street (GOA)
11:40 AM	**Optimising canola establishment** o Factors affecting establishment o Growing high vigour seed o Seed testing	Colin McMaster (NSW DPI)
11:55 AM	**Soil moisture, nitrogen and disease legacy effects of different Central Western farming systems** - 5 years of findings at Trangie.	Greg Brooke (NSW DPI)
12:25 PM	**Lunch**	
1:15 PM	**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)
1:50 PM	**Ryegrass - fitting new pre-emergent chemistries into the farming system.**	Greg Condon (Grassroots Agronomy/WeedSmart)
2:20 PM	**Farming systems discussion** o Making nitrogen decisions in anticipation of favourable spring conditions - balancing seasonal uncertainty with paddock history and deep N testing o Improving weed management - managing cost and sustainability	Discussion led by Maurie Street (GOA), Greg Brooke (NSW DPI), Peter Boutsalis (Plant Science Consulting) and Greg Condon (Grassroots Agronomy/WeedSmart).
2:50 PM	**Close**	

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

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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 (Qols, 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)](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 (1^{st} 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.

Acknowledgements

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Diseases in pulses and canola – the watchouts and implications for 2021

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Key words

canola, lupin, chickpea, field pea, lentil, faba bean, sclerotinia, blackleg, disease management, crop survey, botrytis grey mould

GRDC code

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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***

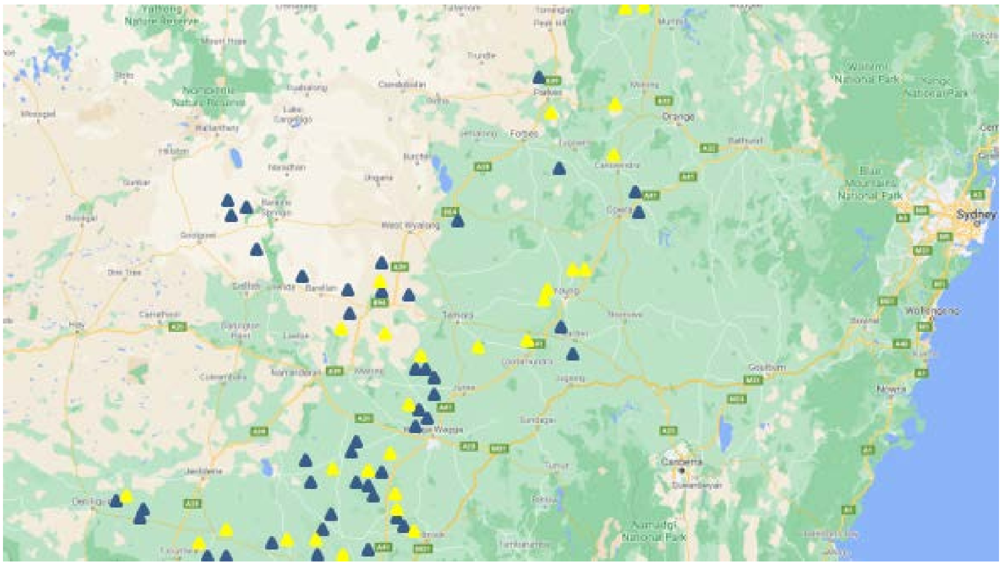

Figure 1. Distribution of pulse and canola paddocks assessed as part of the 2020 IDM crop survey. 45 pulse crops (blue triangles) and 30 canola crops (yellow triangles) were sampled for the presence of foliar and root disease.

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

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Key words

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

GRDC codes

GOA2006-001RTX

Take home messages

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

Introduction

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

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

Methodology

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

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

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

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

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

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

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

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

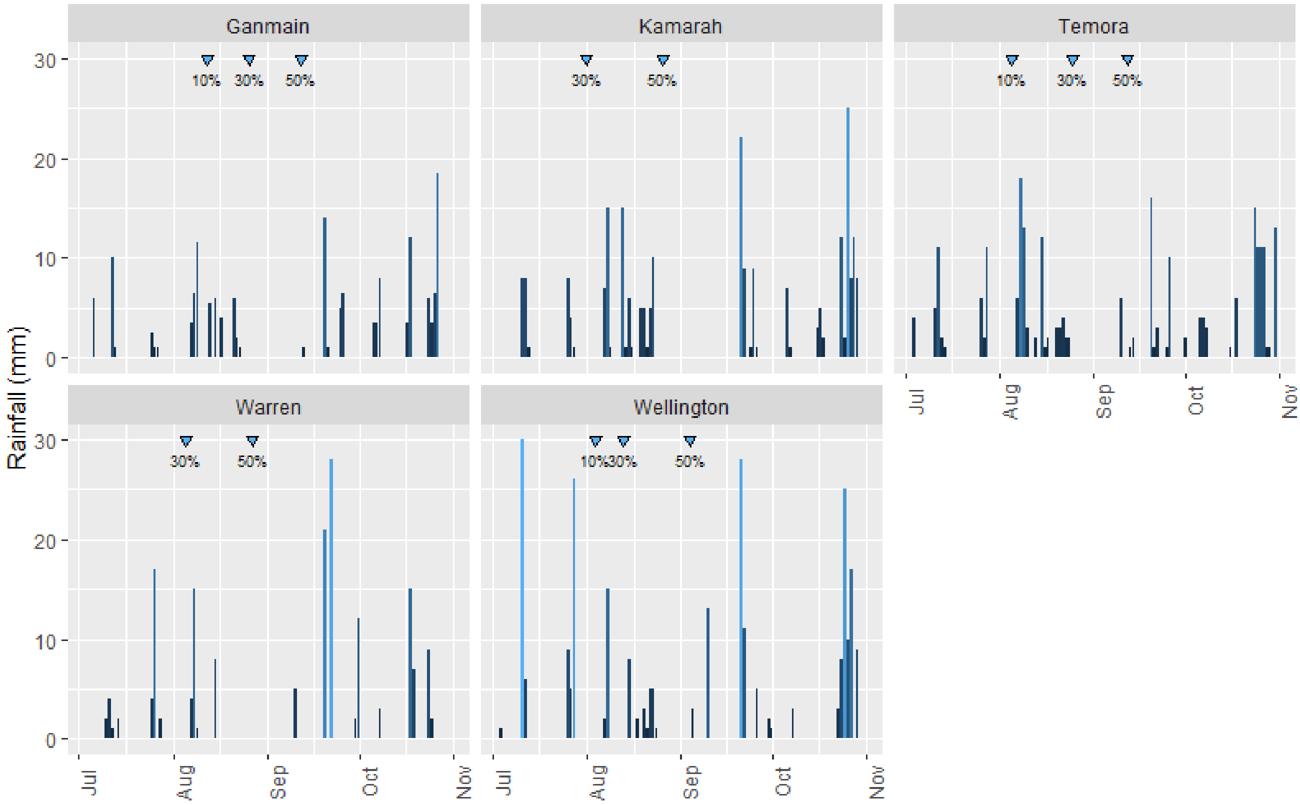

Figure 1. Daily rainfall received (vertical columns) and spray timings (inverted triangles) for five canola fungicide response trials conducted in NSW, 2020. Timings are bloom stage timing, e.g., 10% is 10% bloom stage.

Disease assessment

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

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

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

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

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

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

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

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

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

Results

Sclerotinia petal testing

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

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

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

Geographic disease distribution

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

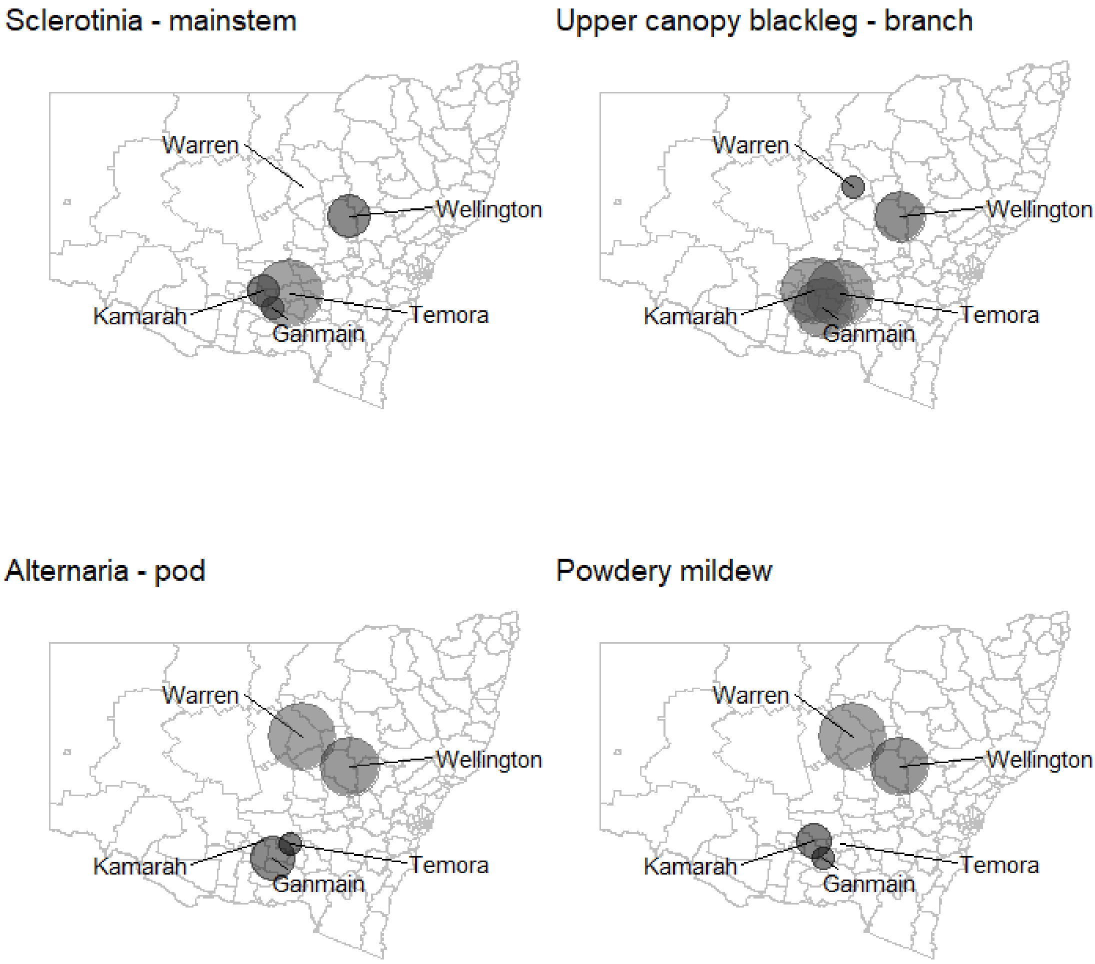

Figure 2. Severity of the diseases Sclerotinia stem rot (main stem), upper canopy blackleg (branch), Alternaria (pod) and powdery mildew across five canola fungicide response trials in NSW in 2020. Larger circles represent greater infection levels (data presented from untreated control). Data presented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

Ganmain

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

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

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

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

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

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

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

Kamarah

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

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

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

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

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

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

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

Temora

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

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

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

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

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

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

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

Warren

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

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

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

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

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

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

Wellington

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

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

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

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

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

Fungicide economics

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

We assumed a price of:

