Dubbo
NSW

THURDAY 25 & FRIDAY 26
FEBRUARY 2021

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

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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,
Gillian Meppem
Senior Regional Manager – North

GRDC Grains Research Update
DUBBO, Dubbo RSL

Theatrette Agenda, Day 1 – Thursday 25 February

Time	Topic	Speaker (s)
10:00 AM	Welcome	GRDC
Barley markets, risk, seasons, and disease		
10:20 AM	**Barley 2030 opportunities -** Vietnam, India and other markets	Mary Raynes (*AEGIC*)
10:55 AM	**Forewarned is forearmed.** Having better conversations with growers on seasonal forecasts and climate risks for more profitable decision making	Peter Hayman (*SARDI*)
11:35 AM	**Cereal disease bingo!** Learnings from 2020 and planning for 2021	Steve Simpfendorfer (*NSW DPI*)
12:10 PM	**Lunch**	
Weeds		
12:50 PM	**Ryegrass - blowouts at seeding in 2020 and management for 2021** • Causes of poor results - resistance vs environment/dose rate • Paraquat stewardship • Optimising glyphosate performance	Peter Boutsalis (*Plant Science Consulting*) & John Broster (*CSU*)
1:35 PM	**Experience fitting in the new pre-emergent chemistries to the farming system and managing them for longevity**	Chris Preston (*University of Adelaide*) & Greg Condon (*Grassroots Agronomy/WeedSmart*)
2:15 PM	**Weeds discussion** • How could we have better managed 2020? Key learnings from blowouts • Messaging for growers on integrating pre-ems into farming systems.	Discussion leader: Campbell Muldoon (*MPAC*)
2:40 PM	**Afternoon tea**	
Canola		
3:10 PM	**Managing upper canopy blackleg and sclerotinia** in lower and medium rainfall western canola crops	Maurie Street (*GOA*)
3:35 PM	**Optimising canola establishment** • Factors affecting establishment • Growing high vigour seed • Optimising P nutrition and placement • Seed testing.	Maurie Street (*GOA*) & Col McMaster (*NSW DPI*)
4:15 PM	**Grazing cattle on dual purpose crops** - managing health risks • Adaptation periods for cattle on canola and practices to mitigate risk • Managing rumen pH depression on cereals • Supplements.	Jeff McCormick (*CSU*) & Paul Cusack *(Central Veterinary Services)*
5:10 PM	**Close**	

Theatrette Agenda, Day 2 – Friday 26 February

Time	Topic	Speaker (s)
Russian wheat aphid, heat tolerance in cereals, data sources and constraint ID		
8:30 AM	**Satellites and other useful data sources that are ready for immediate benefit for on-farm decision making**	Tim Neale (*Data Farming*)
9:05 AM	**ConstraintID –** a free web-based tool to identify areas where soil constraints are most likely to be limiting crop yields	Yash Dang (*UQ*)
9:35 AM	**Heat tolerance in cereals** - best performing lines, new material, mechanisms of tolerance and in season recommendations	Rebecca Thistlethwaite (*University of Sydney*)
10:00 AM	**Russian wheat aphid update thresholds** - insect density, yield impact and control decision making	Maarten van Helden (*SARDI*)
10:25 AM	**Morning Tea**	
Farming systems and soils		
10:55 AM	**The potential role of companion and intercropping systems in Australian grain farming.** Should we be considering them?	Andrew Fletcher (*CSIRO*)
11:25 AM	**Ameliorating soils for sodicity** - deep ripping and soil amendments. Engineering challenges. Yield responses to ripping, gypsum and OM placement in constrained soils	Chris Guppy (*UNE*) & Ehsan Tavakkoli (*NSW DPI*)
12:10 PM	**Lunch**	
Pulses		
12:50 PM	A new desi variety 'CBA Captain⍦' for NSW and SQld in 2021	Kristy Hobson (*NSW DPI*)
1:10 PM	Impact of Ascochyta on chickpea when disease occurs at different growth stages	Kevin Moore and Leigh Jenkins (*NSW DPI*)
1:40 PM	Viral diseases in fababean, chickpeas, lentil and lupins – impacts, vectors/causes and management strategies for 2021	Joop Van Leur (*NSW DPI*)
2:10 PM	Agronomic strategies to optimise pulse productivity in 2021	Discussion leaders: Leigh Jenkins (*NSW DPI*) & Garry Lane (*LaneGrain*)
2:40 PM	**Close**	

Contents

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Barley markets, risk, seasons and disease

Australian barley market opportunities towards 2030

Mary Raynes, Australian Export Grains Innovation Centre

Key words

barley, malting, feed, beer, market diversity, India, Vietnam, China, 2030

Take home messages

- It is important that Australian barley growers have access to a diversity of markets to reduce reliance on a single dominant buyer. The importance of this has been emphasised by the imposition of anti-dumping and countervailing duties on Australian barley exported to China
- Over the next decade Australia will need to maintain and grow its presence in important markets outside China. Users of barley in these markets including Vietnam, India, Japan, South Korea, China, Saudi Arabia, Middle Eastern nations, Iran, Thailand, Philippines, Indonesia, South America and the Sub Saharan Africa require information about Australian barley characteristics, functionality, and new varieties. The Australian industry will need to make breeding and classification decisions accounting for the needs of brewers and maltsters in these markets
- Development and presentation of information packages that reinforce the quality, value and fit of Australian feed barley to suit specific regions and animal types will support greater overseas use of Australian barley in monogastric and ruminant rations
- Towards 2030, China will remain the largest malting barley importer globally by a large margin and Australian barley quality already is well suited to Chinese requirements. There is substantial mutual benefit for the Chinese to remain informed of Australia's barley offering and for the Australian industry to continue to understand the evolving Chinese malting and brewing needs.

Background

The Australian Export Grains Innovation Centre (AEGIC) has examined a range of barley markets to provide insights to the Australian barley industry on their current and future barley needs. A summary of key findings is presented below. The full report can be download from the AEGIC website.

Key findings

Vietnam's growing beer consumption creates new opportunities

- Beer production will increase by a modest 2 to 3 per cent per annum to 2030. This will continue to create strong demand for imported malt and malting barley
- A forecast increase of Vietnam's malting capacity towards 2030, will see malting barley imports increase to about 330,000 mt, nearly double that required in 2019
- Malt imports will be needed to supplement domestic malt production as it adjusts to keep pace with rising demand
- Smaller opportunities may exist for feed barley, but this will be opportunistic and dependent on the price relativity against corn as the major feed ingredient.

Indian maltsters purchase more malting barley

- India is likely to continue to produce barley that is better suited to feed rather than malting use. India’s downward trend in barley production is likely to continue, necessitating increased imports of malting barley
- The market for beer is expanding and it will capture an increasing market share over time as consumers move away from higher alcohol beverages like spirits to lower alcohol beverages like beer
- By 2030 India is likely to import 450,000 to 650,000 mt of malting barley with the Australian industry well positioned to supply a significant share of the imports.

Japan’s demand for high quality food and feed barley will remain

- Demand for malt in Japan is unlikely to change substantially over the next decade
- Intense competition amongst Japanese breweries in the stagnant market is driving innovation in the sector to make more effective use of lower cost ingredients. This may provide opportunities for Australian and other cheaper origin malt to gain market share at the expense of higher priced Canadian alternatives
- Increasing health-consciousness is a robust and durable trend in Japan. Australia’s export grains sector could position itself to gain advantage from this trend. An example is the growing health interest in barley beta-glucan for its health benefits
- Japan’s requirement for a small amount of barley for specialised shōchū manufacture will continue to provide a high value opportunity
- Australia’s historic position of holding a high market share in Japan’s feed barley imports will need to be supported through high quality and competitive pricing against EU (European Union) and Black Sea competitors.

Malt is the main game in South Korea

- Towards 2030, South Korea provides more opportunity for Australian exports of malt than malting barley, but limited growth in Korean beer consumption constrains market prospects
- Opportunities for Australian feed barley in the South Korean feed market are likely to remain limited. South Korean feed manufacturers favour wheat over barley as a cereal feed.

China remains important to Australia’s barley industry

- If tariff free access is restored, Australia will face increased pressure for a share of the Chinese malting market from other barley exporting countries, particularly Canada, Europe Argentina and potentially Ukraine and Russia in the feed market, as the volume of barley available for export from these countries grows
- China will remain the dominant market for malting barley towards 2030, with imports expected to remain at current levels within the range of 2 to 3 mmt per annum
- Over the next decade Chinese barley imports may increase by up to 2.1 mmt but the increase will be mostly feed barley, and strongly affected by government policies directed at other feed grains, particularly corn.

Saudi Arabia’s demand for feed barley is declining but remains significant

- The Saudi Arabian government continues its endeavours to increase the use of domestically processed compound feed instead of imported raw barley. However, there remains a degree of resistance to this change, particularly amongst politically influential Bedouin livestock

users who maintain the historical practice of direct feeding unprocessed barley to their livestock.
- If China continues to impose high tariffs on Australian barley, then Saudi Arabia is the only destination capable of utilising the volume displaced by Chinese barriers.

Other Middle East nations and Iran

- Other Middle East nations: including Kuwait, United Arab Emirates, Qatar, and Oman have historically used Australian barley for feeding livestock. Increasing demand across the Middle East and Iran will continue to be primarily serviced by Black Sea origins and Argentina. When Australian barley is cost competitive in the Saudi Arabian government tender, it is generally cost competitive into many of these markets.

Thailand's feed barley use is an ongoing opportunity

- Thailand's feed industry is an ongoing opportunity for Australian feed barley, when it is price competitive against their domestic crops like corn, or when there is a gap between domestic corn production and animal feed requirements.

Indonesia and Philippines present new feed options

- As incomes and populations increase in Indonesia and the Philippines, feed demand will grow strongly to service growing meat consumption. Currently, government policies in both countries protect domestic corn producers against cheaper corn imports. Imported barley may be price competitive against higher priced domestic corn and could be an effective feed ingredient if local feed millers become familiar with its use.

South America

- Malting barley use and malting capacity in South America will continue to grow with barley sourced mainly from within the region (principally Argentina). Supply disruptions caused by adverse production conditions (floods and droughts) coupled with volatile government policies may shift production incentives away from barley, and so may offer occasional opportunities for Australian exports.

Sub Saharan Africa

- Although South Africa is increasingly self-sufficient in barley, production volatility due to drought may provide occasional opportunities
- Smaller opportunities may arise in countries such as Ethiopia. Some Australian malt is already being supplied to this market.

Australia

- Towards 2030 Australia's barley production could increase to 13 mmt per annum from a current long term average of 9 mmt
- Domestic malting barley use is likely to remain relatively stable around 1.5mmt annually towards 2030
- Domestic feed consumption is likely to increase from 1.5mmt to 1.8mmt with increased use mostly in eastern Australia.

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Forewarned is forearmed – can we have better conversations with farmers about climate risk?

Peter Hayman, SARDI Climate Applications and Barry Mudge, Mudge Consulting

Key words

seasonal climate forecasting, risk, decision making

GRDC code

Rural R&D for Profit Project 16-03-007 *Forewarned is Forearmed* and Using Seasonal Forecasts to increase profit in southern grains region DAV1803-010SAX

Take home messages

- Climate variability represents an important risk for farmers and advisers in central west NSW. The Bureau of Meteorology is issuing more forecasts (weeks, fortnights, months and seasons) which are updated more often. GRDC is partnering with other RDCs to invest in a project to provide more access to forecasts of weather and climate extremes for the grains industry
- Seasonal climate forecasts (SCF) are skilful (better than guessing) and likely to slowly improve. Nevertheless, they are unlikely to approach the remarkable accuracy of short-term weather forecasts and so are best represented as a change in the odds for wetter or drier than a categorical statement that it will be dry or wet. Communicating and using probabilistic forecasts in decision making is challenging. As a general rule, forecasts are right about twice as often as they are wrong and even with a 75% - 80% chance of above median rainfall there is still a minority chance of below average rainfall that can't be ignored
- Forecasts are expressed as probabilities and this is a challenge for communication. One path forward is to use what we are calling Rapid Climate Decision Analysis. This is based on budgeting across deciles. Although this approach is important for incorporating probabilistic seasonal forecasts, we have found that the graphical representation of risk and reward leads to useful conversations about climate risk in the absence of seasonal forecasts.

1. Viable grain enterprises have skills in balancing caution and opportunity in a variable climate

Compared to most of their international competitors, Australian grain growers face a high level of year to year variability in climate with low level of government support. Although every region can point to unique challenges, growers in the central west of NSW deal with a higher degree of variability than southern and western grains regions (variability decreases clockwise around the grains belt). Although the variability is less than in the northern regions, the limited summer cropping in the central west leads to the reliance on a single growing season and hence high variability of annual income from cropping. The high degree of variability in growing season rainfall for Dubbo is shown in Figure 1. Although the decile 5 rainfall is about 300mm, some seasons are as low as 100mm and others over 500mm. Recent experience of three consecutive poor seasons from 2017 to 2019 show the direct cost of climate variability (for more detail see archives in https://www.dpi.nsw.gov.au/climate-and-emergencies/seasonal-conditions). Beyond this direct cost to grain enterprises, the uncertainty of climate variability makes decision making more difficult due to a 'moving target problem"' for inputs and a shift to more cautious lower inputs.

The GRDC RD&E plan 2018-23 observes the balancing act required when dealing with risk: *"Risk management practices that are overly conservative can limit profit in above-average production years, while approaches that are overly aggressive can expose growers to large losses that in turn could contribute to business equity issues that ultimately impact profit and future operations."* Grain enterprises that are viable after riding the variability shown in Figure 1 are clearly skilled at balancing caution and opportunity. The question raised in this short paper is whether there are ways that we can build on this local knowledge and wisdom and make the best use of information on variability from climate science. But first we need to make the point that climate science has something to offer grain growers in the central west.

2. Growing season rainfall in the central west is influenced by El Nino Southern Oscillation and the Indian Ocean

El Nino Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) explain some (by no means all) of the variability in April to October rainfall in the central west. In recent experience the dry spring in 2015 was an El Nino year, the very wet 2016 was consistent with a negative IOD and the dry 2019 linked to a positive IOD with the above average 2020 by a late developing La Nina. The very dry 2017 and 2018 were neutral years and highlight that there can be extremely poor years not explained by climate drivers. Regions that have an impact from ENSO and IOD tend to have higher variability, but as some compensation they also have higher predictability.

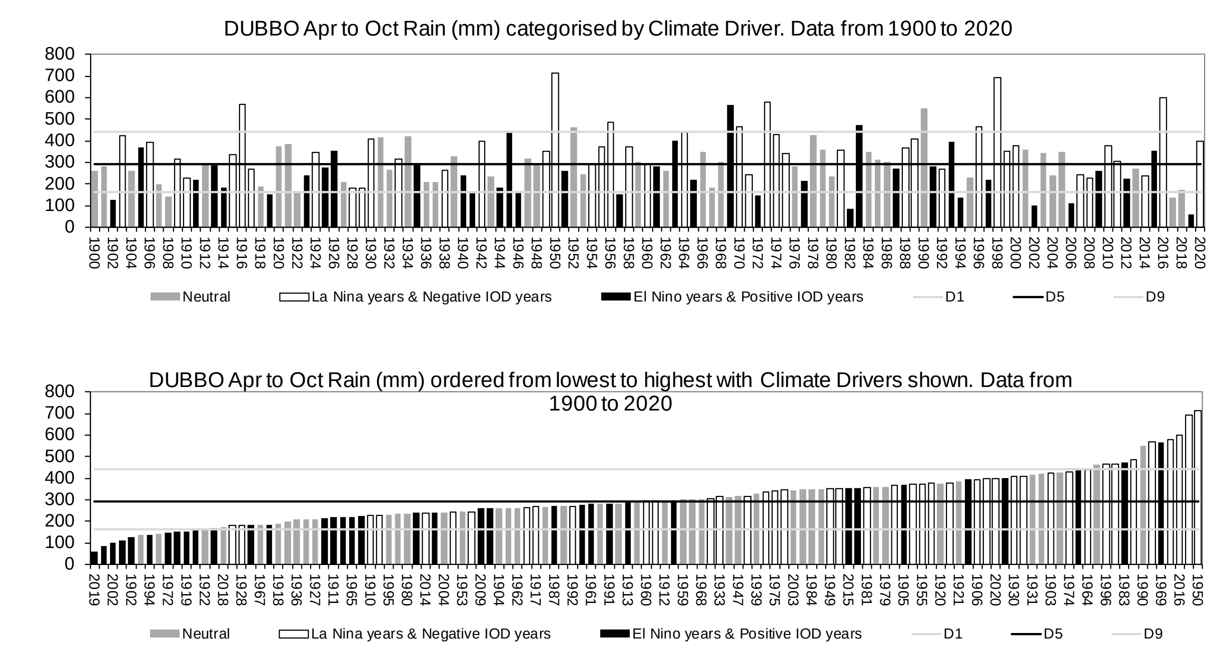

Figure 1. Dubbo April to October rainfall from 1900 to 2020. Bars are shaded for climate drivers

The same data as Figure 1 can be presented in horizontal bars (Figure 2). Across all years there is an equal chance of decile 1 to decile 10. By definition, the chance of being in the driest 2 deciles is 20%. In El Nino or positive IOD years, the odds of a decile 2 outcome double to 40% or higher. In La Nina years the odds of being in the lowest two deciles reduce to less than 10% and in the 19 negative IOD years there have been no years as dry as the lowest 2 deciles. There is a similar pattern of an increase in the chance of the wetter deciles in La Nina and negative IOD years and decrease in El Nino and positive IOD years.

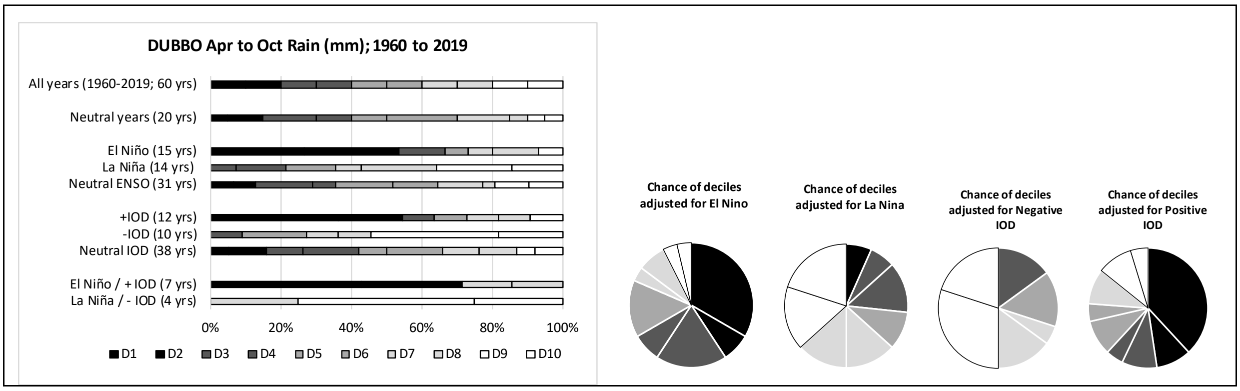

Figure 2. The same data as Figure 1 showing chance of different deciles. Deciles coloured from black (D1 D2) dark grey (D3 D4) grey (D5 D6) light grey (D7 D8) and white (D9 D10).

3. Forewarned is forearmed – GRDC combining with other RDCs and the Australian government in an R&D for Profit project

The last decade has seen an enormous national and international effort to better understand the climate. In Australia this has entailed a substantial investment in super-computing for the Bureau of Meteorology. As the supply of climate information is expanding, so is the demand. Grain growers want the expensive super-computer time and the limited resource of climate scientists to address issues that impact their industry. But increased demand is also coming from other rural industries and other sectors such as energy, water resources, military, health and emergency management.

Although the grains industry may be asking different questions than sectors such as health and the military, many of the questions overlap with other rural industries. For example, what's the chance of next week or next month being extremely wet (decile 9 & 10)? What's the chance of having a hot (decile 9 & 10) week in three or four weeks' time or a very hot month, next month, or the month after? What's the chance of having a very dry (decile 1 & 2) month, next month, or the month after?

These questions are being addressed in a project where Bureau of Meteorology climate scientists are guided by six reference groups; grains, northern beef, southern beef, sugar, dairy and wine grapes. The project Forewarned is Forearmed (FWFA): equipping farmers and agricultural value chains to proactively manage the impacts of extreme climate events, runs from 2017-2022 and will provide five new forecast products for extreme events, weeks to months ahead. Funding partners include the Australian Government Department of Agriculture and Water Resources as part of its Rural Research and Development (R&D) for Profit Program ($6m), with further cash and in-kind contributions ($8m) from 14 project partners. Figures 3 and 4 show some of the experimental output. One of the roles of the grains industry reference group is to aid in selecting forecast products that will become operational. An important point is that these products show the full distribution of outcomes rather than just the percent chance of exceeding the median. The forecast distribution is generated by 99 runs of the model which considers the uncertainty in starting conditions and internal variability from the model.

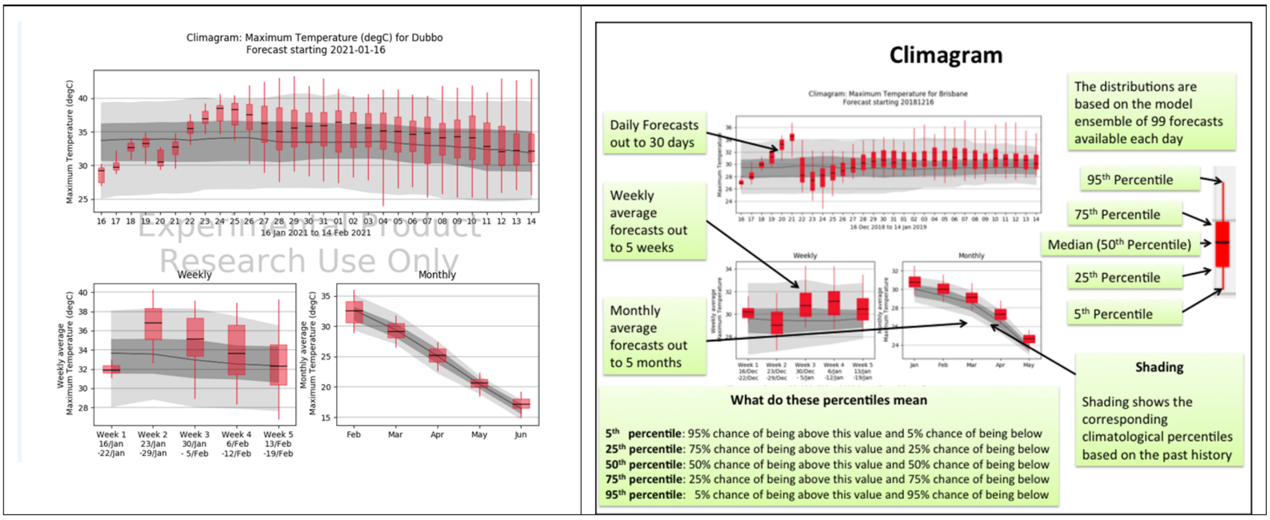

Figure 3. Climagram for maximum temperature for Dubbo showing daily, weekly and monthly distributions.

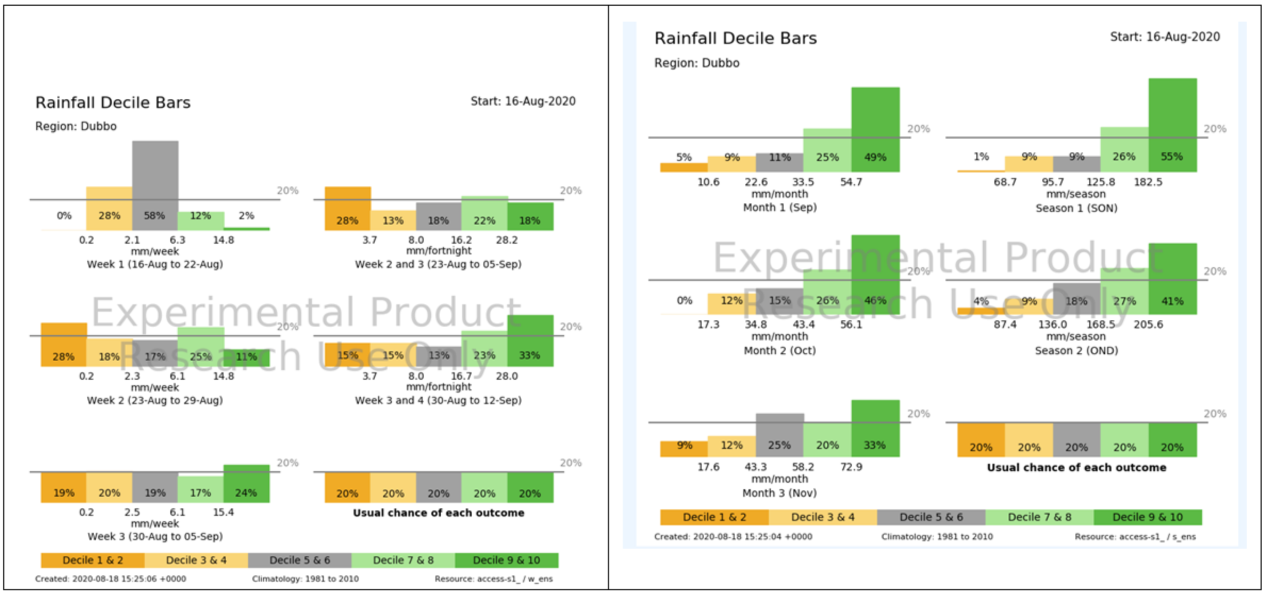

Figure 4. Rainfall decile bars for Dubbo forecast from 16 August 2020 for the coming weeks, fortnights, months and seasons.

In Figure 4, the forecast for October, made on 16 August should be interpreted as; of the 99 model runs, 46% fell into decile 9 & 10, and 26% in deciles 7 & 8. This can be reported as 80% chance of exceeding the median, but the extra information shows the greatly increased chance of deciles 9 and 10 and that of the 20% of model runs that are drier than the median, they are all above decile 3.

There will be ongoing improvements in seasonal forecasts and in the ways that they are communicated. They will still fall into the category of *'too good to ignore but not good enough to be sure'* and they will be best represented as probabilities. Probabilities have long been a barrier to the use of seasonal forecasts. In one of the early reports on farmer use of seasonal climate forecasts in Australia, Ridge and Wylie (1996) noted *"Much climate information is put out in the form of probabilities, which most farmers are not responsive to. Farmers have said that they want to know whether it is likely to be wet, dry or average, not whether there is a 60% chance of getting 40% of average rainfall"*.

Farmers have a deep sense of living with risk and uncertainty and trade-offs between too cautious and too optimistic. It might be that they are unused to hearing about uncertainty from science. There is a suspicion amongst some farmers and advisers that the use of probabilities displays a lack of conviction on behalf of the forecaster, a form of vagueness or mumbling to cover all outcomes and avoid being wrong. Private forecasters who provide emphatic statements are admired as being straight talking. On hearing a talk on El Nino and probabilities an agronomist made the comment *"nice talk on probabilities, but in the real world people have to make decisions".* This overlooks the "real world" use of probabilities in almost all of modern life including aviation safety, health, google searches and artificial intelligence. Most of us who studied agricultural science learn about probability and p values, but it might be that the extremely high confidence level used for agricultural chemicals means that we can be assured the herbicide at label rate will work and so we don't need to practice probabilistic thinking.

Probability theory is a wonderful invention to deal with partial information and risk. The mathematician Jordan Ellennberg points out that probability theory developed surprisingly late in the history of mathematics (mid-17th Century) compared to older subjects such as geometry. Building the pyramids required geometry and understanding of levers, but not probability. Probability theory was developed to solve the seemingly trivial problem of an interrupted gamble. Say we are playing a simple game where we each put $50 on the table and agree the winner will be decided by five tosses of a fair coin. Three or more heads and I take the $100, two or less and my opponent is richer. The game is interrupted after three throws when the score is 1 head (H) and 2 tails (T). The question is whether we can split the $100. It is obvious from probability theory that the player assigned tails should take $75 because there are four possible futures, three of them favouring tails (HT, TT, TH) and the player assigned heads should take $25 representing the 1 in 4 chance of the next two throws being heads. Ellenberg argues that prior to the invention of probability theory, this problem was seen as unresolvable because the next two throws were unknown, or known only to God. The radical idea was that there is an answer and we can show the working. Bernstein (1996) in a history of risk as an idea stated "*The revolutionary idea that defines the boundary between modern times and the past is the mastery of risk… Until human beings discovered a way across that boundary, the future was a mirror of the past or the murky domain of oracles and soothsayers who held a monopoly over knowledge of anticipated events."*

In many ways we are fortunate to have climate science express their confidence as probabilities as this provides the full information and indicates the relative confidence in the forecast. Not only is this a case of climate science being honest and credible, it improves the decisions based on the forecast.