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

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

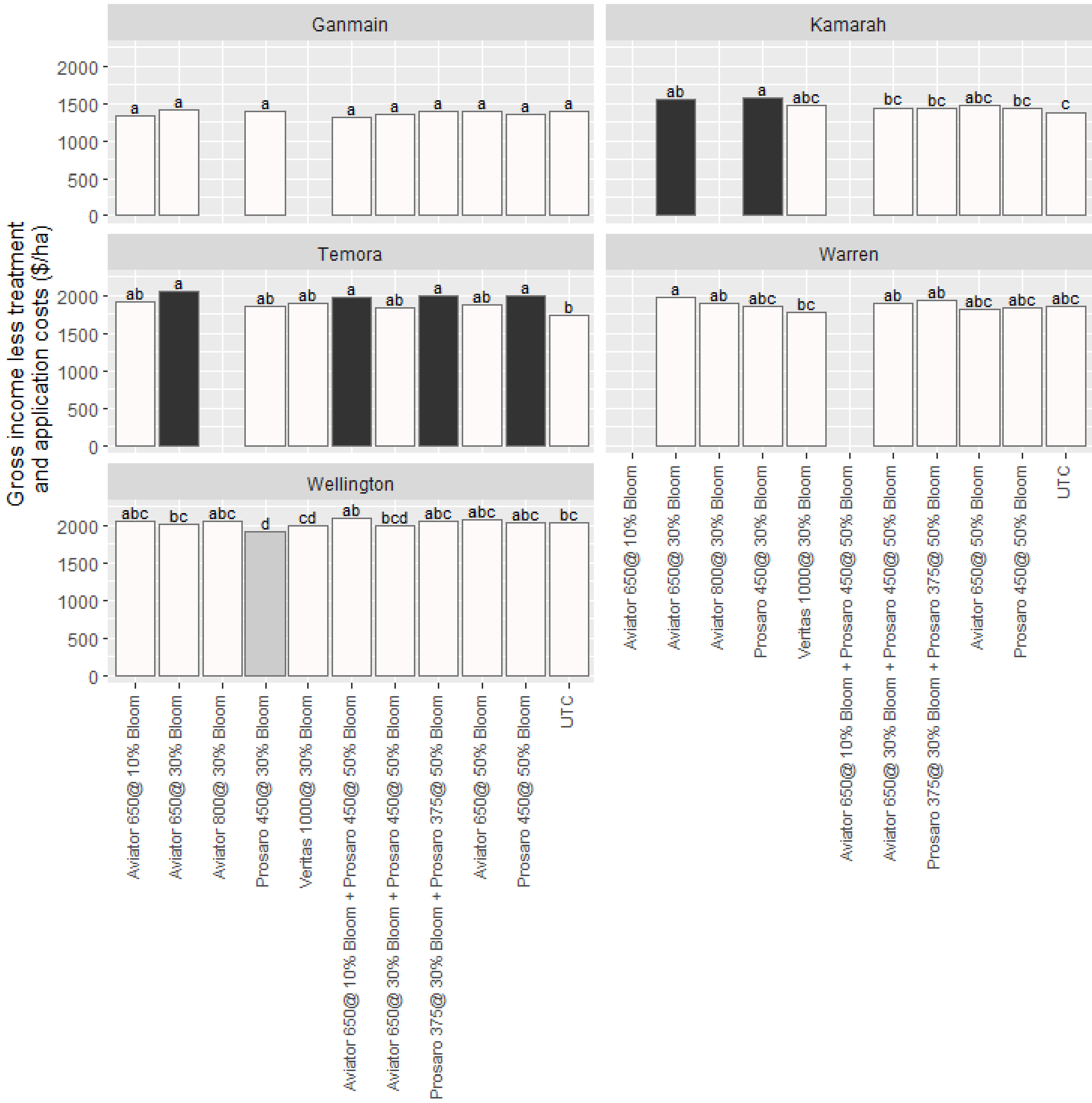

Figure 3. Partial gross margin (gross income less fungicide product and application costs) of fungicide treatments across five sites in NSW in 2020. Treatments with the same letter are not significantly different at p=0.05. Treatments in black are significantly higher than untreated control (UTC) and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

Discussion and conclusion

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

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

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

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

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

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

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

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

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

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

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

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

- Match phenology and sowing date so that crops do not flower too early. Early flowering will usually result in greater exposure to disease - especially upper canopy blackleg
- Closely monitor short-term forecasts as diseases require moisture for infection
- Consider using some of the decision support tools that may quantify the risks of canola diseases and the need for fungicide applications.
    - 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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Canola phenology - targeting varieties to flowering dates in different environments

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Key words

canola, phenology

GRDC code

CSP00187

Take home messages

- Matching flowering date to sowing date is important to minimise the risk of plant stress caused by frost, disease, heat and lack of moisture
- Canola varieties varied markedly in the time it took from sowing to the start of flowering.

Introduction

An important management strategy to maximise yield potential for canola is to sow varieties within their correct sowing window so they start flowering within the optimum flowering period for a particular location. Flowering too early increases the risk of frost damage, upper canopy blackleg and sclerotinia stem rot infection. Flowering too late increases the risk of damage from heat or moisture stress or both, potentially reducing yield.

The optimum start of flowering (determined as 50% of the plants with one open flower) differs for each location. For Trangie, this date is between 15 July and 12 August, with the optimum date being 29 July. The optimum start of flowering for Wagga Wagga is between 31 July and 1 September, with the optimum date around 16 August. For varieties to start flowering within this period, a variety's phenology needs to be understood so growers can sow varieties in the correct window for flowering to start during this optimum time.

Experiments at Trangie and Wagga Wagga in 2018 and 2019 and Wagga Wagga in 2020, examined the phenology of commercial and newly released varieties sown at two sowing dates. Data from trials at Trangie in 2018 and 2019 and Wagga Wagga in 2020 is presented. Phenology and yield data from an Optimised Canola Profitability experiment at Condobolin in 2018 which included five commercial varieties, two nitrogen rates with a wet and dry treatment is also included.

Treatments

Variety

Table 1 lists the details of the varieties sown across the years at Trangie and Wagga Wagga.

Table 1. Details of the varieties sown at Trangie (2018 & 2019) and Wagga Wagga (2020). Grey boxes indicate which sites each variety was sown for those years

Variety	Phenology	Maturity	Herbicide Tolerance	Plant Type	Trangie 2018	Trangie 2019	Wagga Wagga 2020
Archer	Slow	Late	CLF	Hybrid	■	■	
ATR BonitoⓅ	Mid-fast	Early	TT	Open-pollinated (OP)	■	■	■
ATR MakoⓅ		Mid		Open-pollinated (OP)	■		
ATR StingrayⓅ	Fast	Early	TT	Open-pollinated (OP)	■	■	
ATR WahooⓅ	Mid-Slow	Mid	TT	Open-pollinated (OP)	■		■
Bayer 3000TR		Early-mid	RR/TT	Hybrid	■		
Banker CL				Hybrid	■		
GT-53	Mid	Mid	RR	Hybrid	■	■	■
Hyola 350TT	Fast	Early	TT	Hybrid	■	■	■
Hyola 410XX	Mid-fast	Early-mid	TruFlex RR	Hybrid		■	■
Hyola 506RR			RR	Hybrid	■		
Hyola 530XT	Mid-fast	Mid	TruFlex RR/TT	Hybrid		■	
Hyola 540XC		Early-mid	TruFlex RR/CLF	Hybrid			■
Hyola 550TT	Mid-fast	Mid	TT	Hybrid		■	
Hyola 580CT	Fast	Mid	CLF/TT	Hybrid	■	■	■
Hyola Enforcer CT		Early-mid	CLF/TT	Hybrid			■
Hyola Garrison XC		Early-mid	TruFlex RR/CLF	Hybrid			■
HyTTec Trident	Mid-fast	Early	TT	Hybrid		■	■
HyTTec Trifecta		Mid	TT	Hybrid			■
HyTTec Trophy	Mid	Mid	TT	Hybrid	■	■	■
InVigor R 4022P	Mid-fast	Early-mid	RR	Hybrid		■	■
InVigor R 5520P	Mid-slow	Mid	RR	Hybrid	■	■	■
InVigor R3520		Early-mid	RR	Hybrid	■		
InVigor T3510	Mid-fast	Early	TT	Hybrid		■	■
InVigor T4510	Mid-fast	Early-mid	TT	Hybrid	■	■	■
Nuseed Diamond	Fast	Early	Conventional	Hybrid	■	■	■
Nuseed Quartz	Mid	Early-mid	Conventional	Hybrid	■	■	■

Pioneer 43Y23 (RR)		Early	RR	Hybrid			
Pioneer 43Y29 (RR)	Mid-fast	Early	RR	Hybrid			
Pioneer 43Y92 (CL)	Mid-fast	Early	CLF	Hybrid			
Pioneer 44T02 (TT)		Early-mid	TT	Hybrid			
Pioneer 44Y27 (RR)	Mid-fast	Early-mid	RR	Hybrid			
Pioneer 44Y90 (CL)	Mid-fast	Early-mid	CLF	Hybrid			
Pioneer 44Y94 (CL)		Early-mid	CLF	Hybrid			
Pioneer 45T03 (TT)	Mid-fast	Mid	TT	Hybrid			
Pioneer 45Y25 RR		Mid	RR	Hybrid			
Pioneer 45Y28 (RR)		Mid	RR	Hybrid			
Pioneer 45Y91 (CL)	Mid-slow	Mid-late	CLF	Hybrid			
Pioneer 45Y93 (CL)	Mid-slow	Mid	CLF	Hybrid			
Saintly CL	Mid-fast	Early	CLF	Hybrid			
SF Ignite TT	Mid-slow	Mid-late	TT	Hybrid			
SF Spark TT	Fast	Early	TT	Hybrid			
SF Turbine		Early-mid	TT	Hybrid			
Victory V7001CL		Late	CLF	Hybrid			
Victory V5003RR		Mid	RR	Hybrid			
Victory V75-03CL	Mid-slow	Mid	CLF	Hybrid			
Xseed Condor		Mid	RR TruFlex	Hybrid			
Xseed Raptor	Mid-fast	Early-mid	RR TruFlex	Hybrid			

CLF = Clearfield, TT = Triazine tolerant, RR = Roundup Ready® ⦶ protected under the Plant Breeders Rights Act 1994

Sowing dates and treatments

The first sowing date for Trangie in 2018 was in late March, however it was abandoned due to poor establishment caused by high temperatures and a rapidly drying seedbed, so an alternate sowing was done in late May. Table 2 lists the sowing dates for each year for each location.

At Condobolin in 2018, five commercial grown varieties were chosen with a wet and dry treatment. Each variety had two N rates applied a rate to suit a decile 3 rainfall year and a rate for a decile 9 rate rainfall year (Table 3).

Table 2. The sowing dates for each year at each of the locations

	Trangie 2018	**Condobolin 2018**	**Trangie 2019**	**Wagga Wagga 2020**
SD 1	26-Apr	5-Apr	4-Apr	26-Mar
SD 2	23-May	26-Apr	26-Apr	27-Apr

Table 3. Treatment list for Condobolin 2018

Varieties	Water Treatment	Nitrogen Rates
Nuseed Diamond	Dry (151mm in season)	Decile 3 (72 N Units)
ATR Stingrayᶲ	Wet (307mm in season)	Decile 9 (150 N Units)
ATR Bonitoᶲ		
Pioneer 44Y90 (CL)		
ATR Wahooᶲ		

Results

Phenology

In 2018 at Trangie, the earliest varieties to start flowering from the 26 April sowing date were Hyola 350TT, ATR Stingrayᶲ and Nuseed Diamond, with these varieties flowering at the start of the optimum flowering period of 15 July. Hyola 580CT and InVigor T4510 flowered right on the optimum date of 29 July from the 26 April sowing (Figure 1). From this same sowing date, the long season varieties ATR Wahooᶲ and Victory V7001CL flowered outside the optimum flowering window by up to 13 days. From the later sowing date of the 23 May in 2018, all varieties flowered after the optimum start of flowering period. The short season varieties, Hyola 350TT, ATR Stingrayᶲ and Nuseed Diamond reached start of flowering between the 18 August and 21 August. The late season varieties did not start flowering until early September, placing them at a high risk of heat stress (Figure 1).

The first sowing date for Trangie in 2019 was 4 April, the second sowing date 26 April. Nuseed Diamond and Hyola 350TT were the first to flower on 13 and 14 June, well before the optimum start date for Trangie. Varieties flowering this early puts them at a higher risk of frost damage, upper canopy blackleg infection and sclerotinia stem rot. The late maturing varieties were the only ones to start flowering after 15 July from the 4 April sowing date, with SF Ignite TT flowering closest to the optimum date of 29 July. From the late sowing date of 26 April, all early–mid, mid and late season varieties flowered within the optimum start of flowering period. The early season variety Nuseed Diamond started flowering just outside the optimum period between on the 15 July. (Figure 2).

Nuseed Diamond was the first to flower from the 26 March sowing at Wagga Wagga in 2020, flowering on the 13 June, 48 days before the optimum start of flowering period of the 31 July. The only varieties to flower after the 31 July from the 26 March sowing were InVigor R 5520P, Pioneer 45Y23 (CL), Pioneer 45Y91 (CL), Pioneer 45Y28 (RR), ATR Wahooᶲ and SF Ignite TT. ATR Wahooᶲ and SF Ignite TT were the latest to flower on the 10 August. Delaying the sowing date to late April (27 April), the majority of varieties started flowering within the optimum start of flowering period for Wagga Wagga (31 July – 1 September), the earliest being Nuseed Diamond on 10 August. Pioneer 45Y91 (CL) was the last variety to reach start of flowering on 4 September (Figure 3).