4. Rapid climate decision analysis

We developed an Excel based framework called Rapid Climate Decision Analysis to compare the outcomes across deciles of growing season rainfall of a higher risk and return choice (e.g. a higher N rate or a pulse crop) with a more conservative lower risk and return choice (lower N or a cereal). Examples will be provided in the presentation. The key feature is that rather than budgeting for a single outcome (often decile 5) users are stepped through a process to provide information for three to five season types and presented with an interpolated graph that covers outcomes across all deciles. The representation of adviser's knowledge as budgeting by deciles provides a rich source of information on climate risk. The mental switch is to compare the profit of two decisions across states of climate (in this case deciles of growing season rainfall) with careful attention to where the lines cross over (if at all) and the relative size of the downside risk and the upside missed opportunity. A common request is for climate science to indicate which decile is most likely, but a better representation of the forecast is a shift in the likelihood of different deciles. If a seasonal climate forecast is represented as a revised climatology, this revision can be superimposed on the decile by profit graph which allows a new comparison of the two options.

Frameworks such as Rapid Climate Decision Analysis are not designed for routine decision making. The more modest role is as a tool to think, discuss, confirm or start arguments about rules of thumb on climate risk in the grains industry. We subtitled the framework 'fast graphs for slow thinking' as a reference to Khaneman (2011). The graphs can be generated relatively quickly because grain growers and agronomists have a deep understanding of production risk and how this production changes across deciles of growing season rainfall. There is a cost in time and effort of slowing down to put numbers on a page (or spreadsheet). This is only worthwhile where the outcomes matter. On a grain farm, there should be at least tens of thousands of dollars at stake.

As the psychologist Paul Slovic says, "*our emotions are not good at arithmetic, we tend to think of future events as 100% or 0%".* This can translate into hearing about an El Nino outlook and planning for a dry outcome or dismissing the prediction because it isn't certain or because it has rained in past El Nino events. The correct revision of deciles is straightforward in a spreadsheet and agronomists easily recognise patterns of shifts in graphs, especially if they were involved in providing the underlying information.

We ran a workshop with 20 agronomists – some of the comments on the strengths of Rapid Climate Decision Analysis were as follows:

- "Getting numbers down on paper and being able to test the sensitivity of a decision to a change in climate forecast. Fairly easy to use and interpret"
- "Putting numbers around some gut feelings helping to make decisions"
- "To be able to clearly visualise the risk profile of a climate sensitive decision. It makes us think through the financial aspects of a decision, and how the future climate (i.e. rainfall deciles) will impact the outcome"
- "Excellent tool to help explain the probabilities given a set of indicators"
- "Good visual data and rigor around decision based on a range of potential climate outcomes"
- "Assists in helping make a final decision or to confirm what you thought in the field"
- "Good for showing differences and putting numbers to those decisions."

Some of the limits related to the difficulties of using it in the field, included the 'clunky' spreadsheet, how to include other factors, the lack of confidence in seasonal forecasts, having enough empirical data, the challenge of dealing with complex decisions. As one agronomist put it *"It's a good back up, but for me there are so many other factors to consider and as an established agronomist I don't think I'd use this tool as generally everything in the paddock tells me the answers."*

There are opportunities for advisers in the central west to access the experimental products from the Bureau of Meteorology - please contact Peter.Hayman@sa.gov.au.

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Kahneman, D, and Egan, P. (2011). Thinking, fast and slow. New York: Farrar, Straus and Giroux

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support. The work on Rapid Climate Decision Analysis has been conducted with Professor Kevin Parton, Charles Sturt University. Ideas for RCDA have come from projects funded by GRDC, Wine Australia, ACIAR, The Australian Government through Rural R&D for Profit, and SARDI/PIRSA. We appreciate the input of 20 agronomists from the southern region in 2018 and a further 20 in 2020.

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

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

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

Key words

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 (1st node), GS39 (flag leaf emergence) and GS61 (flowering).

Conclusions

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

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

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Key words

glyphosate and paraquat resistance, annual ryegrass, barnyard grass, feathertop Rhodes grass, optimising control, testing, random weed survey, double knock.

GRDC code

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).

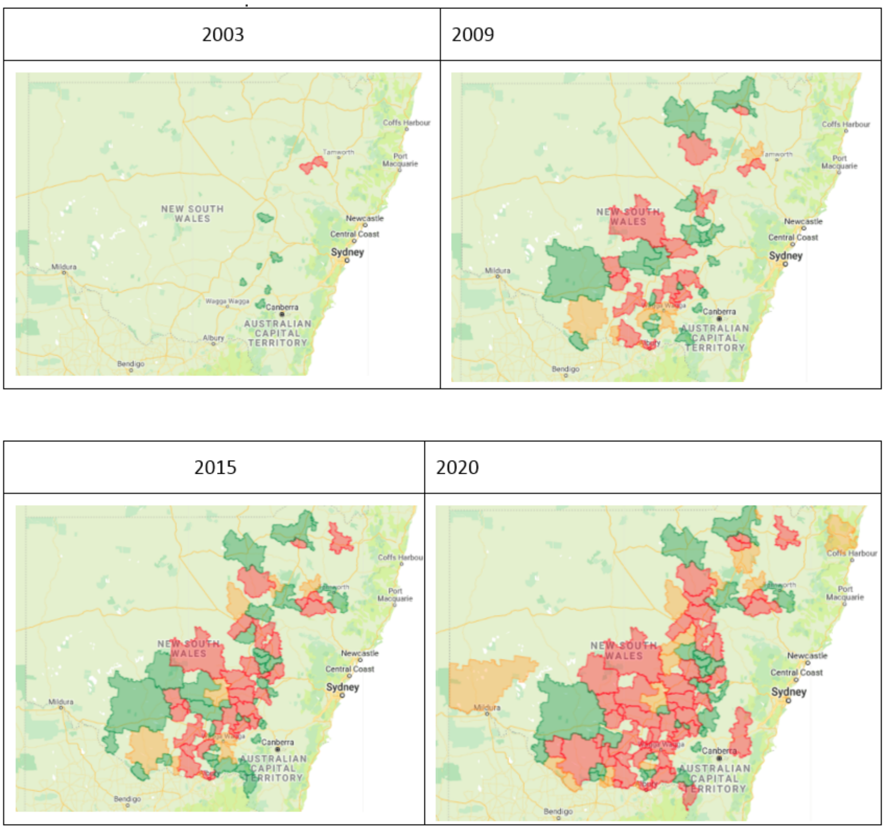

Figure 1. Occurrence of glyphosate resistance in annual ryegrass in NSW in 2003, 2009, 2015 and 2020. **Dark green shading** = postcode regions where testing has not detected glyphosate resistance in ryegrass, **orange shading** = postcodes where glyphosate resistance is developing and **red shading**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

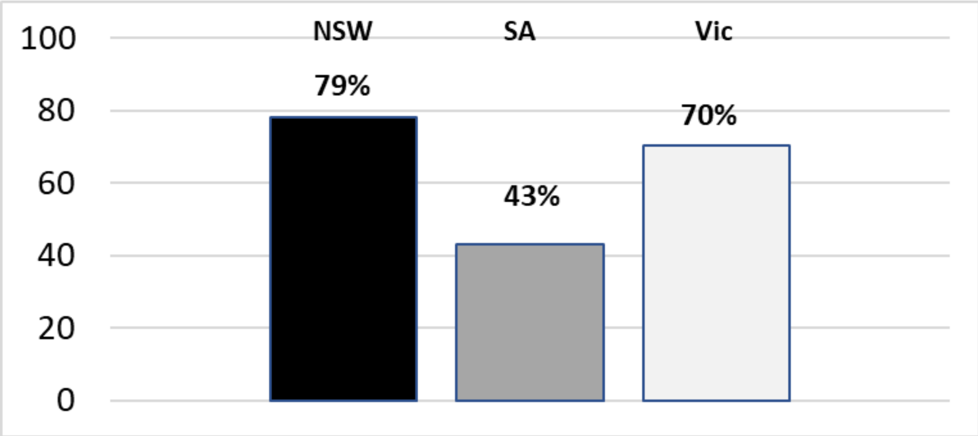

Figure 2. Percent (%) resistance to glyphosate confirmed in farmer ryegrass samples originating from 83 NSW, 37 SA and 74 Vic cropping paddocks treated with glyphosate in autumn 2020. Testing conducted by Plant Science Consulting using the Quick-Test.

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).

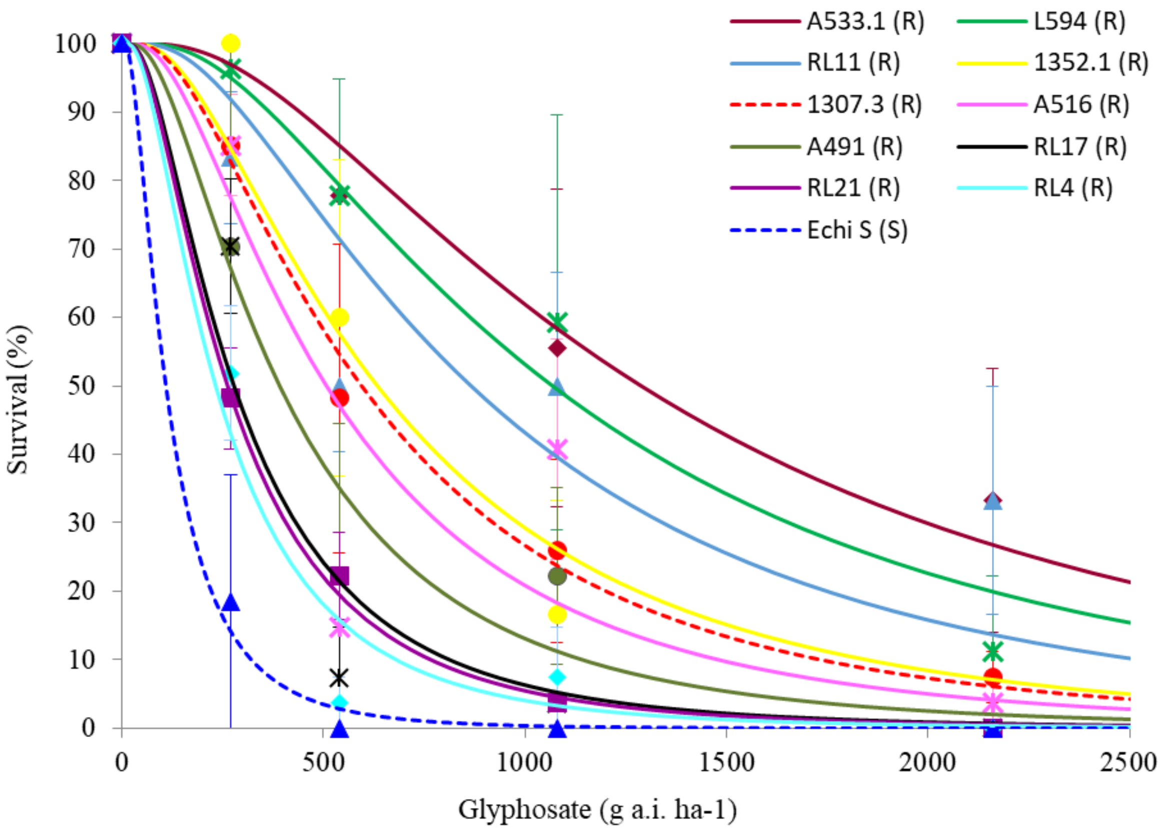

Figure 3. Response of 10 resistant awnless barnyard grass biotypes to increasing rates of glyphosate (The University of Adelaide). 'Echi S' is the susceptible control population.

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.

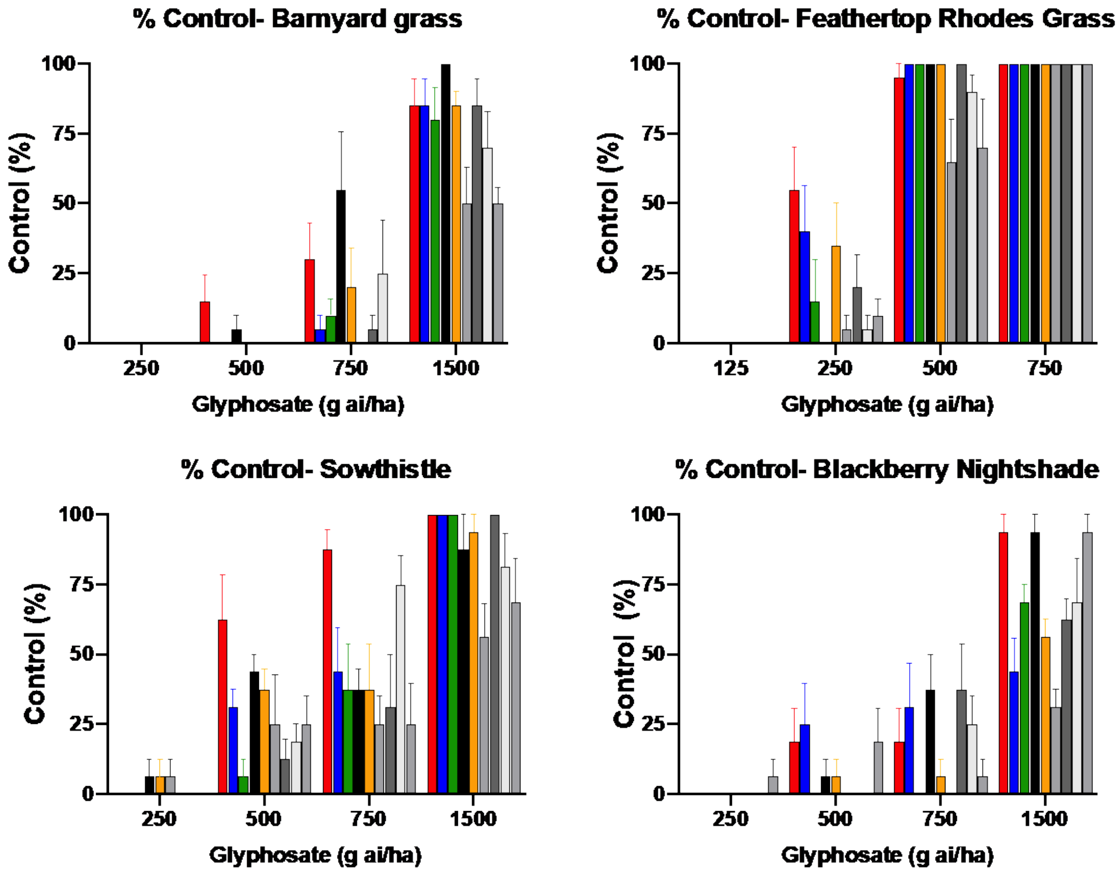

Figure 4. Control of four summer weed species with nine different glyphosate formulations. (Plant Science Consulting)

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.

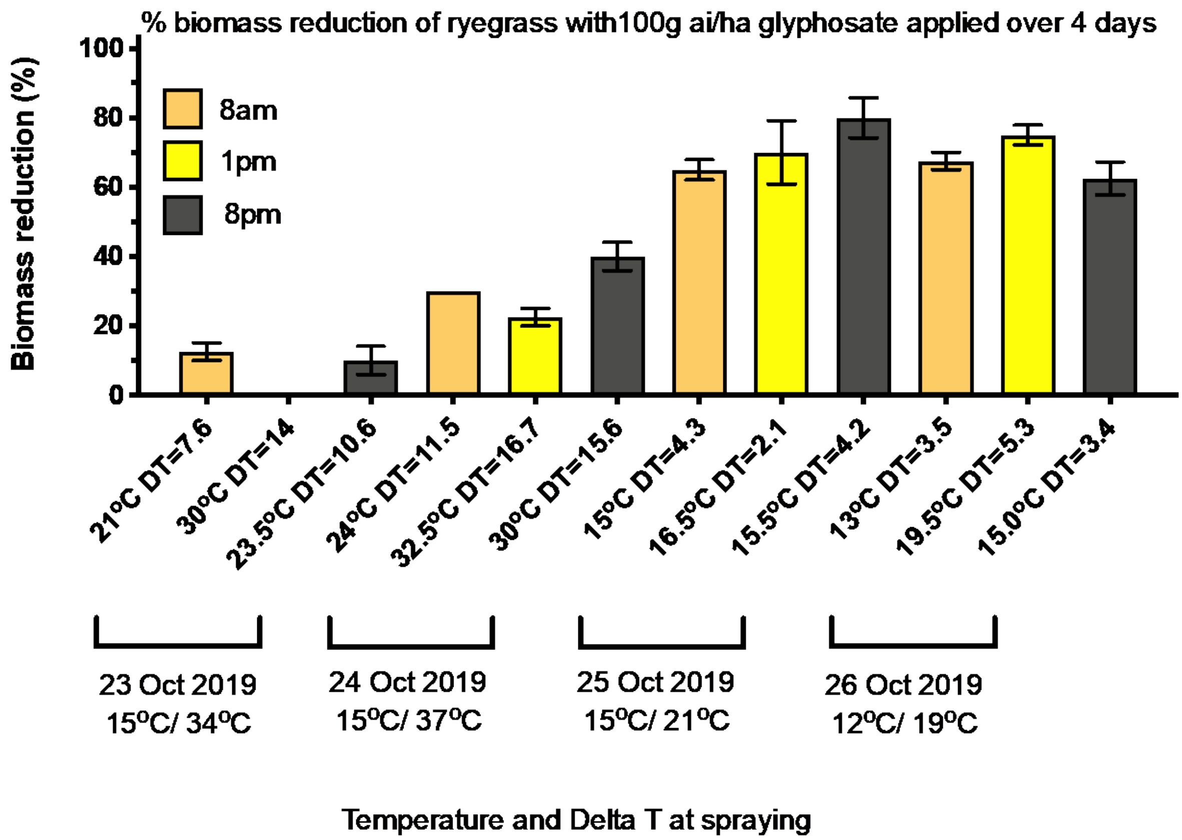

Figure 5. Effect of temperature & Delta T on glyphosate for ryegrass control (Plant Science Consulting)
(A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions).

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).

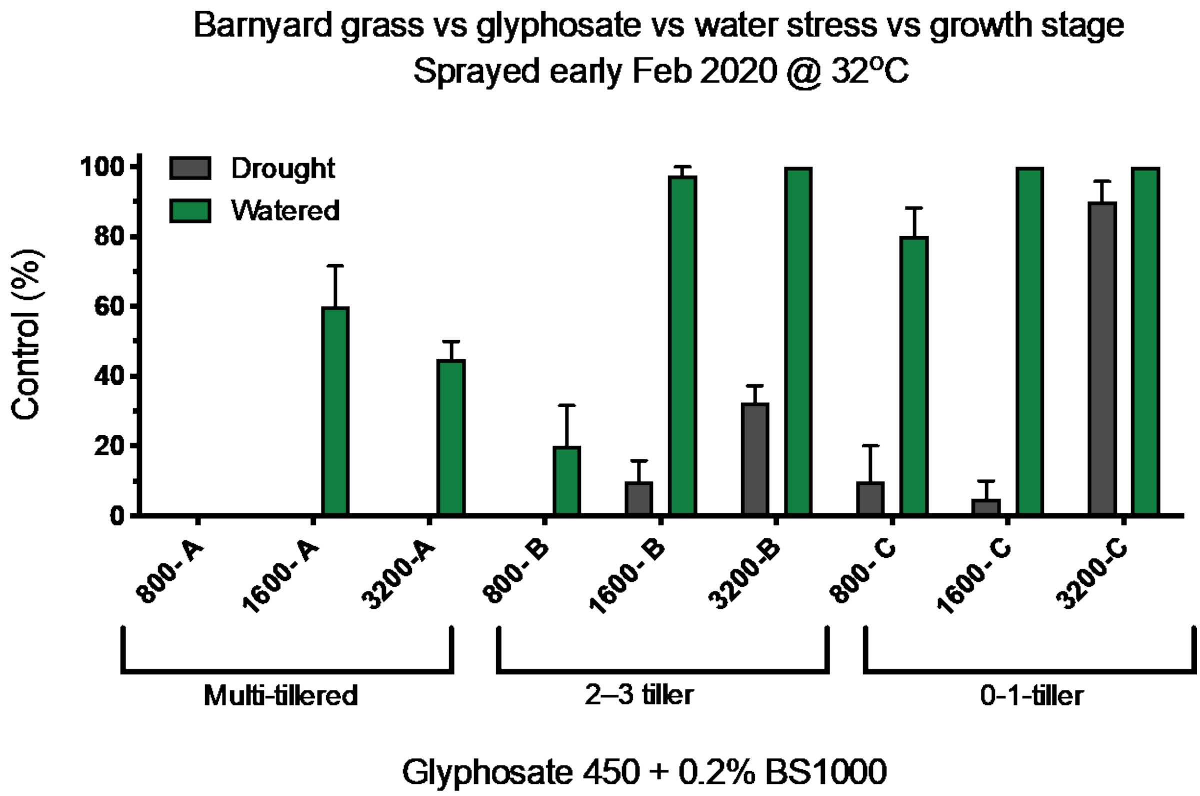

Figure 6. The effect of three rates of glyphosate on three growth stages of barnyard grass, half not water-stressed and the other half water-stressed (Plant Science Consulting)

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.

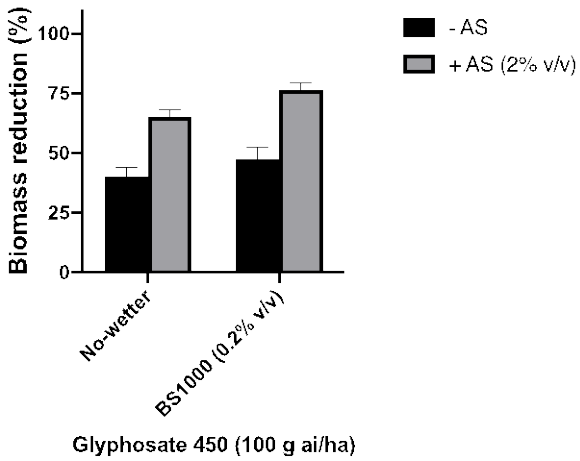

Figure 7. Effect of ammonium sulfate (AS) and wetter on glyphosate for ryegrass control (A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions).

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.

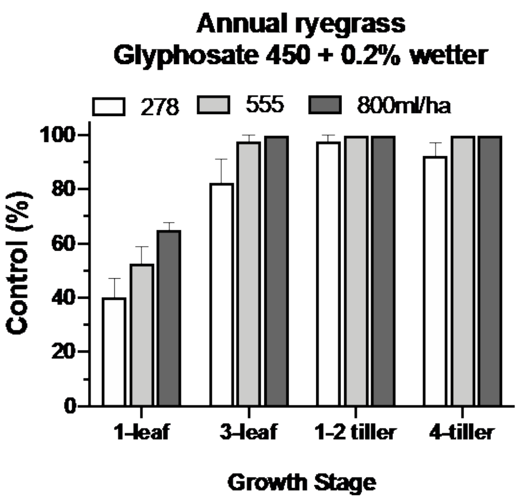

Figure 8. Effect of ryegrass growth stage on glyphosate activity (A sub lethal rate was used to differentiate between treatment differences. Plants were grown and sprayed under optimum conditions).

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.

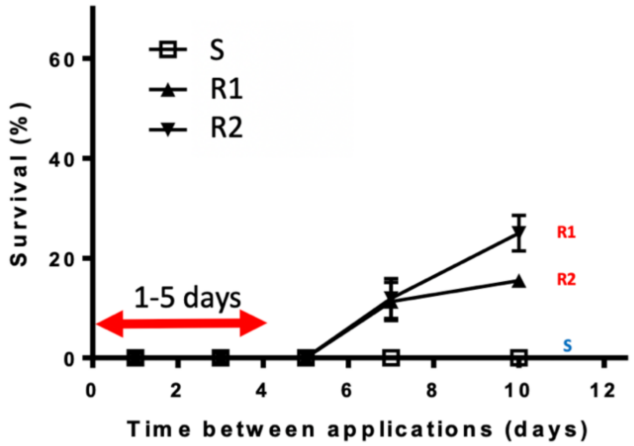

Figure 9. Double knock timing. Glyphosate applied onto a susceptible (S) and two glyphosate resistant ryegrass biotypes (R1 & R2) followed by paraquat 1, 3, 5, 7 and 10 DAA. Trial work conducted by Dr Christopher Preston (The University of Adelaide).

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.

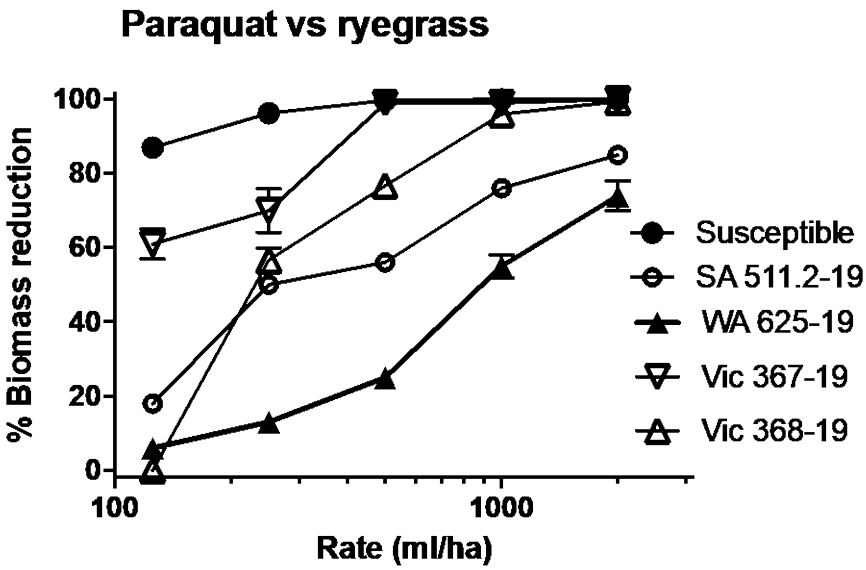

Figure 10: Efficacy of the first confirmed cases of paraquat resistance in annual ryegrass from SA, Vic and WA. Error bars indicate variation. Study conducted by Plant Science Consulting.

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.

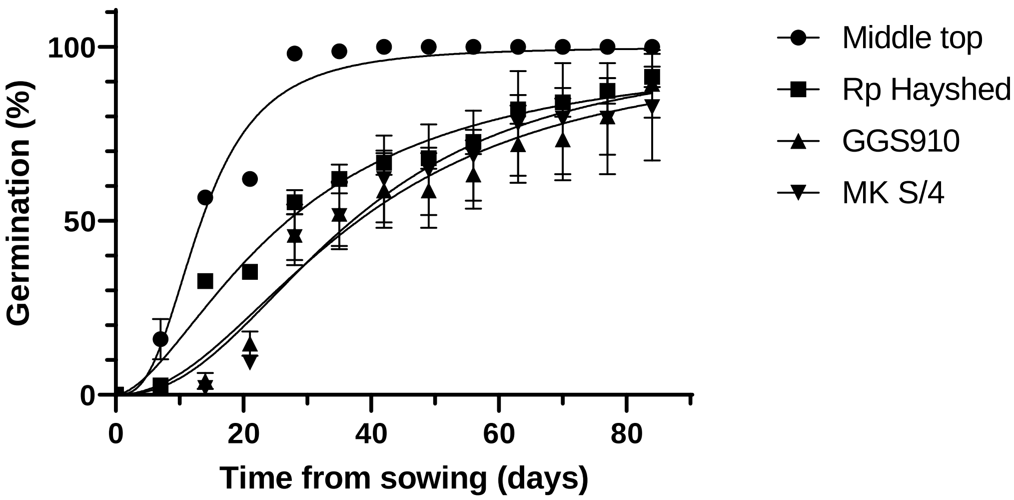

Figure 1. Germination pattern of four populations of annual ryegrass from fields in South Australia tested under ideal conditions.