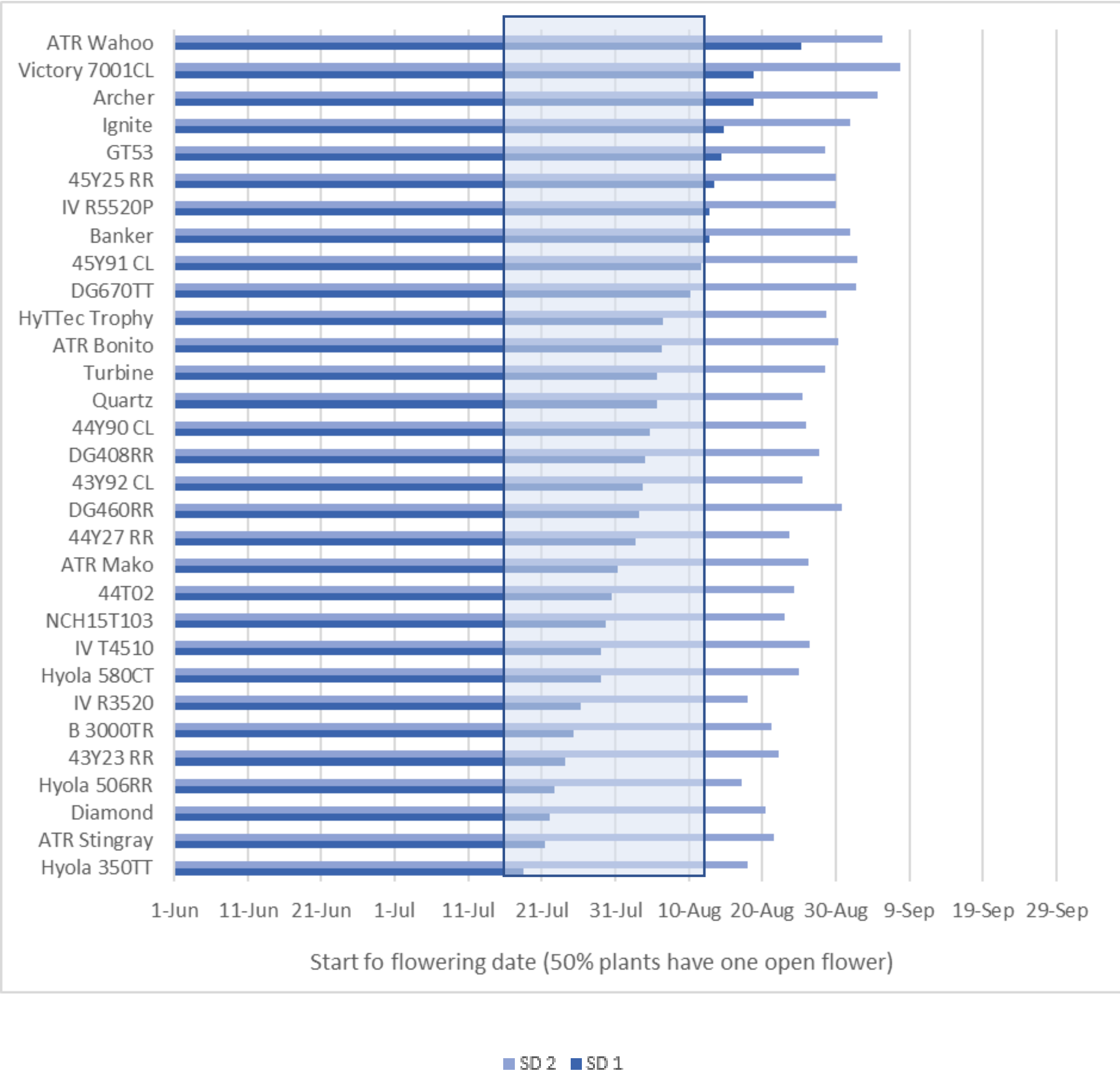

Figure 1. Flowering dates for 2018 Trangie. The shaded area shows the optimum start of flowering period (when 50% of plants have one open flower) for Trangie (15 July to 12 August). Sowing date (SD) 1 (darker bars) was 26 April, sowing date 2 (lighter bars) was 23 May
(Some of the varieties in the figure above are protected under the Plant Breeders Rights Act 1994. Please see Table 1 for which varieties)

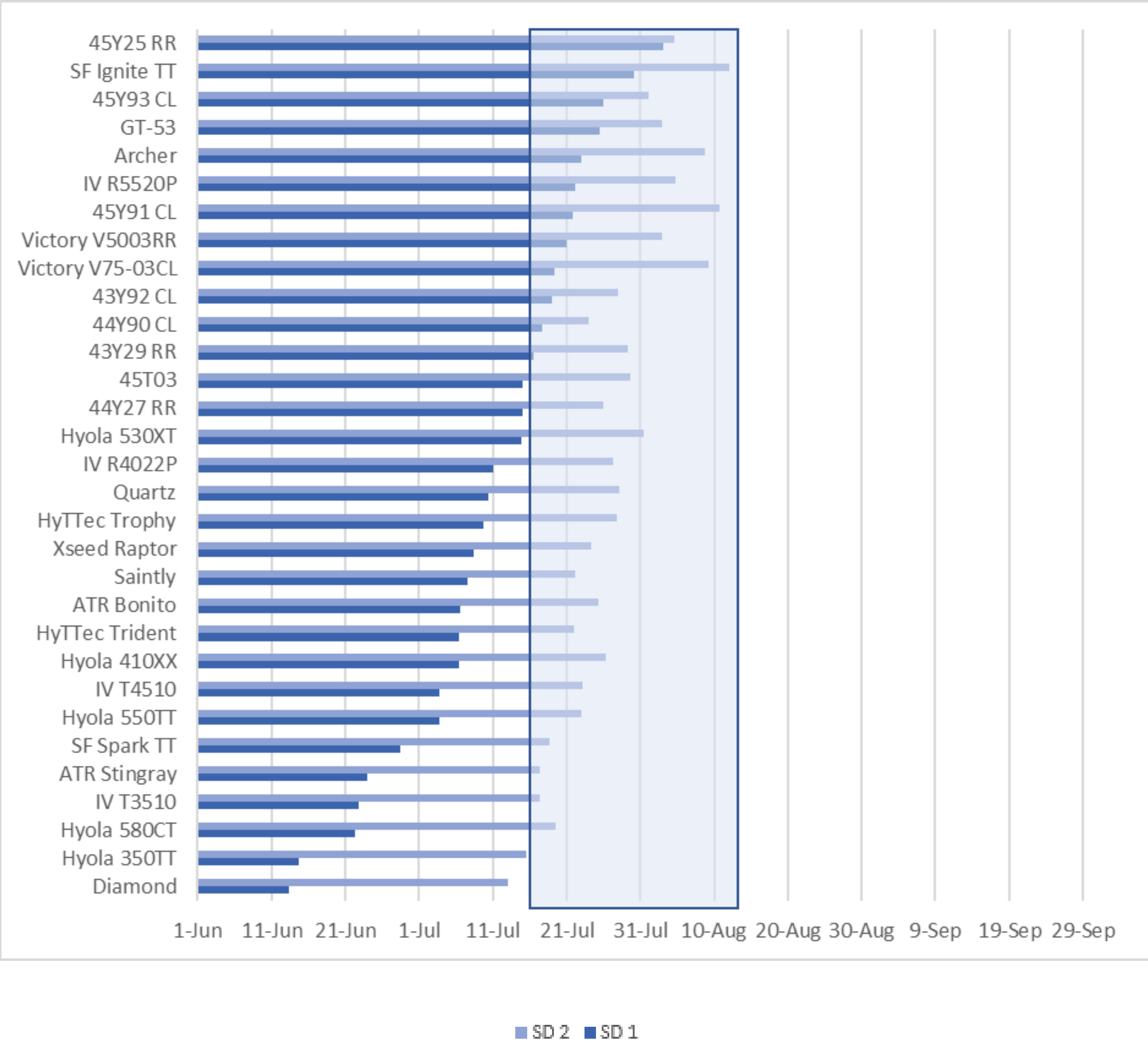

Figure 2. Flowering dates for Trangie, 2019. The shaded area shows the optimum start of flowering period (when 50% of plants have one open flower) for Trangie (15 July to 12 August). Sowing date (SD) 1 (darker bars) was 4 April, sowing date 2 (lighter bars) was 26 April.
(Some of the varieties in the figure above are protected under the Plant Breeders Rights Act 1994. Please see Table 1 for which varieties)

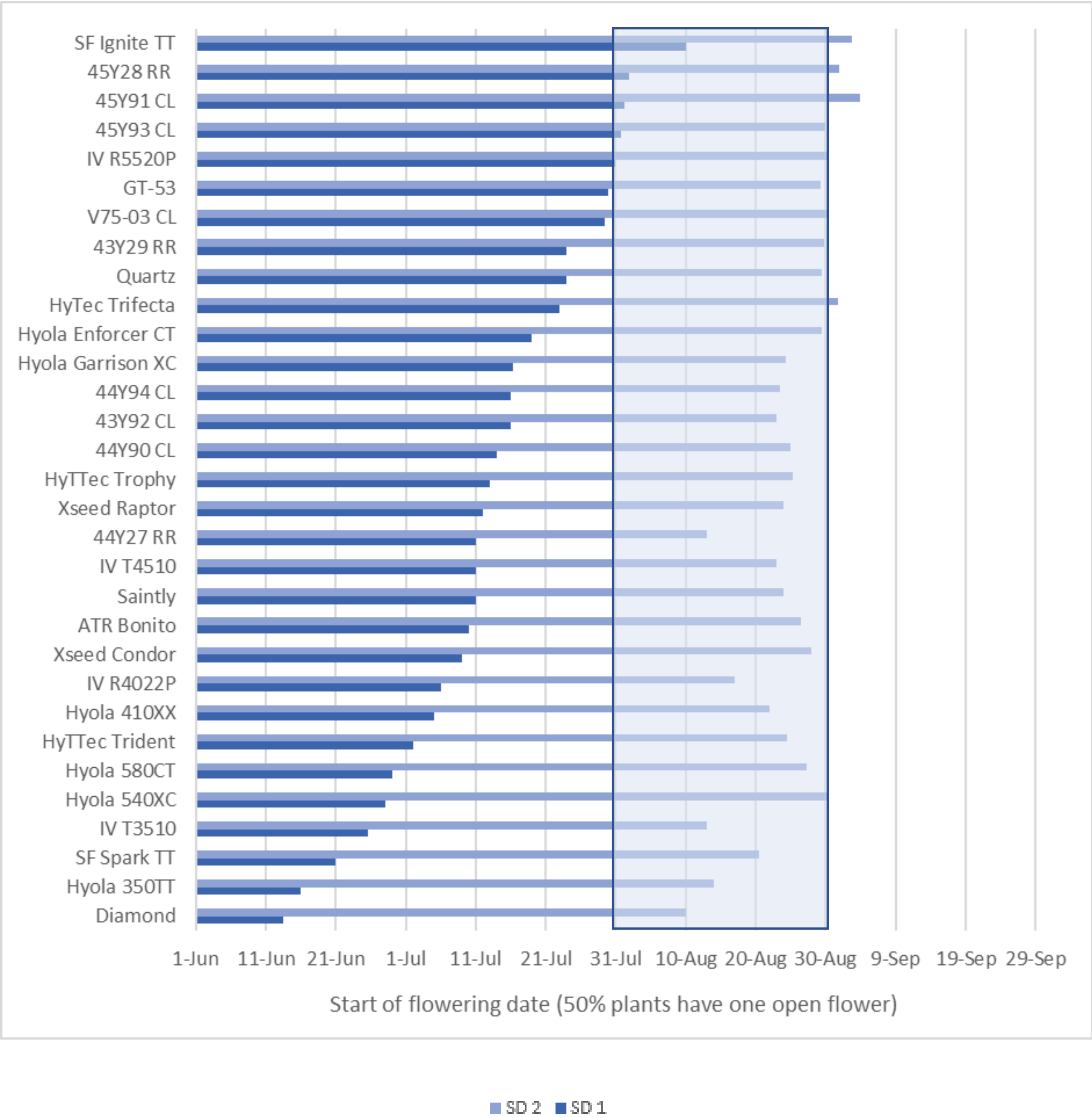

Figure 3. Flowering dates for Wagga Wagga, 2020. The shaded area shows the optimum start of flowering period (when 50% of plants have one open flower) for Wagga Wagga (31 July to 1 September). Sowing date (SD) 1 (darker bars) was 26 March, sowing date 2 (lighter bars) was 27 April.
(Some of the varieties in the figure above are protected under the Plant Breeders Rights Act 1994. Please see Table 1 for which varieties)

At Condobolin in 2018, Nuseed Diamond with a Decile 9 N rate and watered to achieve a total supply of 307mm (subsoil water + in-crop rainfall) was the quickest to flower from the first sowing date (5 April), flowering on 3 July, 23 days earlier than the optimum start of flowering period (26 July – 16 August). Both Nuseed Diamond and ATR Bonito with a Decile 9 N rate in the dry treatment (151mm in season rainfall), flowered close to the optimum start of flowering date of 9 August from the first sowing date, up to a month later than the watered treatment, indicating that moisture stress in plants will delay the start of flowering. In most cases, varieties in the dry treatment flowered well after those in the wet treatment, with the mid and longer season varieties (ATR Bonito from the second sowing date, Pioneer 44Y90 (CL) and ATR Wahoo⁽ᴾ⁾) flowering outside the optimum flowering window, putting them at a high risk of heat stress (Figure 4).

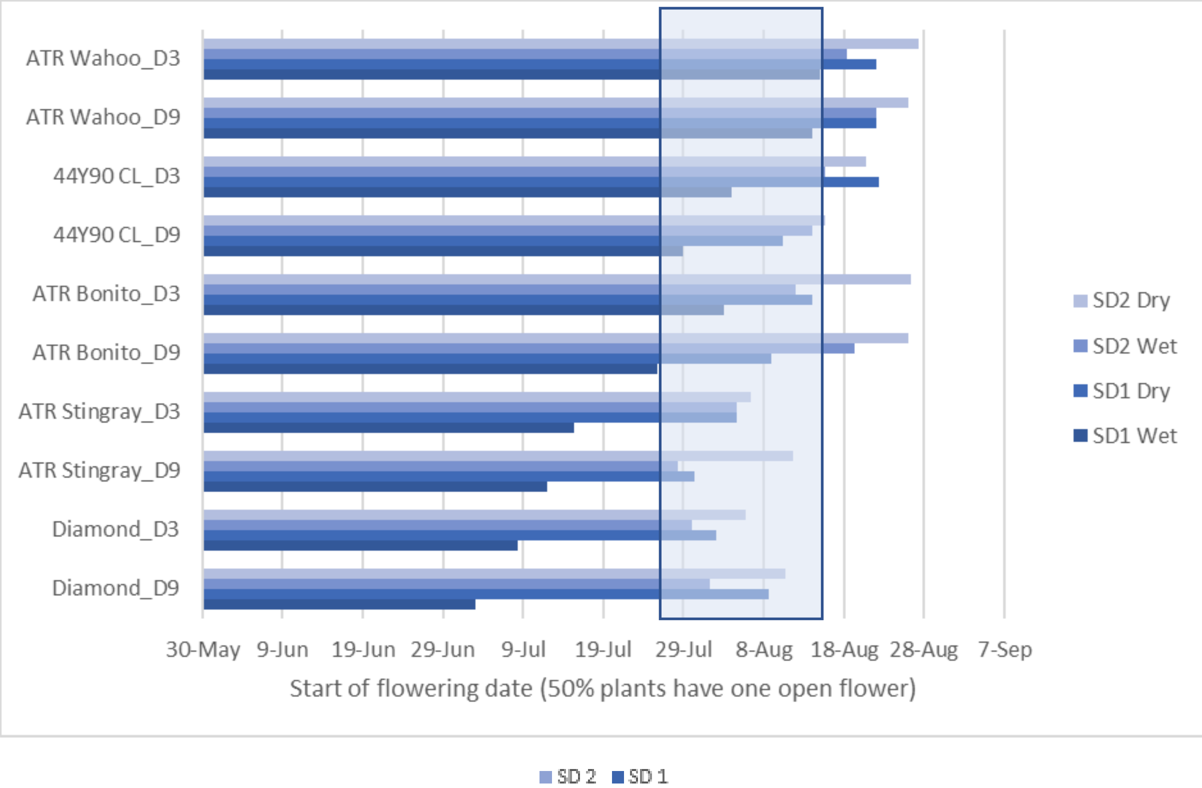

Figure 4. Start of flowering dates (50% of plants have one open flower) for wet and dry treatments and N rates for Condobolin, 2018. D3 and D9 relate to the Decile N rates applied. Shaded area is the optimum flowering window for Condobolin (26 July to 16 August). Sowing date (SD) 1 (darker bars) was 5 April, sowing date 2 (lighter bars) was 26 April.
(Some of the varieties in the figure above are protected under the Plant Breeders Rights Act 1994. Please see Table 1 for which varieties)

Discussion

Flowering time and therefore flowering within a particular period for a given location is one of the most important drivers of grain yield in canola. Having an understanding of a variety's phenology and how that variety responds to temperature influences how the variety will perform in different environments and the correct sowing window in which that variety should be sown. During the leaf production stages of canola growth, varieties can be influenced by thermal time, photoperiod or vernal time, or a combination. For instance, winter varieties (not included in these experiments) need a period of vernalisation (cold temperatures) before they will switch from vegetative stages (leaf production) to reproductive stages (bud and flower production) of growth. The time taken within the reproductive stage, for buds to elongate and initiate flowers is also influenced by thermal time and photoperiod. There is no vernalisation requirement within the reproductive stage.

Although the spring varieties included at Trangie and Wagga Wagga did not require vernalisation before reproductive stages were initiated, the differences observed in flowering times show that the varieties still have different thermal and photoperiod requirements before they will begin flowering. The fast spring varieties such as Nuseed Diamond and Hyola 350TT do not require much thermal time for them to shift to reproductive stages and begin flowering. When these varieties are sown early, they can be exposed to warmer temperatures soon after sowing which increase the accumulated thermal time causing them to begin flowering earlier. In contrast, slow spring varieties such as ATR Wahoo⊕ and SF ignite TT, require a longer period of thermal time before they will begin flowering. Varieties sown in different environments will change the length of time it takes for those varieties to begin flowering. Fast springs will still be fast springs, however in a warmer environment such as Trangie, accumulated thermal time will be quicker than for a cooler environment like Wagga Wagga.

Understanding how a variety responds to thermal time and photoperiod and therefore knowing a varieties phenology will influence a grower's decision on when to sow that variety to avoid flowering when the risk of frost, disease, heat or moisture stress is higher.

Conclusion

Canola varieties differ in their flowering times depending on where and when they are sown. Sowing a fast variety too early can lead to flowering when the risks of frost and disease are high; sowing a slow variety too late increases the risk of heat and moisture stress.

Matching a variety's phenology to its sowing time is critical for flowering to start during the optimum flowering period for each region, which is when environmental and disease risks are balanced for the highest yield potential. More information on sowing windows to suit variety phenology can be found in the DPI's Winter crop variety sowing guide 2020.

Further information

https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide

https://grdc.com.au/resources-and-publications/all-publications/publications/2018/ten-tips-to-early-sown-canola

https://grdc.com.au/resources-and-publications/all-publications/publications/2019/20-tips-for-profitable-canola-central-and-southern-nsw

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

Optimising canola establishment and performance by phosphorus fertiliser placement

Maurie Street and Ben O'Brien, Grain Orana Alliance

Key words

phosphorus, canola, fertiliser, placement, establishment

GRDC code

GOA00002

Take home message

- Traditional methods of applying phosphorus-based starter fertilisers with the seed is often reducing canola establishment, in some cases, by well over 50%
- This is costing growers through the need to increase seeding rates to compensate for losses, reduced yields through low populations or, in extreme cases, the need to resow crops
- Placing fertiliser away from the seed, either below or broadcast on the soil surface either before or after sowing largely eliminated the negative impacts on crop establishment
- These alternate application placement options produced similar yield responses as the traditional option of putting the fertiliser with the seed
- Applying phosphorus fertilisers by these alternate methods may also offer some logistical advantage in timing of operations
- Dry soil conditions may hinder access to applied phosphorus in the surface applied options, but in these trials, there was limited occurrences at commercial rates of phosphorus.

Background

Phosphorus (P) is an important nutrient to optimise canola production. Traditionally, P fertiliser has been applied at planting, banded near the seed. This approach is likely to be based on the premise that P is relatively immobile in the soil and needs to be placed close to the developing root systems of crops to be readily accessible early in the crop cycle.

However, damage to establishing crops by placing fertiliser close to seed has long been accepted. Trials in 2013, by Jenkins and Brill from the Department of Primary Industries demonstrated significant reductions in canola establishment with increasing rates of P (up to 20 kg/ha) applied at seeding. However, yields still increased with increasing rates of P despite the suppression in emergence, demonstrating the ability of canola to compensate for lower plant populations in the circumstances tested.

So, if the crop can compensate and maintain yield despite lower establishment, what is the problem?

Firstly, seed costs for growing canola can be high. When only a fraction of the seed purchased results in an established plant, this inefficiency represents a significant cost, particularly where seed can cost more than $80/ha. Secondly, the impacts on plant establishment can be variable and un-predictable which has resulted in growers increasing seeding rates to cover the possibility of decreased establishments. Thirdly, in extreme cases crop establishment impacts may be so severe, that yields are impacted, or crops need resowing.

Recent changes to farming systems may further increase risk of damage. The adoption of wider row spacings and sowing with knife points or disc seeders all have the effect of increasing fertiliser concentration within the drill line, thus increasing potential for damage. Furthermore, the move to earlier sowing, into warmer and potentially more rapidly drying soils could only be thought to further exacerbate the risks of variable crop establishment.

A field survey undertaken in 2017 (McMaster, C. 2019) assessed canola establishment across 95 commercial crops in the central west of NSW. This survey showed that crop establishments ranged from as low as 17% up to 86% with an average of 48%. Whilst the report suggested that seed size had the greatest influence over establishment it also mentioned several other factors also correlated well, including stubble loads, sowing speed, seeding depth and starter fertiliser and its proximity to the seed.

So how do we apply enough P to optimise yields, without a negative impact on establishment while maintaining or even improving P fertiliser efficiencies? Could altering our way of applying P fertilisers to canola crops also improve the reliability of crop establishment which is a key deterrent to many growers from growing canola (GRDC Grower Network, 2020)?

Trial work undertaken by GOA under the Grower Solutions Group Project since 2015 has been investigating alternate options for applying conventional P fertilisers in canola to address these key questions.

This paper details the outcomes from this series of trials and proposes alternate ways to apply P in winter grown canola crops.

Methodology

The hypothesis was 'can we apply P fertiliser in an alternate manner to the standard approach of banding it with the seed, that minimises the impact on crop establishment whilst maintaining the fertiliser response in crop performance (yield)?'.

A series of 15 trials have been run since 2015 investigating alternate methods of P starter fertiliser placement as detailed below-

- With seed (with)- fertiliser applied through the same seed boot as the seed is delivered
- Below seed (below)- delivered though a second boot set to deliver the fertiliser below the seed with at least 2-3 cm separation from the seed position
- Incorporate by sowing (IBS)- fertiliser was broadcast just prior to sowing and incorporated by the seeder (knife point and press wheel- 27cm row spacing)
- Top-dressed- fertiliser was broadcast just after seeding to the soil surface with no incorporation.

Initially the P fertiliser used was Trifos (triple super) because of the absence of N in its makeup. However, this product is now largely unavailable, and many growers were simply using ammonium phosphate fertilisers such as DAP or MAP as their P source and as such MAP, was used in more recent trials. Details of the fertiliser type, rates tested, and the range of placements is detailed in Table 1 below. Although this report does report the treatments in terms of the rate of P applied, it should be considered that with P supplied as MAP there is an associated amount of N delivered with that rate of P. This Nitrogen may be also contributing to damage but as most starter fertilisers contain both these elements, apportioning the blame to P or N is difficult but also somewhat academic.

However, in trials where MAP was used, the differing nitrogen levels applied were balanced out with urea across all rates to ensure any yield responses were not influenced by differences in N rates applied.

Table 1. Details of trial site and treatments

Year	Location	Site Colwell P (0-10cm)	Fertiliser tested	P rates applied kg P/ha	Fertiliser placement treatments
2015	Wellington	21 ppm	Trifos	0, 10, 20	With, below, IBS
2015	Gilgandra	12 ppm	Trifos	0, 10, 20	With, below, IBS
2016	Gilgandra	18 ppm	Trifos	0, 15, 30, 45	With, below, IBS, top-dressed
2016	Alectown	10 ppm	Trifos	0, 15, 30, 45	With, below, IBS, top-dressed
2017	Nyngan	33 ppm	Trifos	0, 15, 30, 45	With, below, IBS, top-dressed
2017	Jemalong	19 ppm	Trifos	0, 15, 30, 45	With, below, IBS, top-dressed
2017	Gilgandra	21 ppm	Trifos	0, 15, 30, 45	With, below, IBS, top-dressed
2017	Geurie	<5 ppm	Trifos	0, 15, 30, 45	With, below, IBS, top-dressed
2018	Wellington	20 ppm	Trifos	0, 10, 20, 40	With, below, IBS, top-dressed
2018	Canowindra	36 ppm	Trifos	0, 10, 20, 40	With, below, IBS, top-dressed
2019	Gilgandra	23 ppm	MAP	0, 10, 20, 40	With, below, IBS, top-dressed
2020	Gilgandra	39 ppm	MAP	0, 10, 20, 40	With, below, IBS, top-dressed
2020	Gollan	23 ppm	MAP	0, 10, 20, 40	With, below, IBS, top-dressed
2020	Wongarbon	32 ppm	MAP	0, 10, 20, 40	With, below, IBS, top-dressed

Results

Table 2 summarises the statistically analysed responses on two main measures- plant population and yield response to P rate and placement. As the traditional method of P placement is 'with' this is a common comparison made. Further detail on individual trial reports can be found at www.grainorana.com.au.

The '>' indicate the yields from the aforementioned treatment exceeds the following treatment, '&' between two treatments indicates there was no difference between those treatments. Alternate placement methods in **bold** highlight only cases where yields are lower than the traditional 'with' placement.

Table 2 also details the rainfall received for the 60 days following seeding for each site/year, as this is thought to influence nutrient access for some of the placement methods. The yield range of the site is also included for the reader to consider the nutrient requirement for the crop as a pseudo indicator of crop growing conditions throughout the year.

Table 2. Trial results from 15 trials on P rate and placement in canola, summarising the impact on plant population and yield when P fertiliser was applied 'with seed', 'below seed', top-dressed or incorporated by sowing (IBS).