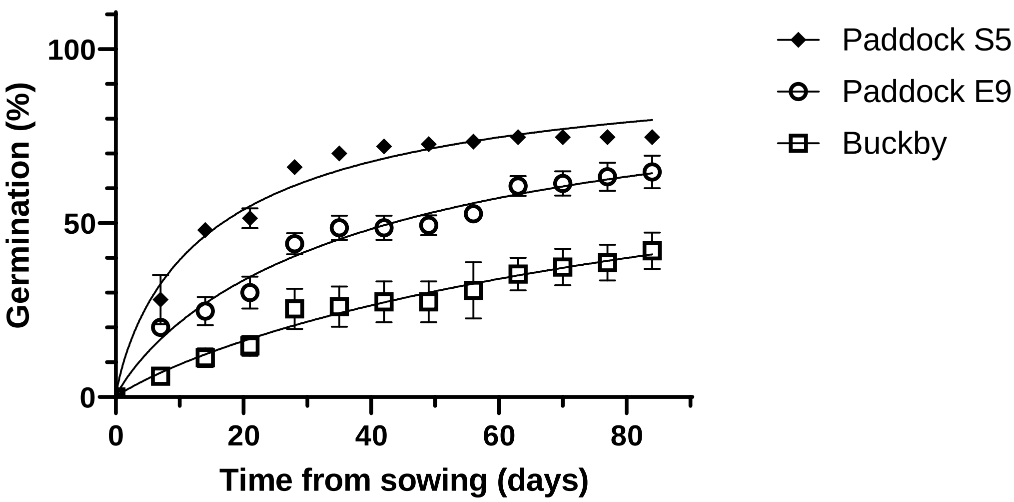

Figure 2. Germination pattern of three populations of annual ryegrass from fields on the Roseworthy farm in South Australia tested under ideal conditions.

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.

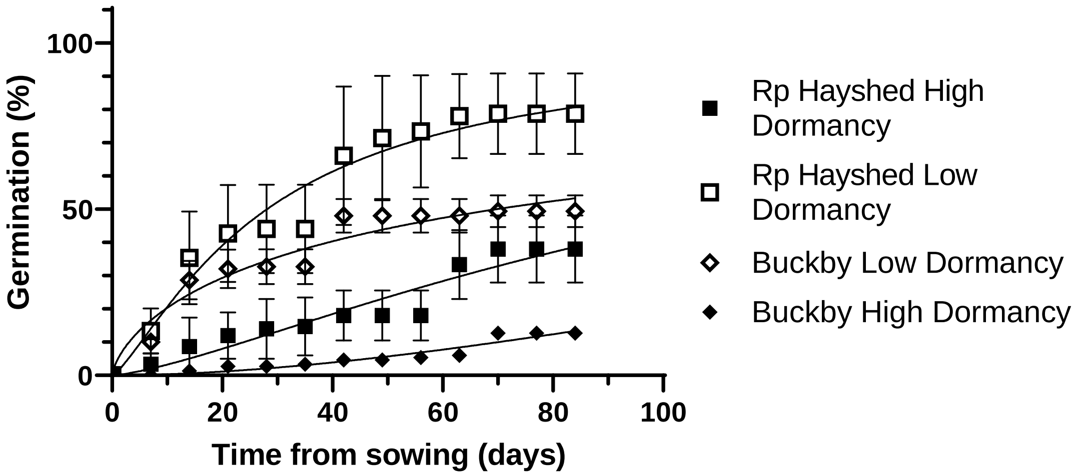

Figure 3. Germination of high and low dormancy sub-populations of annual ryegrass from two populations created by selecting early and late emerging individuals from each population.

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.

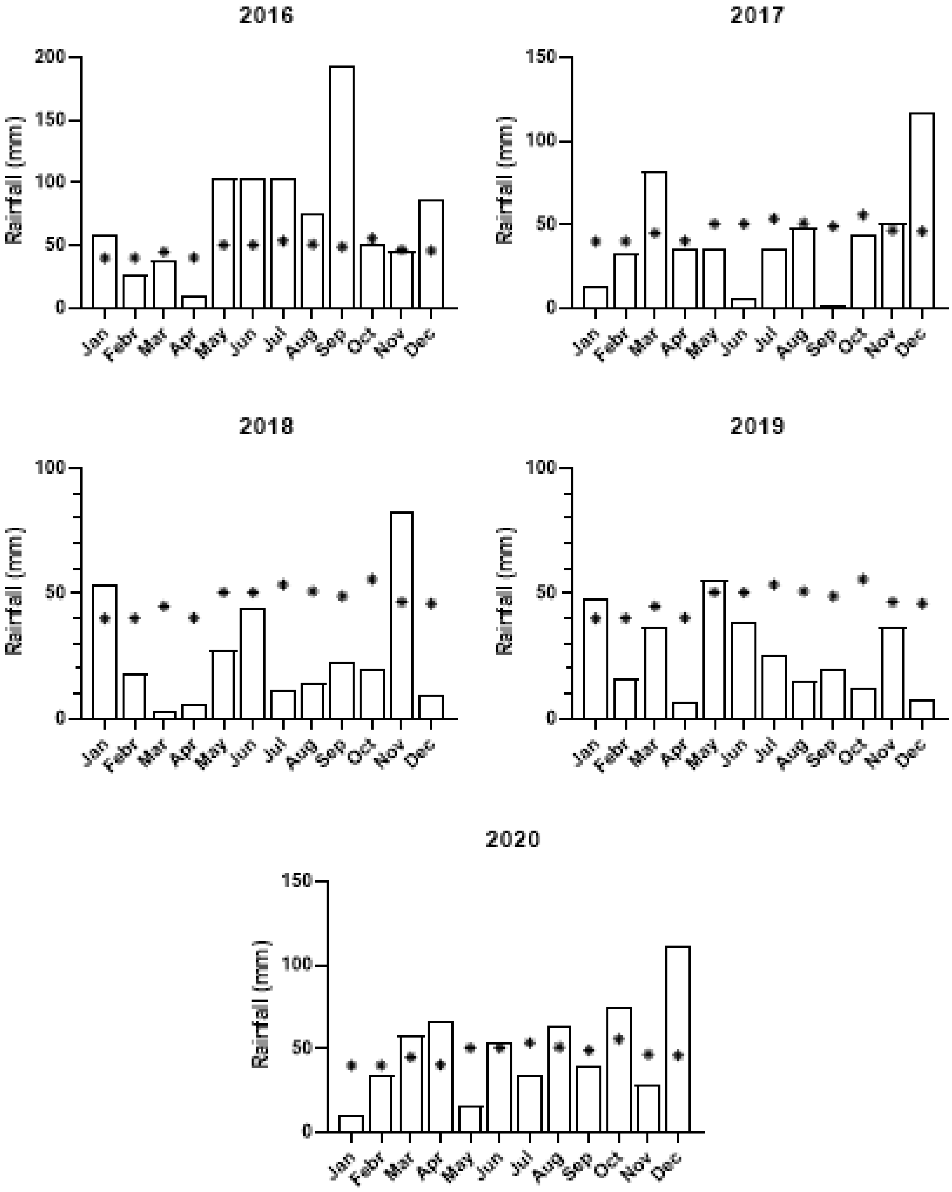

Figure 4. Monthly rainfall at Old Junee, NSW from 2016 to 2020. Asterisks indicate the mean monthly rainfall.

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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The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

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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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Canola

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.

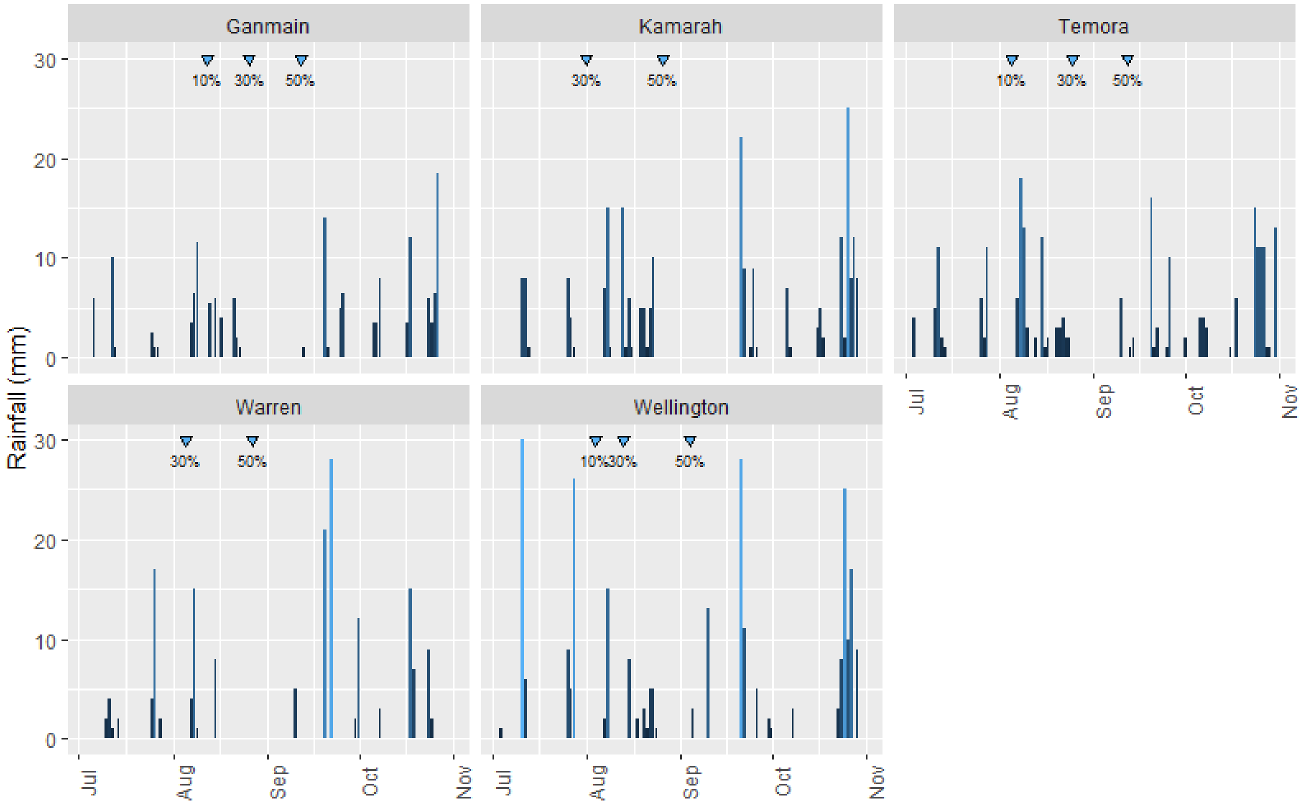

Figure 1. Daily rainfall received (vertical columns) and spray timings (inverted triangles) for five canola fungicide response trials conducted in NSW, 2020. Timings are bloom stage timing, e.g., 10% is 10% bloom stage.

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.

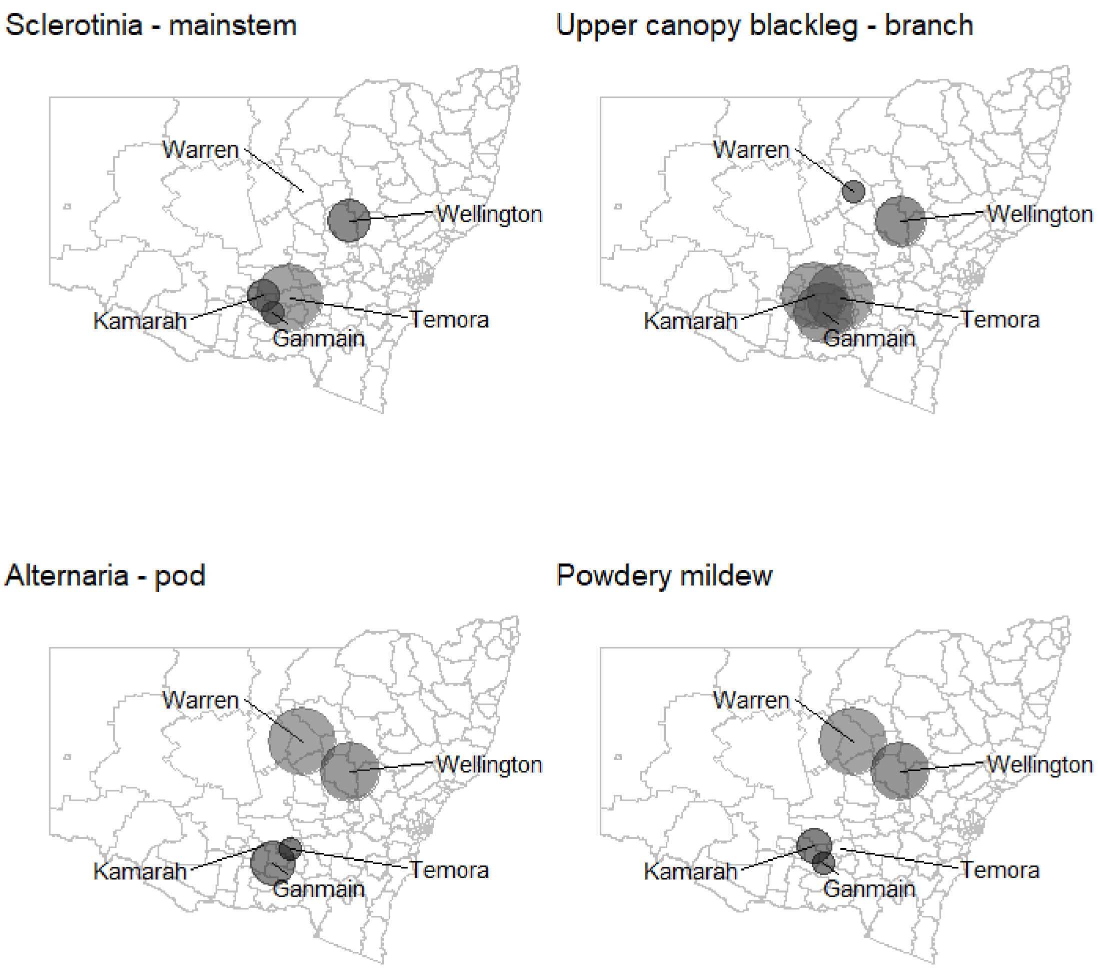

Figure 2. Severity of the diseases Sclerotinia stem rot (main stem), upper canopy blackleg (branch), Alternaria (pod) and powdery mildew across five canola fungicide response trials in NSW in 2020. Larger circles represent greater infection levels (data presented from untreated control). Data presented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