Site/year	Impact on plant populations	Impact on yields	Rainfall 60 days post planting ^	Yield range t/ha
Wellington 2015	P rate applied or placement had no impact	P rate applied or placement had no impact	118 mm	1.4- 1.9
Gilgandra 2015	20 kg/ha P 'with seed' resulted in lower populations than 10 kg/ha. 'Below seed' & IBS had no impact on populations regardless of P rate	Site was rate responsive when P was applied 'with seed' 10 & 20 kg/ha > Nil P At 10 kg/ha P- No impact of placement At 20 kg/ha P- 'with seed' & 'below seed' > **IBS**	159 mm	1.3 – 2.1
Gilgandra 2016	All rates of P applied 'with seed' resulted in lower plant populations by around 30%, compared to 'below seed', IBS & top-dressed in all but one case.	Site was rate responsive when P was applied 'with seed' 30kg/ha > 15 & 45kg/ha > Nil P At 15kg/ha P- No impact of placement At 30kg/ha P- No impact of placement At 45 kg/ha P- IBS, top-dressed & 'below seed > 'with seed'	256 mm	1.8- 2.7
Alectown 2016	At 30 & 45 kg/ha of P 'with seed' resulted in up 40% lower plant populations than 'below seed, IBS or top-dressed which were not different to one another At 15 kg/ha P 'with seed' was lower than IBS & 'below seed' but not different to top-dressed	Site was rate responsive when P was applied 'with seed' 30 kg/ha > 45, 15 kg/ha & Nil At 15kg/ha P- no impact of placement At 30kg/ha P- No impact of placement At 45 kg/ha- IBS & top-dressed > 'with seed & 'below seed'	172 mm	2.3 – 3.4
Nyngan 2017	At 45kg/ha of P 'with seed' or 'below seed' plant populations were reduced by 65% and 40% respectively compared to the best treatment, top-dressed. At 15kg/ha & 30 kg/ha of P 'with seed' there was no impact by placement.	Site was rate responsive when P was applied 'with seed' 15, 30 & 45 kg/ha > Nil At 15 kg/ha P- no impact of placement At 30 kg/ha- 'below seed' > IBS, top-dressed & 'with seed' At 45 kg/ha- 'with seed' & top-dressed > **IBS** & **'below seed'**	27 mm	0.3 – 0.5
Jemalong 2017-	P rate applied, or placement had no impact	P rate applied or placement had no impact	13 mm	0.3 – 0.9

Site/year	Impact on plant populations	Impact on yields	Rainfall 60 days post planting ^	Yield range t/ha
Gilgandra 2017-	P rate applied, or placement had no impact	Site was rate responsive when P was applied 'with seed' 45 kg/ha & 30 kg/ha >15kg/ha > Nil At 15 kg/ha P- No impact of placement At 30 kg/ha- 'below seed', 'with seed' & top-dressed > **IBS** 45 kg/ha- 'below seed' > 'with seed', IBS and top-dressed	11.6 mm	0.9 – 1.4
Geurie 2017-	P rate applied, or placement had no impact	Site was rate responsive when P was applied 'with seed' 45 kg/ha, 30 kg/ha > 15 kg/ha > Nil At 15 kg/ha P- 'below seed' > 'with seed' & top-dressed > **IBS** At 30 kg/ha P- 'below seed' & 'with seed' > **top-dressed** & **IBS** 45 kg/ha P- 'below seed' & 'with seed' > **IBS** & **top-dressed**	47 mm	0.2 – 1.2
Wellington 2018	At 45 kg/ha P applied 'with seed' resulted in a lower plant population (~37%) than when applied 'below seed', IBS or top-dressed At 10 or 20 kg/ha there was no impact of placement.	Site was not rate responsive when P was applied 'with seed' At 10 kg/ha P- no impact of placement At 20 kg/ha P- 'with seed', 'below seed' & top-dressed > **IBS** At 40 kg/ha P- no impact of placement	37 mm	1.0 – 1.4
Canowindra 2018	At 40 kg/ha P 'with seed' resulted in lower plant populations than top-dressed and IBS At 20 kg/ha there was no impact of P placement. At 10 kg/ha 'with seed' & 'below seed' resulted in lower plant populations.	Site was rate responsive when P was applied 'with seed' 40 & 20 kg/ha > 10 kg/ha & Nil At 10 kg/ha P- below> 'with seed', top-dressed & IBS At 20 kg/ha P- top-dressed & 'below seed' > 'with seed' & IBS At 40 kg/ha P- 'below seed' & 'with seed'> **top-dressed** and **IBS**	31.5 mm	0.4 – 0.5
Gilgandra 2019	At all rates of P applied 'with seed' resulted in the lower plant populations than IBS, top-dressed &	Site was rate responsive when P was applied 'with seed' 40 kg/ha >10, 20 kg/ha & Nil At 10 kg/ha P- no impact of	18.6 mm	0.6 – 0.9

Site/year	Impact on plant populations	Impact on yields	Rainfall 60 days post planting ^	Yield range t/ha
	'below seed' except at 10 kg/ha P where 'below seed' only was no different to 'with seed'.	placement At 20 kg/ha P- top-dressed & 'below seed' > 'with seed' & IBS At 40 kg/ha P- 'below seed' &, top-dressed > IBS & 'with seed'		
Gilgandra 2020	At any rate of P applied 'with seed' resulted in the lowest plant population. At 40 kg/ha placed 'with seed' the seed reduced establishment by 81% compared to top dressed	There was an inverse response to P rate when applied 'with seed' # No impact when applied by the alternate placements. At 10 kg/ha P- no impact of placement At 20 kg/ha P- top dressed, IBS & 'below seed' > 'with seed' At 40 kg/ha P- IBS, top-dressed & 'below seed' > 'with seed'	52 mm	1.7 – 2.4* *Site was hail damaged prior to harvest- treat results with caution*
Gollan 2020	At any rate of P, establishment was lowest when applied 'with seed'. At 40 kg/ha establishment was reduced by ~58% compared with IBS, top-dressed & 'below seed'. At both 20 & 40 kg/ha there was no difference between IBS and top-dressed but better than 'with seed'	Site was P rate responsive when applied 'with seed' 40 kg/ha >20 kg/ha>10 kg/ha > Nil At 10 kg/ha P- no impact of placement At 20 kg/ha P- no impact of placement At 40 kg/ha P- no impact of placement	58 mm	2.2 – 3.7
Wongarbon 2020	At 10 kg/ha 'with seed', 'below seed' & top-dressed had lower plant populations than IBS, at 20 & 40 kg/ha 'with seed' was lower than IBS and top-dressed all which were no different	Site was P rate responsive when applied 'with seed'- 40, 20 & 10 kg/ha > nil At 10 kg/ha P- no impact of placement At 20 kg/ha P- no impact of placement At 40 kg/ha P- 'with seed', IBS and top-dressed > 'below seed'	93.6 mm	3.7 – 4.1

*- *Site was hail damaged prior to harvest- treat results with caution*

#- *Increasing P applied 'with' the seed reduced yields suggested to be because of very significant reductions in plant populations.*

^- *rainfall data from the nearest BOM or other automatic weather stations*

Summation of trial outcomes

As evidenced above, the P placement and rate can impact on plant populations (crop establishment), and it can be variable. In 11 out of 15 trials, plant populations were lower when P fertiliser was placed 'with the seed' when compared with alternate placements tested, in some cases by up to 80%. In general, the negative impact on plant populations increased as the P rate increased, but in some cases as little as 10 kg/ha of P was sufficient to reduce plant establishment.

Three trials in 2017 showed no impact of P rate or placement on plant populations, but all sites experienced very dry soil conditions just after planting. The only other site to show no impact of P on plant population was Wellington in 2015. This site was also not yield responsive to P rate or placement.

In contrast, where fertiliser was placed away from the seed using either IBS or top-dressed, there was no reduction in plant populations. In all cases, plant populations were comparable to where nil fertiliser was applied (data not shown), suggesting that any impact of P fertiliser on plant population had been negated by changing its position relative to the seed.

Placing P fertiliser below the seed did sometimes, but not always avoid impacts on plant populations.

In eight out of the 15 sites the yields of the alternate placements matched the performance of the traditional 'with seed' placement and in a small number of cases yields were improved.

Three sites, Gilgandra 2015 & 2017 and Wellington in 2018 had instances where only the IBS option had lower yields than the 'with seed' treatment. At Gilgandra in 2017, only the 30 kg/ha of P IBS treatment had lower yields. At all other rates (15 & 45 kg/ha) 'with seed' performed equally or worse than the alternates. At Gilgandra 2015 and Wellington 2018 the difference in the IBS treatment was only apparent at 20 kg/ha of P. At all other rates there no difference between placements.

Two sites had instances where the IBS and top-dressed had lower yields than the 'with seed' treatment, although only at the higher rates of 30 & 40 kg/ha , but not at the lower, 'more commercial' rates tested. It should be noted that most of these cases where differences occurred were in the drier years of 2017 and 2018.

The remaining two sites were non-responsive to both placement and rate for yield and establishment (Wellington 2015 and Jemalong 2017).

This body of work demonstrates that if P fertiliser is placed away from the seed, either IBS or top-dressed and to a lesser extent below the seed, this avoids the negative impacts on plant populations. It has also shown that in most cases, the yield response to the applied rate of P, matched the response where the P was applied 'with' the seed.

The placement 'below seed' resulted in only two cases where the yield was lower than the 'with seed' treatment, though this effect was only evident at the highest rate (45kg/ha) of P, rates that may be considered experimental rather than commercial. This however is not unexpected given the fertiliser was directly under the seed separated by only 2-3 cm where roots would naturally extend through this fertiliser band. However, placement of P 'below seed' did not always avoid reduction in plant populations as did IBS or top-dressed.

Interestingly, in most cases both the IBS and top-dressed treatments recorded a yield response even though the resting position of the fertiliser would have been above and or to the side of the seed. Large proliferations of surface roots were commonly observed in these trials, and it is assumed that these facilitated crop P uptake in sufficient quantity and time frame so as not to penalise crop performance.

The notable exception was the drier years, primarily 2017 where the rainfall received in the 60 days post planting was very low and may have limited the development and ability of surface roots to access fertiliser. It these years, in some cases, the 'with seed' or 'below seed' treatments did outperform the IBS and top-dressed options, but only at the higher rates tested of 30-45 kg/ha. At the more commercially relevant rate of 15 kg/ha, there was no impact of P placement. In a stark contrast, in many other trials applying such high rates of P with the seed was highly detrimental to plant populations and in some cases yields.

Given that not all farmers have the option to apply fertiliser below the seed and there may be some cases, in dry years when IBS and top-dressing may risk underperforming, another option may be to 'split' the starter fertiliser application. That is, apply a proportion of the P fertiliser at sowing, say 5-10 kg P/ha, with the seed and apply the balance IBS or top-dressed. In this scenario smaller amounts of P applied with the seed may be sufficient to meet crop requirements in a dry period/season, while reducing the impact on establishment. The remainder of the fertiliser applied IBS or top-dressed, becoming available if wetter (and higher yielding) conditions prevail.

This 'split' approach has been tested on a limited basis in the past few years, but further work is needed before this can be recommended.

What does this mean to canola growers?

Clearly placing fertiliser away from seed improving the rate and reliability of establishment of canola crops is a key advantage of this alternate approach. However, there may be further advantages.

In the case of surface applications growers may be able to apply most of their canola P fertiliser requirements ahead of seasonal breaks or the busy sowing periods and this will have significant logistic advantages. The low sowing rates of canola combined with reduced rates (if split) or nil P fertiliser will greatly increase the area that can be sown in any given period, as the number of seeder refills could be greatly reduced.

For growers that have very low seed bed utilisation (wider row spacing, knife points or disc openers), this approach may be the most practical option to apply higher rates of P fertiliser to canola crops without the associated risks and downsides. An alternative that is often considered is applying higher rates in the previous crop. However, this may increase the risk of nutrient tie up and it will extend the time until cash invested in fertiliser is recouped.

Conclusions

The traditional placement of P fertilisers such as MAP/ DAP or other high analysis starter fertilisers can reduce crop establishment by 50% or more. Factoring in these typical losses combined with the need for increased seed rates could potentially be costing growers more than $45/ha. In extreme cases the costs could be greater where yields are impacted or resowing is required. The impact of P fertilisers with seed is also likely to be contributing to the variable establishments growers often experience.

Over five years and 15 trials GOA has looked at alternate placements of P to avoid this issue. This work has shown that reductions in plant populations can be avoided by moving P away from intimate contact with the seed. This work has also shown that in most cases fertiliser efficiency has been maintained and in some cases of high rates of P, improved.

Placing the fertiliser below the seed maybe preferred if growers have suitable machinery. However, for growers who do not have this option, simply broadcasting the fertiliser and incorporating it by sowing (IBS), or even top-dressing post sowing has proven to be similarly effective.

The risk for the latter two approaches is likely to occur when dry soil conditions occur post sowing, which limit the crops ability to forage for that fertiliser, as was experienced in the drought year of 2017. However, in those years, crop fertiliser requirement was less, and yield differences were not apparent at commercial rates of 15 kg/ha. These alternate surface application approaches will have logistical advantages by offsetting some of the fertilising task from away sowing, which alone may be a key attraction.

GOA is planning to fine tune an approach of splitting the P fertiliser application, i.e. small basal amount with the seed and the balance applied to the soil surface. It is hypothesised that this approach may deliver the following advantages: minimise crop establishment impacts, reduce risks in dry conditions whilst maintaining fertiliser responses and improve sowing efficiencies (logistics).

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Soil moisture, nitrogen and disease legacy effects of different Central Western farming systems - 5 years of findings at Trangie

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Notes

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

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UCS00020

Take home messages

- Glyphosate resistance in annual ryegrass continues to increase whereas resistance to paraquat remains very low
- Significant glyphosate resistance in fleabane, awnless barnyard grass and feathertop Rhodes grass, especially in samples from Queensland
- Reduced control occurs if herbicides are applied to stressed weeds
- Improving herbicide efficacy by good application can reduce selection for herbicide resistance.

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 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 number of populations resistant to glyphosate in some of the 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 oats 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

An additional survey collected weed species across northern NSW and Queensland in summer 2016/17. The species collected during this survey included awnless barnyard grass, feathertop Rhodes grass, fleabane and some additional sowthistle samples. These samples were screened for resistance to glyphosate, with a significant percentage of the populations for all species (except for sowthistle) resistant to this herbicide (Table 3).

Table 3. Extent (percentage) of glyphosate resistance for weed species collected in 2016 summer survey (Includes sowthistle collected in northern NSW and Queensland winter survey)

	Northern NSW		Queensland	
	% Resistant	Populations tested	% Resistant	Populations tested
Awnless barnyard grass	0	5	37	37
Feathertop Rhodes grass	50	2	70	60
Fleabane	100	25	100	36
Sowthistle	7	45	3	62

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 1).

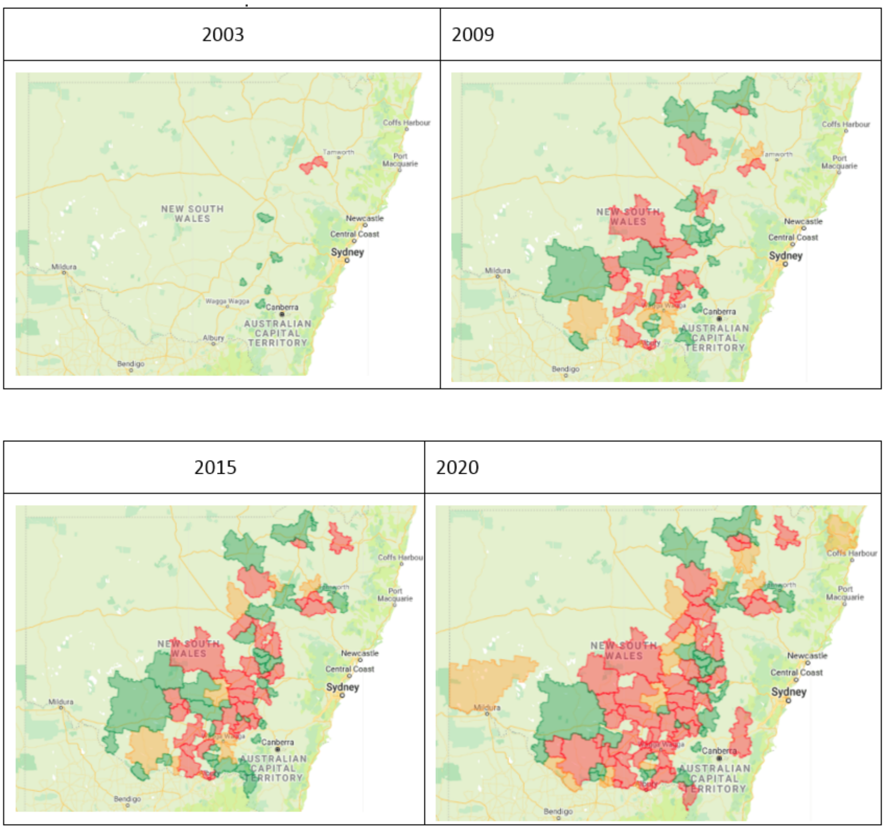

Figure 1. Occurrence of glyphosate resistance in annual ryegrass in NSW in 2003, 2009, 2015 and 2020. **Dark green shading** = postcode regions where testing has not detected glyphosate resistance in ryegrass, **orange shading** = postcodes where glyphosate resistance is developing and **red shading** = 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 2 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.

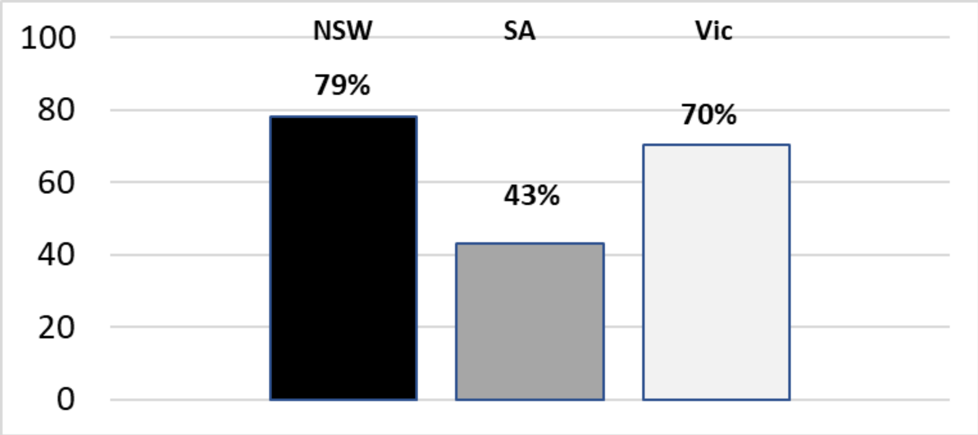

Figure 2. Percent (%) resistance to glyphosate confirmed in farmer ryegrass samples originating from 83 NSW, 37 SA and 74 Vic cropping paddocks treated with glyphosate in autumn 2020. Testing conducted by Plant Science Consulting using the Quick-Test.

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 and other weed species to glyphosate with generally more than one factor responsible. Reducing rates can increase the selection for 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. Differences in the level of resistance has also been detected in self-pollinating species such as awnless barnyard grass (Figure 3).

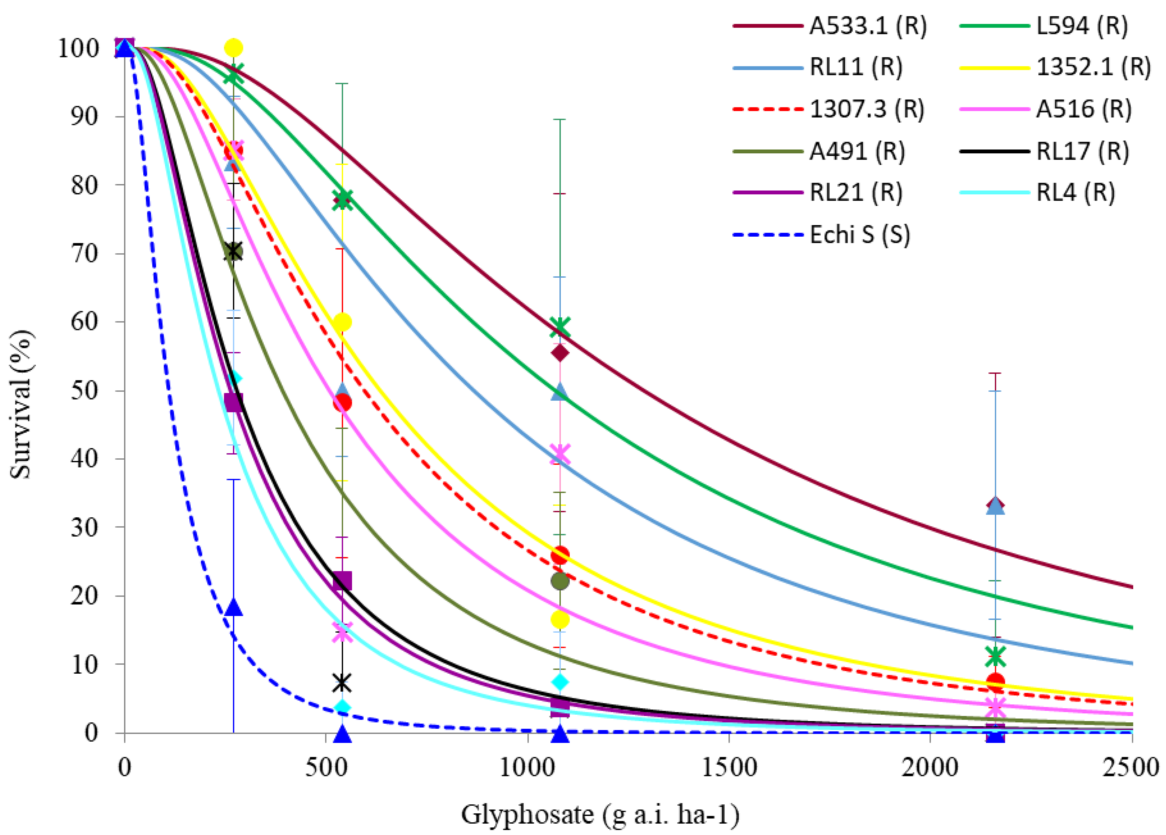

Figure 3. Response of 10 resistant awnless barnyard grass biotypes to increasing rates of glyphosate (The University of Adelaide). 'Echi S' is the susceptible control population.

Other factors that can select for glyphosate resistance by reducing efficacy include:

1. Using low quality glyphosate products and surfactants. Currently there are over 500 glyphosate products registered in Australia. Numerous trials have confirmed significant differences in activity between some glyphosate products on various weed species. In a recent outdoor pot trial conducted over summer nine glyphosate formulations were tested on susceptible barnyard grass, feathertop Rhodes grass, blackberry nightshade and glyphosate resistant sowthistle at equivalent g ai/ha rates. Significant differences were observed between most glyphosate products with some products providing significant control of glyphosate resistant sowthistle at the registered rate of 750g ai/ha. One of the most likely reasons for the difference between products is likely to be the quality of inbuilt surfactants.

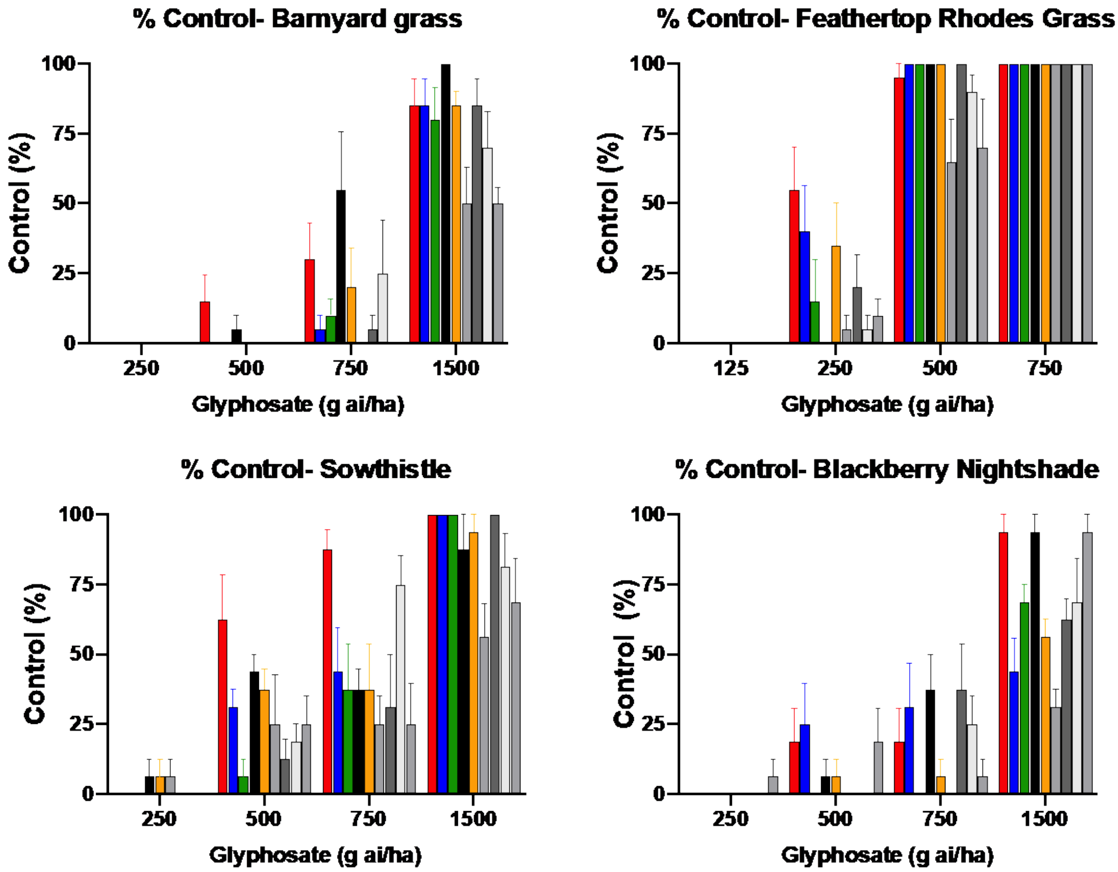

Figure 4. Control of four summer weed species with nine different glyphosate formulations. (Plant Science Consulting)

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 5). 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.