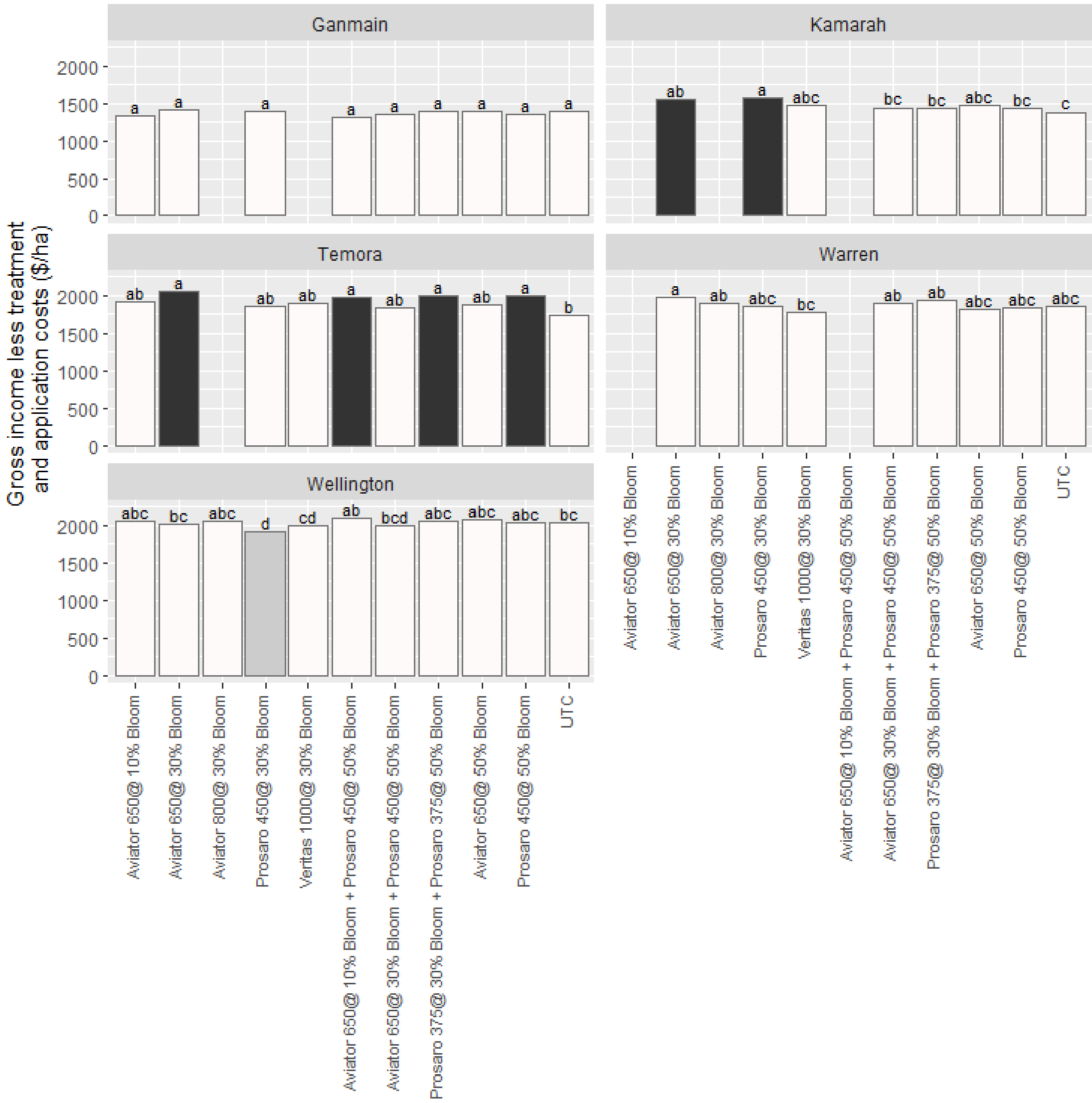

Figure 3. Partial gross margin (gross income less fungicide product and application costs) of fungicide treatments across five sites in NSW in 2020. Treatments with the same letter are not significantly different at p=0.05. Treatments in black are significantly higher than untreated control (UTC) and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

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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

Site/year	Impact on plant populations	Impact on yields	Rainfall 60 days post planting ^	Yield range t/ha
Jemalong 2017-	P rate applied, or placement had no impact	P rate applied or placement had no impact	13 mm	0.3 – 0.9
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	Site was rate responsive when P was applied 'with seed'	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
	the lower plant populations than IBS, top-dressed & 'below seed' except at 10 kg/ha P where 'below seed' only was no different to 'with seed'.	40 kg/ha >10, 20 kg/ha & Nil At 10 kg/ha P- no impact of 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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Grazing cattle on dual purpose crops - managing health risks

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Key words

ruminal acidosis, bloat, polioencephalomalacia, buffers, fibre

Take home message

- Cattle grazing dual purpose crops can be a highly profitable option
- Cattle are more susceptible than sheep to livestock forage disorders, including; nitrate toxicity, acidosis, bloat and polioencephalomalcia (induced thiamine deficiency)
- Cattle grazing dual purpose wheat should be supplemented with minerals
- Cattle grazing dual purpose canola should be adapted onto the crop to ensure that rumen adaptation occurs.

Opportunities for cattle on dual purpose crops

The use of dual purpose crops has been well established across the mixed farming zone for more than a decade. Commonly, grazing has occurred with sheep enterprises and has dramatically changed the feed budget on mixed farms, significantly reducing the winter feed gap. Research and uptake of dual purpose crops has occurred primarily with sheep. In the mixed farming zone, sheep are the dominant livestock enterprise. Greater use of dual purpose crops on farms by sheep is unlikely and therefore growers are missing out on utilising the potential of large amounts of forage production. This is because at the time of grazing (May-July) it is common that ewes are pregnant or have recently lambed. There is limited market for young sheep for a grower to expand and respond to large amounts of feed that might be available. In comparison, at that time of year there are often a significant number of young cattle requiring feed either in the saleyards or being hand fed on grazing properties. Research conducted on dual purpose crops with cattle grazing has demonstrated high cattle liveweight gains, with the practice generally safe to livestock. Commercially, cattle have been grazed on wheat and canola dual purpose crops, but there have been some examples of poor cattle health outcomes.

Cattle production from dual-purpose crops

The potential for producing very large amounts of forage from dual purpose crops is high due to the large area for producing these crops. Currently within the mixed farming zone in southern Australia only 10-20% of crop land is utilised as dual purpose. If this area was increased by another 10% in the wheat sheep zone and 50% in the high rainfall zone then approximately 2.2 M head of cattle could be grazed across southern Australia.

Available feed is the driving force behind cattle production on dual purpose crops. Experiments conducted with yearling cattle grazing wheat and canola dual purpose crops have regularly exceeded growth rates of 2 kg/hd/day (McCormick et al., 2020). There is an opportunity to produce large amounts of forage during winter by increasing the area of dual purpose crops sown on a mixed farm leading to an opportunity to either agist or trade in cattle. Calculating a simple gross margin for trading young cattle that includes costs such as transport, agent fees and death rates, indicates that a gross margin per hectare could be $342-$945/ha with a buy/sell price of 350 c/kg liveweight just for the cattle enterprise.

Dual purpose crop agronomy for forage and grain production.

Achieving high forage production in dual purpose crops relies on good agronomic planning and management including:

- Paddock selection. Select paddocks with low weed pressure as weeds in dual purpose crops can be difficult to manage.
- Control summer weeds. Maintain weed free fallows over summer which will conserve soil water and nitrogen and enable early sowing.
- Select appropriate cultivars. Early sowing of dual purpose crops requires the selection of cultivars with true winter requirement.
- Sow early. Sowing of dual purpose canola can commence from February whereas wheat can start from March depending on soil moisture. Need to be ready to sow when the opportunity is available. Increase sowing rate to ensure good density of plants (>150 plants/m^2 for wheat and >40 plants/m^2 canola)
- Fertiliser use. Dual purpose crops require nitrogen to produce forage. Total nitrogen supply available at sowing for dual purpose wheat and canola should be 100-150 kgN/ha.
- Starting grazing. Grazing can be initiated when the crops will not be pulled from the ground by the cattle commonly this is when wheat has 4-5 leaves and canola has 6-8 leaves. This can occur anywhere from March to June depending on the season with canola commonly grazed before wheat.
- Finishing grazing. The completion of grazing depends on crop growth stage (up to commencement of stem elongation) and is affected by location and cultivar. Winter canola types tend to elongate the stem from mid-late July, while winter wheats tend to elongate during August. Crops can be grazed for longer periods but the residual crop after grazing needs to keep increasing the later the grazing period.
- Stocking rate. Young cattle (approx. 200kg/head) can be grazed at 2-3 head/hectare depending on forage availability. This means that crops could be grazed from 60-90 days with 2-3 young cattle (120-270 cattle grazing days per hectare).
- Nitrogen top-dressing. It is beneficial to top-dress nitrogen after the grazing period to aid in crop recovery and grain yield. Top-dressing before or during grazing is not recommended due to nitrate toxicity.

Risks for cattle on dual purpose crops

Some cattle have died from a range of livestock diseases as a result of feeding on dual purpose crops. Cattle are more susceptible than sheep to many forage induced diseases, so it is critical that the grower understands and manages the risks associated with grazing dual purpose crops.

Nitrate toxicity

Nitrate toxicity can occur in ruminants when cattle consume plants that have accumulated nitrate. Within the rumen, nitrate is converted to nitrite and then to ammonia. High nitrate levels in the plant lead to a high conversion of nitrite, which results in it being directly absorbed into the bloodstream. Here it binds with haemoglobin preventing oxygen from binding and being transported around the body which in turn starves the animal of oxygen.

Within the plant, nitrate is transported within the vascular network and is converted to amino acids in the plant cells. Nitrate can start to accumulate to high levels within the vascular network when the conversion from nitrate to amino acids slows. Nitrate toxicity can be a particular concern in broadleaf leaf crops like dual purpose canola. It has been demonstrated that the stem and petiole have much higher levels of nitrate than the leaf lamina. McCormick et al., (2020) measured nitrate levels of 4465 and 13847 mg/kg in the stem and petiole respectively, compared to 1155 mg/kg in the leaf lamina. A critical value for nitrate where the risk of nitrate toxicity greatly increases has been determined at 5000 mg/kg dry matter (Hibbard et al., 1998).

The use of high levels of nitrogen fertiliser can exacerbate nitrate accumulation as can climate conditions that limit photosynthesis, such as drought stress, cloudy days or cold temperatures. In these situations, nitrate accumulates in the plants vascular network which can lead to higher levels of nitrate intake by livestock. Practices that reduce the risk of nitrate toxicity include not applying high levels of nitrogen fertiliser and delaying grazing until the plant is more mature, as nitrate tends to dilute in plants as they develop. Undertaking a period of adaptation reduces cattle's sensitivity to nitrate levels. In canola crops, having high forage availability and a lower stocking rate will enable livestock to select the leaf lamina and therefore reduce the risk of nitrate toxicity.

Acidosis

Acidosis is a cause of major health problems and production losses that occur in ruminants grazing cereals or canola. It is related to rumen pH depression. The rumen is a large microbial fermentation vat which produces a range of volatile fatty acids (VFA). VFAs are absorbed through the rumen wall and are the main source of energy for cattle. The rumen microbial population is sensitive to pH. Changes in pH result in changes to the VFA profile. Ruminal acidosis can occur with any dietary intake high in rapidly fermentable carbohydrate and low in fibre. Forage with high crude protein concentrations, which result in high rumen ammonia concentrations, can prevent the pH depression that would otherwise occur with a poorly buffered, low fibre intake that is high in water soluble carbohydrates. However, feed with lots of rapidly fermentable carbohydrate that lack sufficient roughage to generate a substantial flow of salivary bicarbonate, can overwhelm the alkalinising effect of the elevated rumen ammonia, leading to acidification. This combination of forage characteristics is a potent stimulant for lactic acidosis. Sub-acute ruminal acidosis can occur simply due to the rapid production of volatile fatty acids (VFA) in excess of rumen absorptive capacity, particularly in cattle newly introduced to a greater availability of lush forage. There is a strong inverse relationship between VFA concentration and rumen pH (Figure 1) – i.e. as rumen pH decreases, total rumen VFA concentration increases.

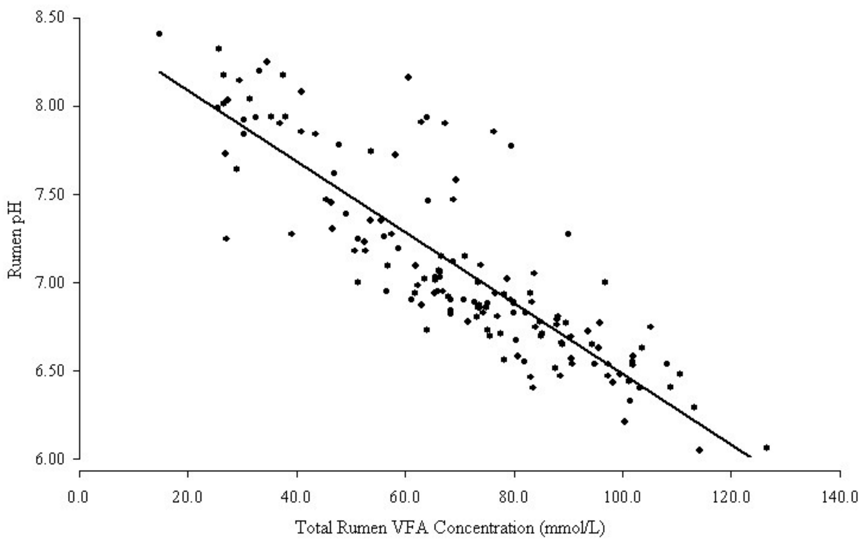

Figure 1. Relationship between total concentration of rumen VFA and rumen pH ($r^2 = 0.742$, $P<0.001$; Packer 2010).

Further research is required with cattle, but growth rate has been increased in lambs grazing cereals that were supplemented with a rumen buffer and an alkalinising agent (MgO and $CaCO_3$; Grain and Graze projects, Dove and Kelman 2015). This suggests that rumen pH might drop sufficiently in forage ruminal acidosis to reduce fermentation efficiency i.e. below 5.6 where the molar proportion of propionate starts to decline (Figure 2). The use of therapeutic agents, such as the ionophores (monensin, salinomycin or lasalocid), that select against lactate producers. If we can reduce this pH drop without significantly diluting dietary nutrient density, we might achieve cost effective increases in growth rate with cattle, as was observed with lambs.