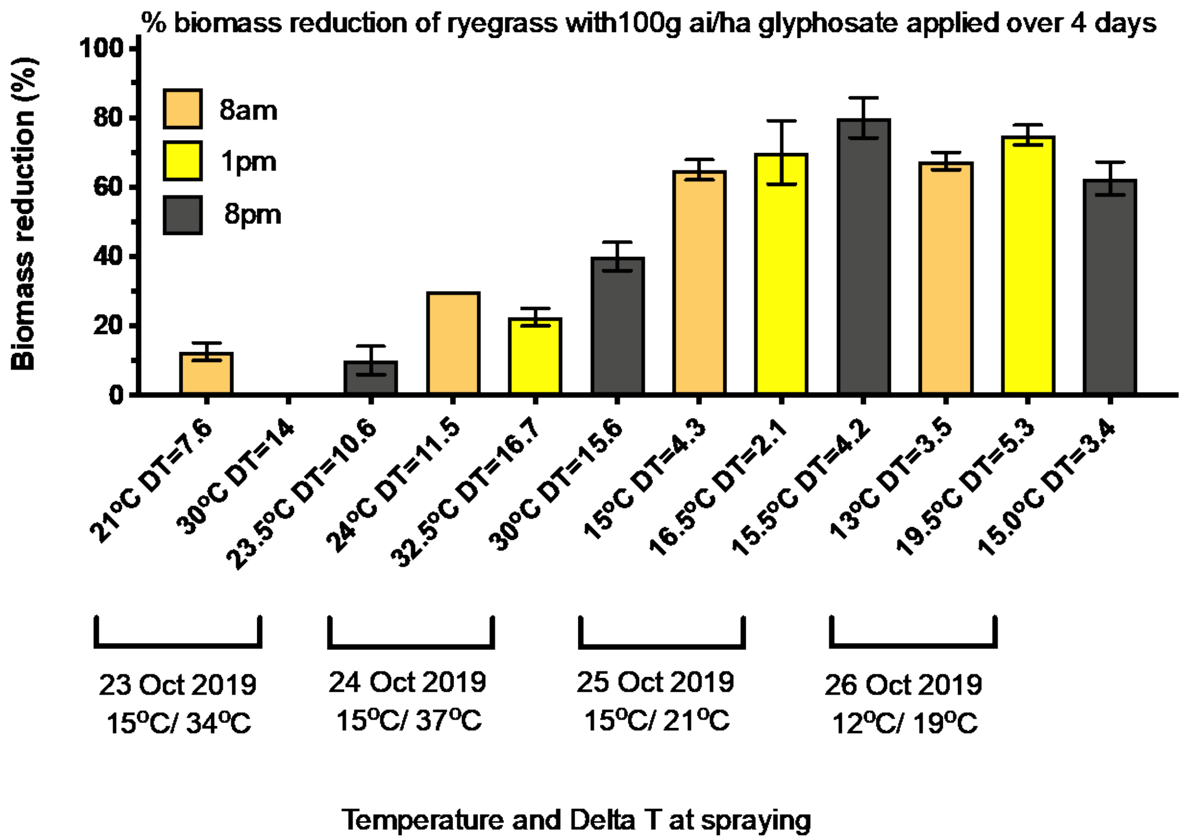

Figure 5. Effect of temperature & Delta T on glyphosate for ryegrass control
(Plant Science Consulting)
(A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions).

Reduced control can occur if plants are water stressed. In an outdoor summer pot trial, the effect of water stress on glyphosate activity on barnyard grass was assessed. A sub-set of plants were water stressed 2 days prior to application with glyphosate. Plants at three growth stages were included. Control of stressed plants (drought treatment) was significantly less than of non-stressed plants at all growth stages (Figure 6).

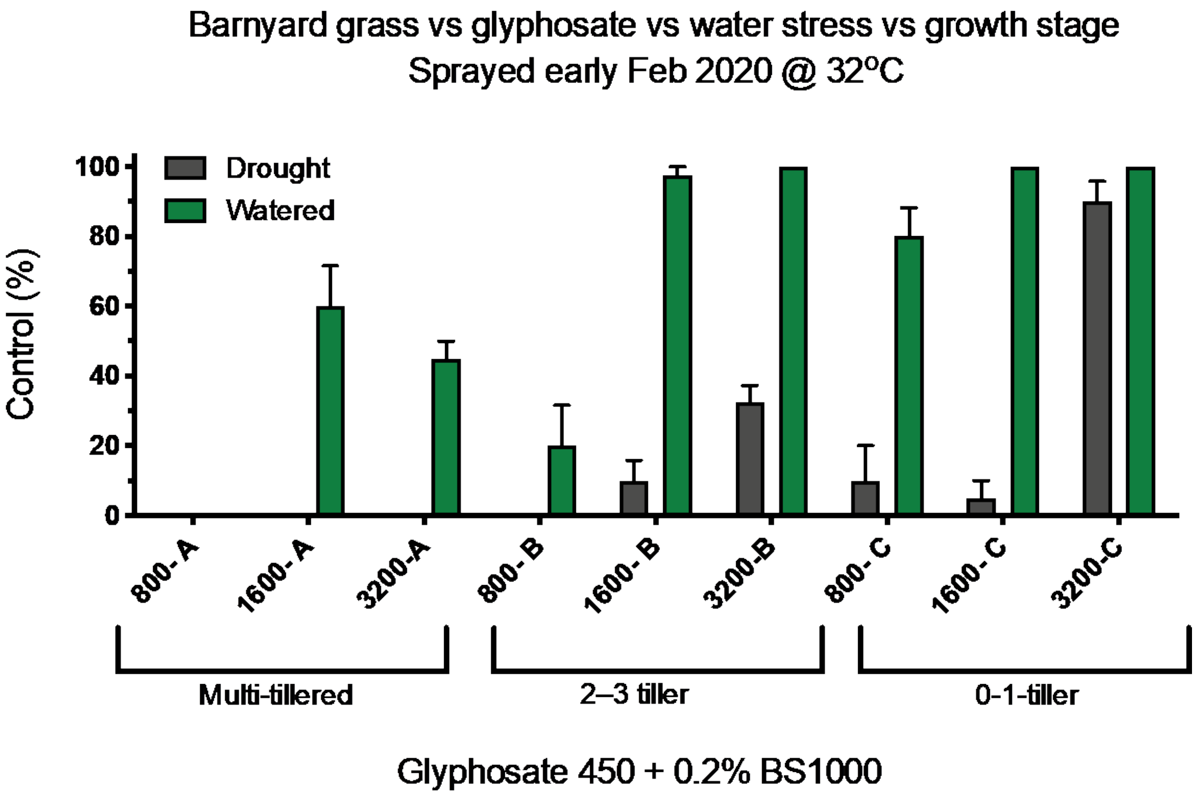

Figure 6. The effect of three rates of glyphosate on three growth stages of barnyard grass, half not water-stressed and the other half water-stressed (Plant Science Consulting)

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 its 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 222 mL/ha (100 g ai/ha) of glyphosate 450 (Figure 7). As a general rule, growers using rainwater (soft) should consider 1% of a liquid AMS formulation, if using hardwater (i.e. bore, dam) 2% AMS is recommended. The addition of a wetter resulted in a further improvement of herbicide efficacy.

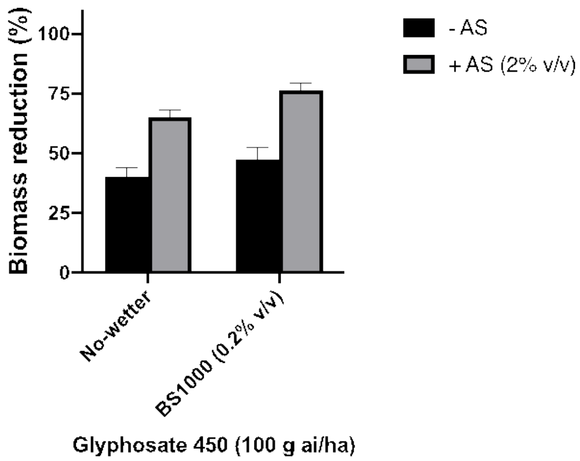

Figure 7. Effect of ammonium sulfate (AS) and wetter on glyphosate for ryegrass control
(A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions).

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 of shoots and roots (meristem), reducing efficacy.

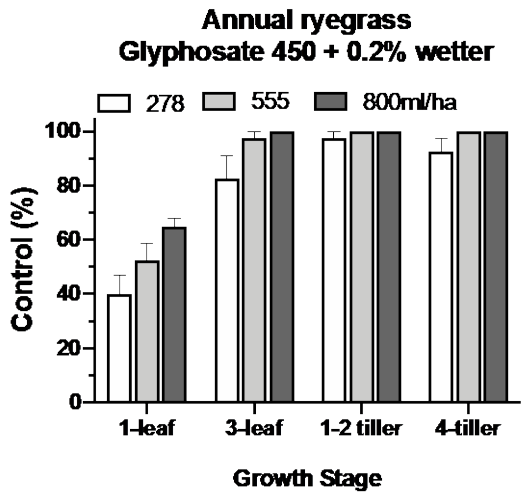

Figure 8. Effect of ryegrass growth stage on glyphosate activity
(A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions).

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.

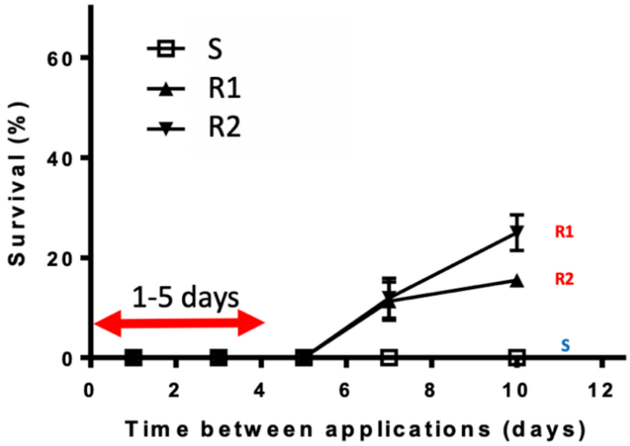

Figure 9. Double knock timing. Glyphosate applied onto a susceptible (S) and two glyphosate resistant ryegrass biotypes (R1 & R2) followed by paraquat 1, 3, 5, 7 and 10 DAA. Trial work conducted by Dr Christopher Preston (The University of Adelaide).

Incidence of paraquat resistance

Resistance to paraquat has been detected in a few ryegrass populations from WA, SA, Vic. They have originated along fencelines, non-cropped farm areas, lucerne/clover seed production paddocks and vineyards (Figure 10). Detection has been via random weed surveys and 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 is also highly resistant to glyphosate.

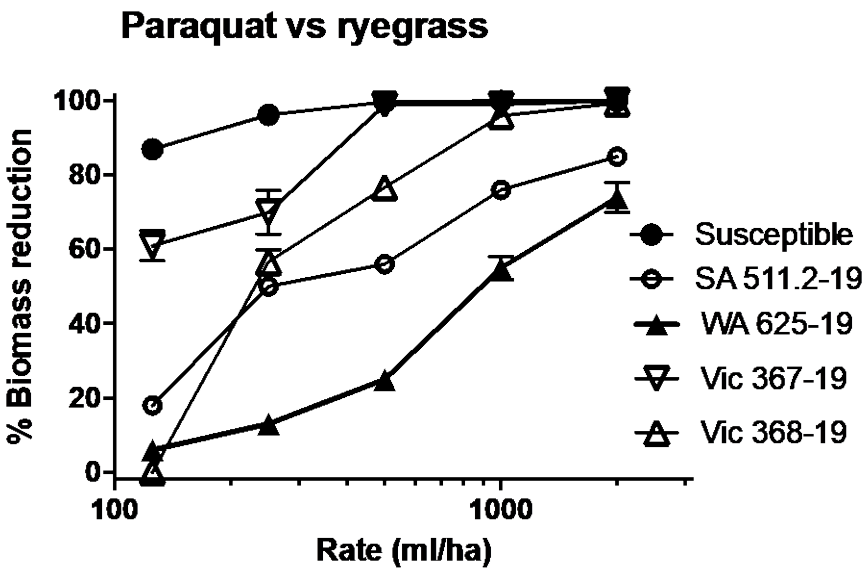

Figure 10: Efficacy of the first confirmed cases of paraquat resistance in annual ryegrass from SA, Vic and WA. Error bars indicate variation. Study conducted by Plant Science Consulting.

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

Summary

The number of cases of glyphosate resistant weed populations continues to rise particularly for annual ryegrass, barnyard grass, feathertop Rhodes grass and sowthistle. 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 sub-optimum conditions have contributed to increasing resistance levels. More efficient use of glyphosate combined with effective IWM strategies is required to reduce further increases in resistance.

Although paraquat resistance remains very low, it is concerning that it has been detected in annual ryegrass.

Acknowledgements

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Seed dormancy and emergence patterns in annual ryegrass populations from cropped fields - why a big flush was expected in 2020 and what is on the cards for 2021 in SNSW

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Key words

seed dormancy, glyphosate resistance, weed seed bank

GRDC codes

UOA1803-008RTX, UCS00020

Take home message

- Continuous cropping leads to annual ryegrass populations with higher dormancy
- Early annual ryegrass emergence occurs often after a drought break
- Glyphosate resistance is present at low frequencies in many crop fields
- Annual ryegrass emergence in 2021 will be 'more normal'.

Seed dormancy changes in annual grass

Annual ryegrass has high genetic diversity. This has allowed it to become widely adapted across southern Australia, but also allows it to adapt to changes in the environment. One of the most obvious adaptive traits of annual ryegrass is the widespread evolution of herbicide resistance. However, this is not the only way annual ryegrass populations evolve. In the 1970s, studies of annual ryegrass emergence found 95 % of the population emerged in two flushes shortly after the autumn break of the season. By the 2000s, studies were finding higher levels of seed dormancy and carryover between seasons for annual ryegrass.

There is considerable variability in emergence patterns of annual ryegrass between weed populations. Figure 1 shows the germination of four populations of annual ryegrass from different farms across the mid-North of South Australia under ideal conditions. The population 'Middle top' germinates rapidly within 24 days from sowing. This population has low levels of primary seed dormancy. The other three populations all show delayed germination, taking at least twice as long to reach 50 % germination.