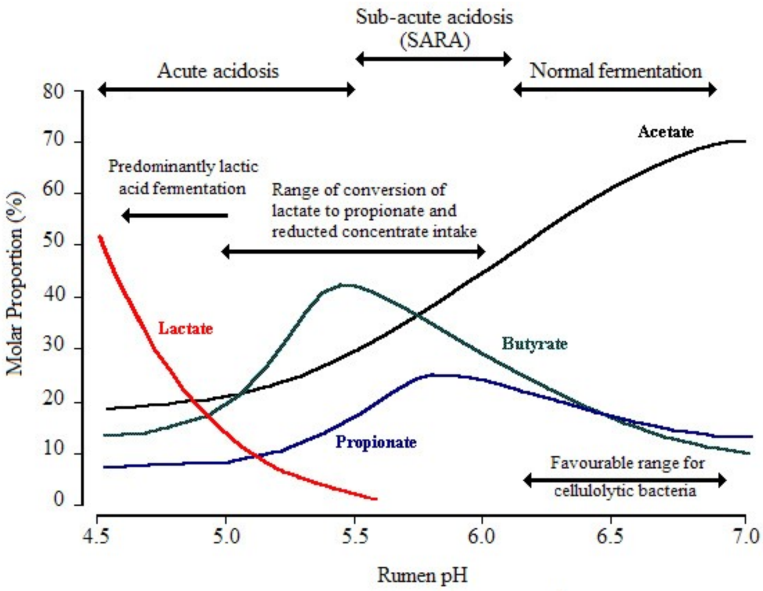

Figure 2. Changes in molar proportions of VFA at with changing pH as presented by Packer (2010) BVSc honours thesis.

Rumen pH depression not only results in direct mortalities and sub-clinical reduction in growth rate and feed efficiency, but it also predisposes ruminants grazing lush forages to bloat and polioencephalomalcia (PEM).

Bloat

The bloat seen when grazing dual purpose canola and cereal crops differs from bloat seen when grazing legumes. The bloat that occurs when grazing dual purpose canola and cereals, does not involve the specific chloroplast proteins that contribute to the formation of a stable foam in legume bloat, although intake of a legume (with these proteins), in addition to the lush forage of a canola/cereal crop could exacerbate the condition. Bloat on lush canola/cereal forages occurs as a result of the rumen contents being more viscous at lower pH, and the contribution of the slimy capsule of *Streptococcus bovis* to the formation of a stable foam. *Streptococcus bovis* overgrows at the expense of its neighbours in the rumen microbial ecosystem when rumen pH is low enough (< 5.6) for long enough, and it produces lactic acid, which is a 10 x stronger acid than the VFA's.

Polioencephalomalacia

Polioencephalomalacia (PEM) occurs due to an induced thiamine (vitamin B1) deficiency. A healthy rumen microbial ecosystem provides the ruminant's requirements for thiamine. However, when there is a high dietary intake of sulphur and when rumen pH is depressed, the rate at which thiamine is destroyed can exceed production and lead to a deficiency in thiamine and PEM. PEM can cause symptoms such as blindness, seizures or holding their head in an unusual position (stargazing). An acidic rumen increases the likelihood of PEM by increasing the release of a thiaminase exoenzyme through acid shocking of certain species of rumen bacteria. An acidic rumen also increases the rate of thiamine destruction by sulphite which is produced from the bacterial reduction of sulphate. Rumen bacteria also reduce sulphate to sulphite, therefore high dietary intakes of sulphate (e.g. from grazing brassicas) can have thiamine-antagonistic activities. Canola crops are often fertilised with sulphur. It is likely that this could increase the risk of PEM as the plants would have higher sulphur levels, although this has not been demonstrated with research.

Management practices to reduce forage disorders

Managing cattle grazing dual purpose crops requires an understanding of the animal health risks and regular observations to ensure a successful outcome. General rules regarding the introduction of a new feed source to cattle should always ensure that the cattle are always full. Hungry cattle are highly susceptible to changes in diet and gorging themselves on unfamiliar forage. One way to enable this is to introduce the livestock to a new forage mid-morning. Cattle will tend to eat a large proportion of their daily intake early in the morning. Care should be taken if cattle are grazing very short pastures prior to introduction as they are likely to still be hungry. The supplementation of hay will enable this transition. There is no requirement to adapt cattle to dual purpose wheat over time. In comparison it is still recommended to adapt cattle to canola over a period of at least 4-6 days. This is because cattle have been known to avoid canola initially leading to hungry cattle. When they finally do start to eat the crop they are likely to gorge themselves leading to health problems. To adapt cattle onto canola it is worth introducing them initially for 2-3 hours and increase the time by 2-3 hours each day. It is critical to observe that the cattle are eating significant amounts of canola before allowing them to be on the crop full time.

Mineral supplementation in wheat

Supplementation of sheep on dual purpose wheat is standard practice. Wheat is deficient in sodium (Na) and magnesium (Mg) for ruminant livestock production. Lime has also showed benefit through supplying calcium (Ca) to the livestock. While there are only limited studies in beef cattle, McCormick et al., (2021) demonstrated a cattle response to mineral supplementation in two out of three experiments, with liveweight gains of up to 27%. The supplement cost 4.5c/hd/day for a cattle liveweight increase of 0.5 kg/hd/day. It is recommended that cattle grazing wheat should be supplied with a loose-lick mineral supplement consisting of salt (NaCl), Causmag® (MgO) and lime ($CaCO_3$) (1:1:1 by weight, as-fed), offered *ad libitum* (at all times). Mineral supplementation with cattle grazing canola has not been tested, but previous research in sheep demonstrated a decrease in liveweight gain.

Liveweight lag period in canola

It has been identified that both sheep and cattle undergo a lag phase of liveweight gain for 1-2 weeks after introduction to dual purpose canola (McCormick et al., 2021). This can occur from cattle avoiding the canola crop, as many cattle in Australian grazing systems are not familiar with brassica grazing crops, or due to rumen adjustment. If cattle avoid eating the crop, this can increase the risk of other conditions such as bloat, as they are not adapted to the crop. The lag phase occurs even when cattle are adapted to the crop over a period of time. Practically this means that cattle should be grazed on canola for at least a month to enable weight gain to catch up.

Use of roughage

The use of roughage is a common risk management strategy to avoid animal health problems in cattle. No research has been conducted on the requirement of roughage when cattle graze dual purpose crops. From experience, there is generally no need to add roughage to cattle grazing dual purpose cereal crops. Due to the higher risk of forage disorders in cattle grazing canola, roughage has generally been recommended as a risk management strategy. Growers should be aware that a potential outcome of using roughage during grazing is that liveweight gains can be reduced. This is due to the reduced forage crop intake as the roughage can part fill the rumen. This effectively dilutes the nutrient intake of the livestock.

Best management practice for cattle on dual purpose crops

To minimise the risk of cattle health problems grazing dual purpose crops it is suggested to:

- Ensure stock are not introduced to a new paddock when hungry. Fill them with a fibre source before introduction – we seek a compromise between quality and fibre, therefore good quality cereal hay is recommended
- Introducing cattle to the crop mid-late morning during the adaptation period will reduce the risk of cattle gorging themselves
- Cattle should be adapted onto dual purpose canola to ensure they are eating the crop and to allow time for rumen adjustment
- Supply mineral supplements for cattle grazing dual purpose wheat
- Reduce pre-sowing sulphur fertilisers for dual purpose canola to reduce the risk of PEM
- Research has found low nitrate levels in the canola leaf, so ensuring that that there are high forage levels available will allow animals to select the leaf and reduce the risk of nitrate toxicity
- Provide hay in the paddock for dual purpose canola to allow cattle to select different forage. This will enable cattle to substitute hay for canola in the diet and increase dietary fibre levels. Be aware that this may result in nutrient dilution
- During the adjustment period the cattle need to eat the crop. If they are grazing fence lines or any other non-crop areas during the adjustment period, it is unlikely the animals have been adjusted
- Supplementation with palatable buffers, alkalinising agents or therapeutic agents can be used to reduce acidosis although limited research has occurred with cattle on dual purpose crops

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Satellites and other useful tools that are ready for immediate benefit for on-farm decision making

Tim Neale, DataFarming

Key words

satellite imagery, precision agriculture, sensors, adoption

Take home message

Growers and agronomists have access to free (and paid) precision agriculture (PA) tools to obtain immediate benefits for their crop management. Satellite imagery represents one of the simplest entry points to get started on the journey of precision agriculture. Many Australian farms have yield variation of more than 300% in every single paddock. Combined with targeted soil and plant sampling, a deeper understanding of the factors impacting on production can be identified and remediated. Coupled with that, variable rate technology (VRT) offers the ability to better target crop inputs.

Barriers to adoption

In a GRDC/CSIRO survey several years ago, it showed that whilst around 75-80% of farmers had adopted auto-steer GPS systems on machinery, only 4% of farms had viewed a satellite image of their property, and only 10% were using variable rate technology (Llewellyn and Ouzman, 2014). DataFarming set about to identify the barriers to adoption of digital agriculture technologies, and narrowed them down into five main areas:

1. Cost of entry
2. Complexity of the systems available
3. Ease of use and user experience
4. Connectivity (internet, and between equipment brands) and
5. Not getting instant value.

Whilst many farmers embrace digital ag technologies, agronomists are making more and more complex decisions on increasingly bigger farms and paddocks; so there is a great opportunity to become far more efficient in the way we check, manage and treat crops.

Getting started

The first step is to get satellite imagery of your paddocks whilst the crop is growing. With the availability of 10 metre resolution data every five days anywhere in the world, essentially for free, this is a great starting point. The key difference is that satellite imagery shows impacts beyond what our eyes can see – so we can detect crop problems earlier, and easily measure the impacted area. A crop growth index called NDVI which measures in the infrared spectrum, picks up difference in crop health/greenness/biomass. This helps direct where to look when scouting or checking crops. See below (Figure 1) for an example from the DataFarming platform – where the blue areas (centre) of the paddock are high growth, and the areas in red (left and right) are poorer growth.

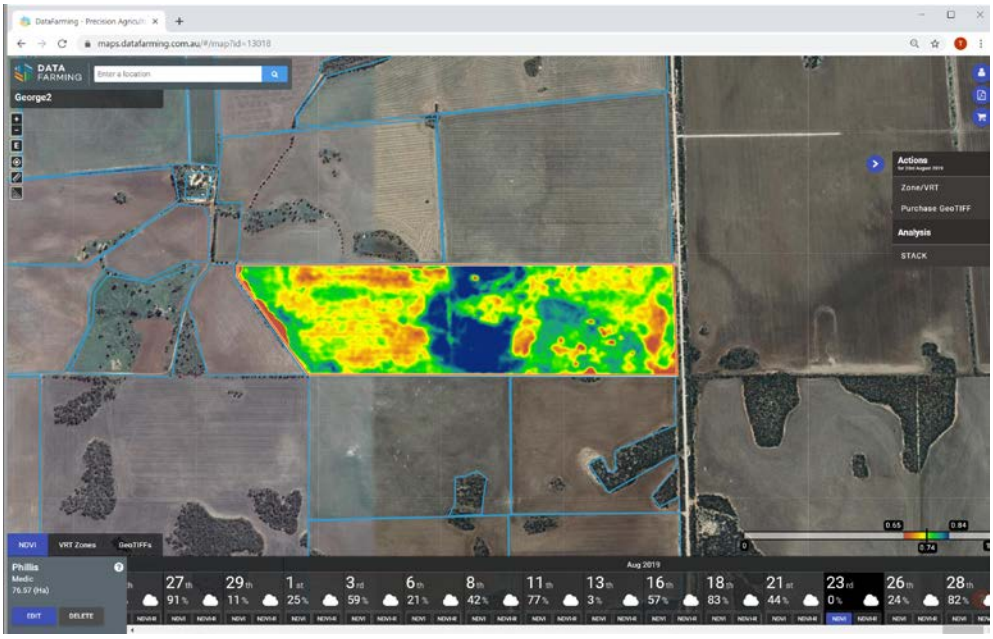

Figure 1. An example from the DataFarming platform – where the blue areas (centre) of the paddock are high growth, and the areas in red (right and left) are poorer growth.

After three years (up to the end of 2020) there are now 20,000 farms loaded in the DataFarming platform covering almost ¼ of the Australian grains industry, and 20M acres of paddock level data processed.

Targeted soil and plant sampling

Whilst technologies such as EM (electromagnetic) mapping have been around for decades, only a few key contractors offer the service in Australia. With the advent of new tools, any agronomist can now capture soil type data using EM from the comfort of the ute. EM typically measures down to 1.5m into the soil to detect differences in clay content, moisture content, and soil salts. Below (Figure 2) is an example of one of these tools, and the resultant data on the right.

Figure 2. An example of an EM machine on the back of a ute (left) and resulting data map (right)

For agronomists collecting soil samples, the APAL Farm2Lab app takes the out the paperwork and streamlines the whole process. It doesn't make the practical part of sampling any easier, but certainly speeds up the process and improves efficiency. You can add zonal layers at the planning stage, before entering the paddock, which helps select the right spot to sample. Once sites are selected and you determine the suite of tests you want, the points are available in an offline app which directs you in the field. Once collected the geo-referenced results are presented back in the app for easy viewing and understanding. The results can also be pushed to BackPaddock or Agworld software for interpretation and building recommendations.

The image (Figure 3) below shows zone maps in the Farm2Lab app, ready for soil sampling.

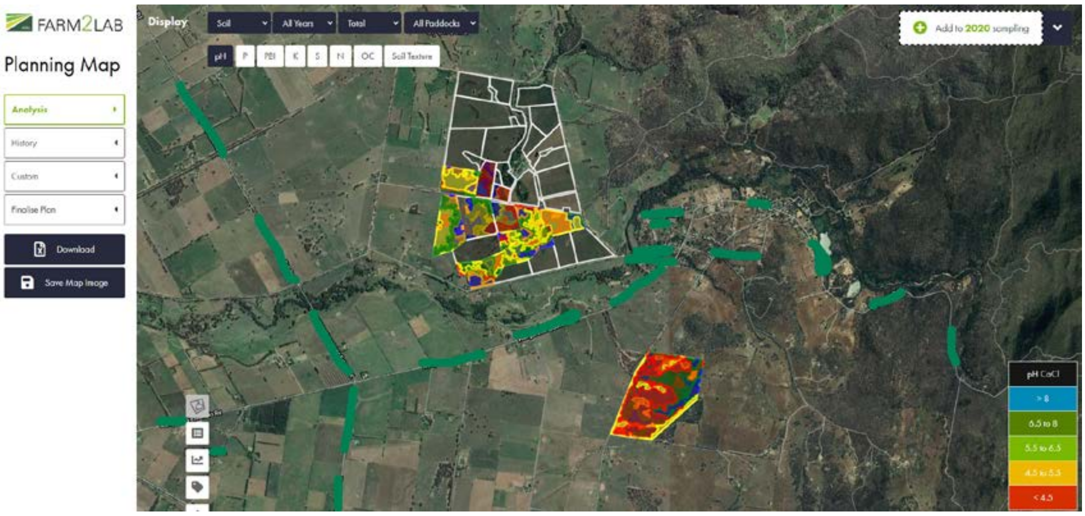

Figure 3. Zone maps in the Farm2Lab app, ready for soil sampling

Results can also be displayed in other platforms. The image below (Figure 4), shows the resultant soil test levels overlaying the NDVI imagery in the Summit fertiliser app. This enables farmers and agronomists to get better value out of soil testing, as well as understand and alleviate production limiting factors.