These changes in germination pattern are not just due to environmental conditions. Figure 2 shows the germination patterns of 3 populations of annual ryegrass from fields on the University of Adelaide's Roseworthy farm in the mid-north of South Australia. Even with the same environment, there are differences in emergence pattern for the different fields. The Roseworthy farm is operated as a mixed farming enterprise. Buckby is located at the extreme northern end of the farm and has been continuously cropped for more than 20 years. The other two fields have also been cropped for much of that time, but lucerne and pasture have also been grown in those fields.

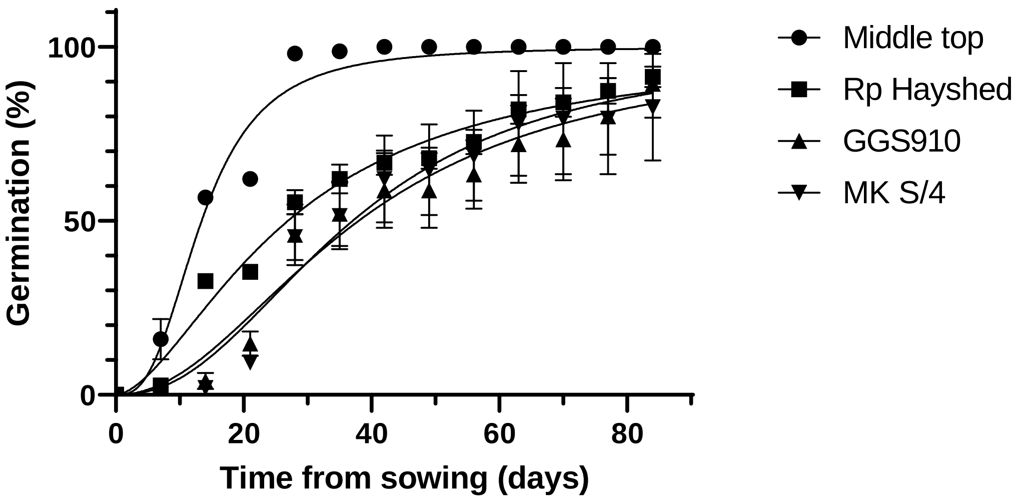

Figure 1. Germination pattern of four populations of annual ryegrass from fields in South Australia tested under ideal conditions.

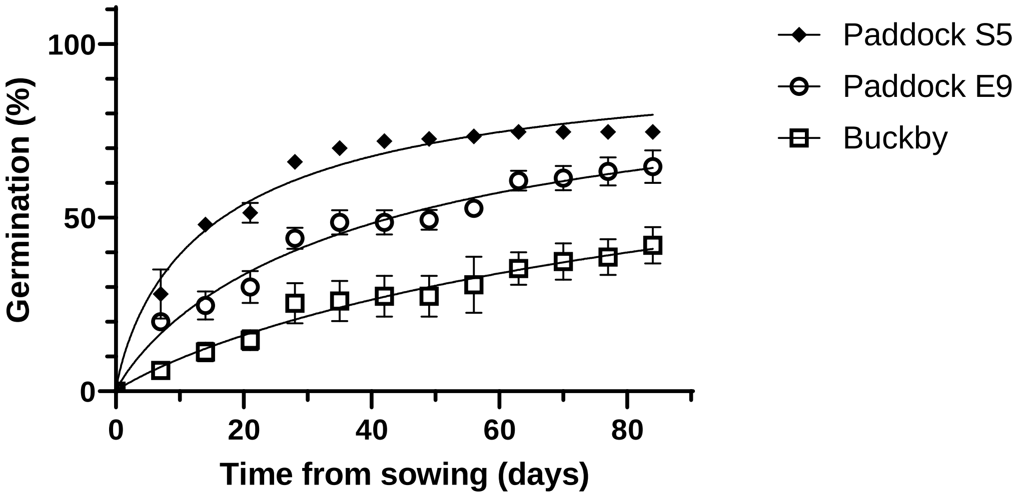

Figure 2. Germination pattern of three populations of annual ryegrass from fields on the Roseworthy farm in South Australia tested under ideal conditions.

Early and late germination is heritable

It is possible to select for higher dormancy in annual ryegrass populations by crossing later germinating individuals among themselves (Figure 3). Likewise, by selecting the early germinating individuals, a low dormancy population can be selected.

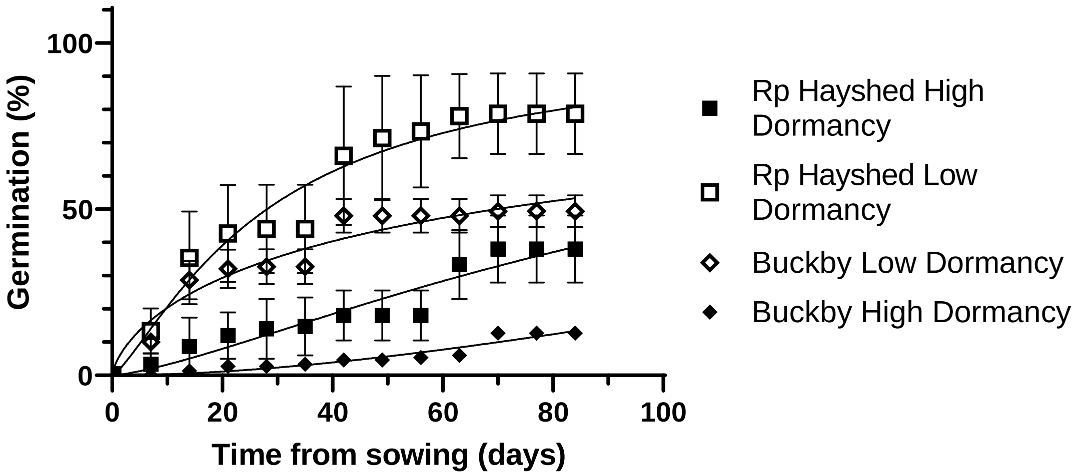

Figure 3. Germination of high and low dormancy sub-populations of annual ryegrass from two populations created by selecting early and late emerging individuals from each population.

As has been observed with brome grass and barley grass populations, it is evident that annual ryegrass populations are evolving in response to continuous cropping by developing more dormant populations. These can escape knockdown herbicide control and emerge once pre-emergent herbicides have declined in concentration. Our previous work looking at early versus delayed sowing in continuously cropped fields found that annual ryegrass numbers in crop were not different with sowing at the start of May compared to the start of June, despite an extra knockdown herbicide application. The selection for increased dormancy in annual ryegrass will be slower than in barley grass and brome grass, due to annual ryegrass being an obligate outcrossing species.

High emergence of annual ryegrass was seen in 2020 – Was this predictable?

The short answer to this question is “Yes”. To understand why, we need to go back to 2016. In 2016, there was an extended wet spring (Figure 4). While this was good for grain yield, it was also good for annual ryegrass seed set. The wet spring also made it hard to get crop-topping applications right and more ryegrass seed was shed before harvest. In addition, cool wet spring periods result in seed with greater dormancy than in years with dry springs.

Emergence of annual ryegrass from the soil seed bank requires sufficient moisture, primarily in autumn and winter when the soil temperature has fallen, and the loss of primary dormancy of seed in the seed bank. Shallow seed burial can encourage emergence; however, deeper burial discourages emergence and induces secondary dormancy, extending the life of the seed bank. However, 2017 had a slightly drier than normal autumn and spring period. By 2018, much of the 2016 seed bank would be ready to germinate, but a drier than average autumn and winter discouraged emergence. Spring was dry, meaning that any new seed produced tended to have low primary dormancy. Similar conditions occurred in 2019, only with even less rainfall.

These conditions created a situation in 2020 where nearly all the annual ryegrass seed in the seed bank had lost primary dormancy and was ready to germinate, provided sufficient rainfall occurred. There were large rainfall events from early in autumn 2020 that allowed this annual ryegrass seed to germinate and establish.

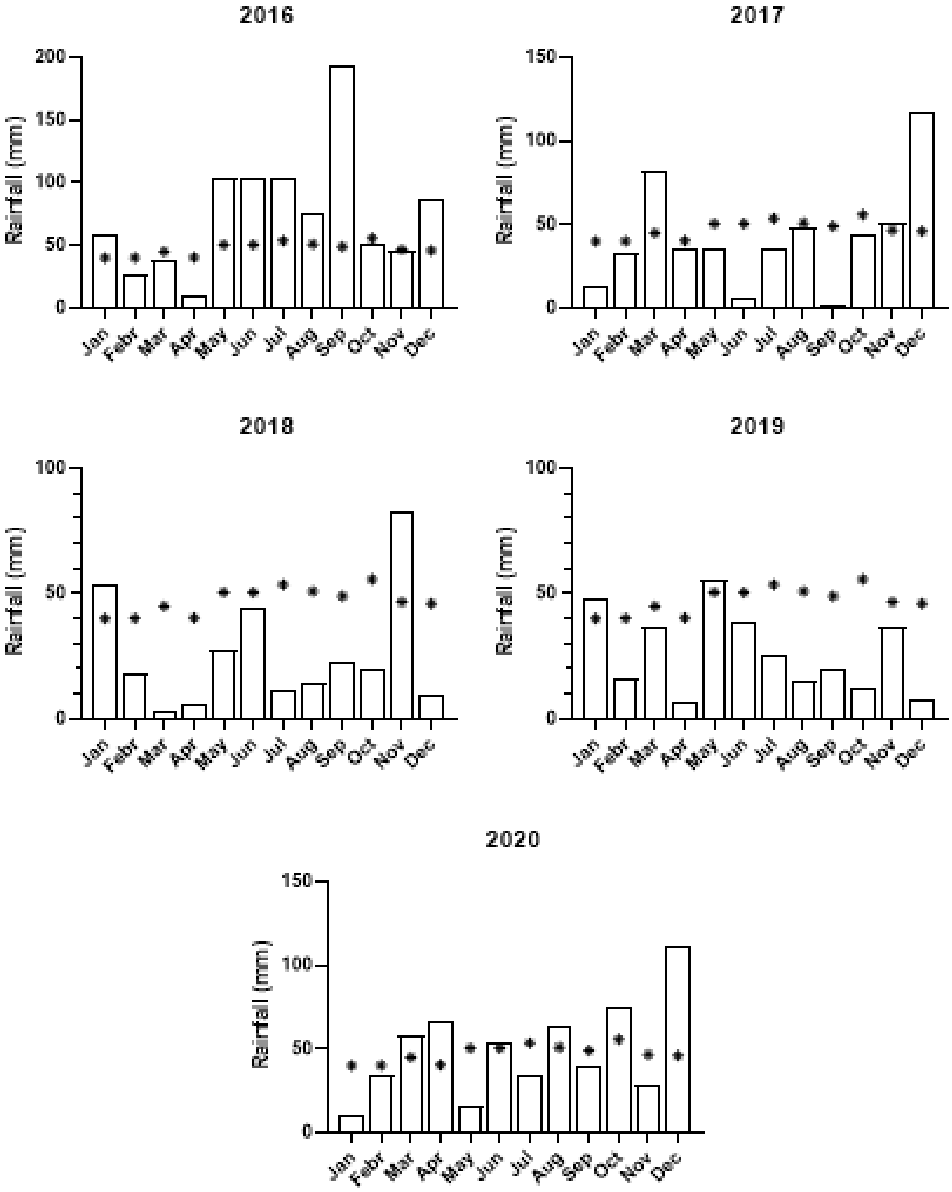

Figure 4. Monthly rainfall at Old Junee, NSW from 2016 to 2020. Asterisks indicate the mean monthly rainfall.

Early annual ryegrass emergence made glyphosate resistance obvious

One consequence of the rainfall patterns was glyphosate resistant annual ryegrass was particularly obvious in 2020. The early autumn rains resulted in the emergence of a lot of weeds well in front of sowing. The longer than normal time between when glyphosate was applied in 2020 and sowing commenced made glyphosate resistant annual ryegrass easy to observe. Reduced glyphosate availability exacerbated the problem. Growers likely used products they were less familiar with and trimmed rates to stretch the product available across the farm. Resistance surveys have shown that glyphosate resistant annual ryegrass is present in low frequencies across the cropping region. Mostly this is not noticed, because the crop is sown shortly after the knockdown applications and other practices tend to keep the low numbers under control.

What to expect for 2021

Most of the residual seed bank of annual ryegrass from previous years has been exhausted. This means most of the seed in the seed bank now will be from 2020, which had a more normal rainfall pattern compared to 2018 and 2019 (Figure 4). This means annual ryegrass seed will have its normal level of seed dormancy. The size of the annual ryegrass flush will depend on how much and how early rain falls in autumn, but it should be smaller than in 2020.

Are there any management practices that can change ryegrass emergence patterns?

It has long been known that light burial, an autumn tickle, can encourage annual ryegrass to germinate. However, doing this will have less impact on the dormant part of the annual ryegrass population and will severely compromise pre-emergent herbicide efficacy. Introducing pasture into the cropping system will select for earlier emerging annual ryegrass and shift the population towards lower dormancy. The most practical management change can come from understanding what to do after a drought. This is when there is likely to be a large autumn flush of annual ryegrass, as there will be little dormant seed left in the seed bank. This is the best time to employ a double knock prior to sowing. It is also the time when more effective pre-emergent herbicide strategies should be employed to help deal with the expected large emergence.

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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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