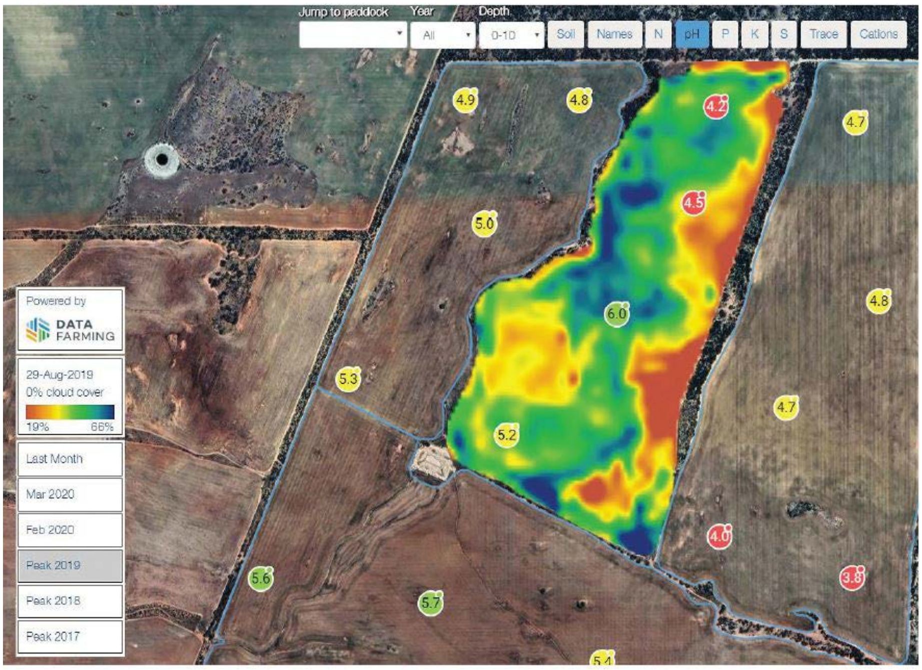

Figure 4. Soil test levels overlaying the NDVI imagery in the Summit fertiliser app

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ConstraintID – a free web-based tool to identify areas where soil constraints are most likely to be limiting crop yields

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Key words

ConstraintID, soil constraints, crop yield, decision support tool, remote sensing, Landsat

GRDC code

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Take home messages

- Better knowledge and understanding of the variation of past crop yields (both spatially across a paddock, and temporally from season to season) can help growers make better management decisions to improve yields in future
- Remote-sensing data compiled from earth-observing satellites provide a valuable information source about past crop yields, allowing us to look through multiple years of imagery for consistent patterns through time – that is, spatial patterns of yield variation that repeat season after season
- Such consistent patterns might imply the presence of some kind of soil constraint limiting yields in parts of the field
- This web-based tool enables growers to easily look at processed remote-sensing data representing past crop yields in their paddocks. The tool will show if there are any consistent spatial patterns in the data and will compile and present maps of soil constraints for comparison. The data on these driving factors could help the user to interpret the variation shown by the remote-sensing data.

Introduction

Within-field spatial variation of crop yields can occur for various reasons, but perhaps the most important driver of this variation is the soil. There are different management strategies available to growers to address soil constraints (amelioration, adjusting inputs to match potential, switching to growing tolerant species), but a necessary first step is the identification of affected areas (Dang et al., 2010).

Persistent spatial patterns of yield variation within fields that have otherwise been managed uniformly (spatially) provide an indication that soil constraints are driving variation. Remotely sensed data from satellites provide a valuable information source for helping with the task of identifying persistent yield patterns (Orton et al., 2018). In particular, the Landsat series of satellites provide a very useful dataset for several reasons:

(i) The long history (in this area of data collection from 1999-present), which allows persistent spatial patterns of within-field yield variation (similar patterns repeating season after season) to be identified
(ii) The time between repeated images of the same area (8 days when two of the Landsat satellites are operating), which allows growth patterns within a season to be identified
(iii) The spatial coverage of satellite data (data readily available across the whole region)

(iv) The spatial detail (30-m pixel sizes), which is detailed enough to allow within-field patterns of spatial variation to be identified, and

(v) It is freely available.

While Landsat imagery provides an excellent source of raw data, there are a number of processing and analysis steps required to extract the potentially useful information. We have developed a freely available online software tool, ConstraintID (http://constraintid.com.au), to make this task easy for growers, and to present results in a way that is straightforward to interpret. The tool should assist growers with identification of potentially constrained areas, giving them the information to make more informed management decisions. Here we present an illustration of the software tool applied to a field in northern NSW.

Illustration

Remote-sensing data to give crop performance information for all years

The software undertakes the spatial analysis within the confined boundary of a field. It is important that there has been consistent management across the field, so that spatial differences due to management will not be confused with differences due to soil constraints. The software then collates all of the remote-sensing data for this field, and for each year from 1999 to the latest complete season, generates a map of an index representing crop performance. This aim of this index is to show, for any given year, which parts of the field were above average and which parts were below average. In some of these years a winter crop might not have been grown, so the software looks at the growth patterns within each season to check whether the field has been cropped and determines if it that years observations should be included in the analysis. For illustration, Figure 1 shows the resulting maps for the years 2005-2010 at Sunbury. In this case, the software deemed that there was good evidence of 2005, 2006, 2008 and 2009 being cropped years (shown by the green ticks), so these would be included in further analysis.

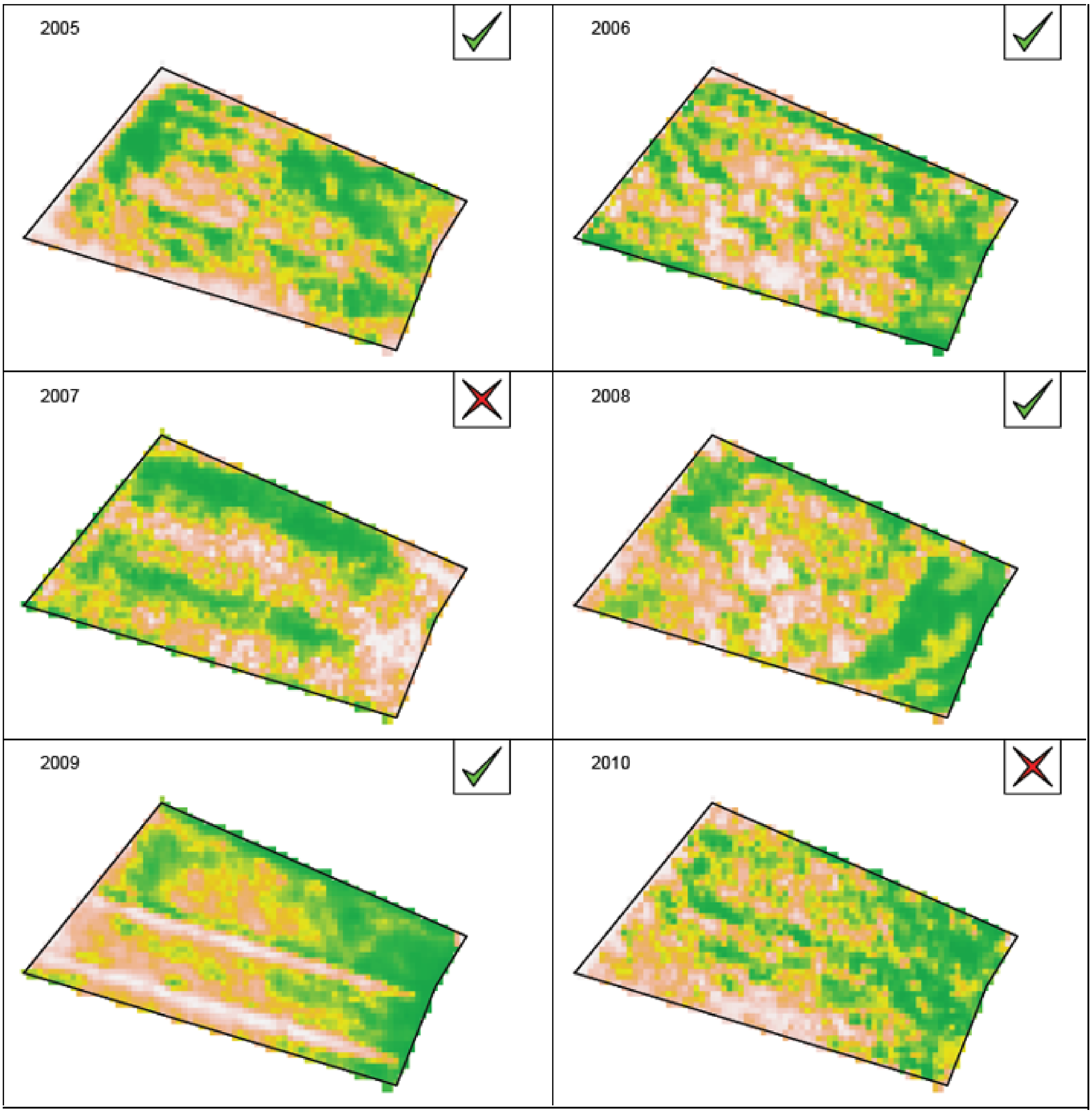


Figure 1. Maps of the index representing the spatial distribution of crop performance at Sunbury for the years 2005-2010. Green (darker areas) shows relatively good crop performance, beige relatively poor. The tick or cross in the corner of each panel indicates whether the analysis deemed that year to have been cropped or not.

Consistent spatial patterns in the remote-sensing data

It is important to note that the spatial pattern of the index has some aspects that repeat year after year, and other aspects that do not repeat. For example, in Figure 1 it seems that the east of the field was consistently higher yielding than the west. Also note that this was not the case in 2007, though for that year the field was deemed to not have been cropped. This highlights the importance of having a multiyear analysis when the goal is to identify soil constraints, which we would expect to give rise to similar spatial patterns of yield year after year (as opposed to diseases or weeds which might give reduced yields in part of the field in isolated seasons).

To identify the patterns that repeat season after season, the long-term average of the index is calculated for each pixel (using only the years when a crop was grown). A statistical test is then performed to evaluate whether there is evidence that a pixel consistently performs above or below average. Figure 2 shows an example of this type of analysis, from which it is clear that the east side of the field gave consistently better performance than the west side. Within some fields there will not be strong variation in soil constraints, and then we might not expect much consistent variation in yields. However, for fields where soil constraints exhibit strong within-field variation, we would expect a consistent pattern of spatial variation, such as that illustrated in Figure 2.

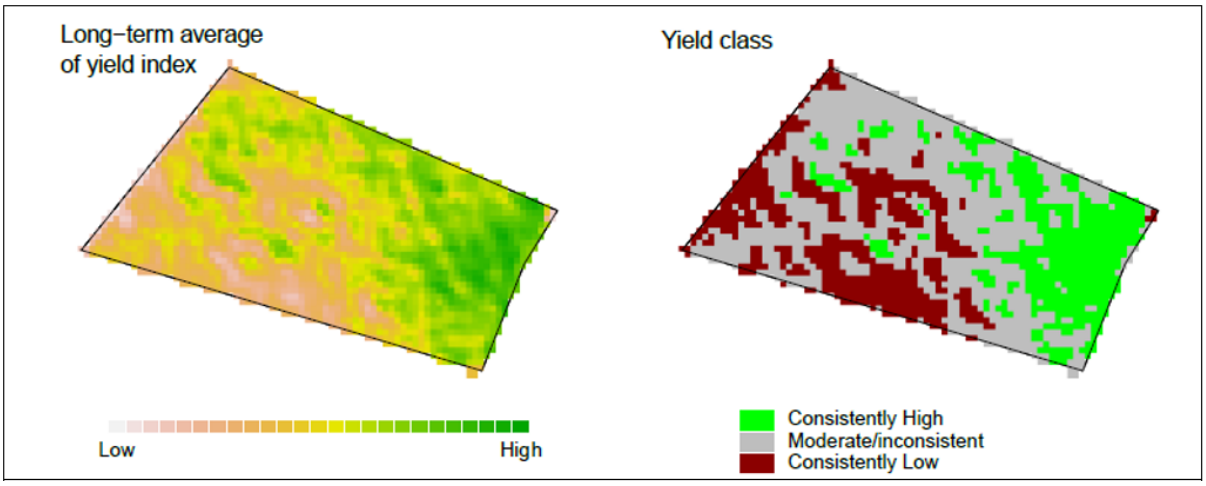


Figure 2. Maps summarising the multi-year analysis of remote-sensing data at Sunbury.

Comparing the remote-sensing information with soil data

The maps shown so far are based only on analysis of the remote-sensing data. Soil data from within the field are vital to validate what is causing the variation in yield. Information from the remote-sensing analysis (Figure 2) can be used to select locations for soil sampling. An advisable strategy might be to collect soil cores to a depth of 1.2 m from a few locations (minimum 3-4) in the areas with consistently high values of the crop yield index (green (mostly to the east) areas in Figure 2) and from a few locations in the consistently poor-performing areas (red (mostly to the west) areas in Figure 2). Once a dataset of soil analysis results from profiles in the field has been compiled, the software tool allows the user to upload/input the data, and it can be used to compare soil constraints in the in the good and poor-performing areas of the field.

For the Sunbury field, ten soil profiles were collected, of which two profiles were in the areas with consistently low crop yield index values, and three were in the consistently high yield index areas. The soil constraint data from the profiles in the better-performing areas are averaged and plotted as the green lines (generally to the left) in Figure 3; the red lines (generally to the right) show the averages from the poor-performing areas. Also shown are critical values for potential (light orange background - on left) or severe effects (light red background – on right) of the soil constraints on wheat yields. These critical values have come from a recent review of the literature on soil constraints to cropping in Australia (Page et al., 2020).

These plots indicate that there are differences in the salinity of the soil profiles from the constrained and unconstrained areas, with the profiles from the constrained areas exceeding the critical values for severe salinity effects below around 40cm in the soil profile. The differences between the constrained and unconstrained profiles in terms of sodicity were not as great.

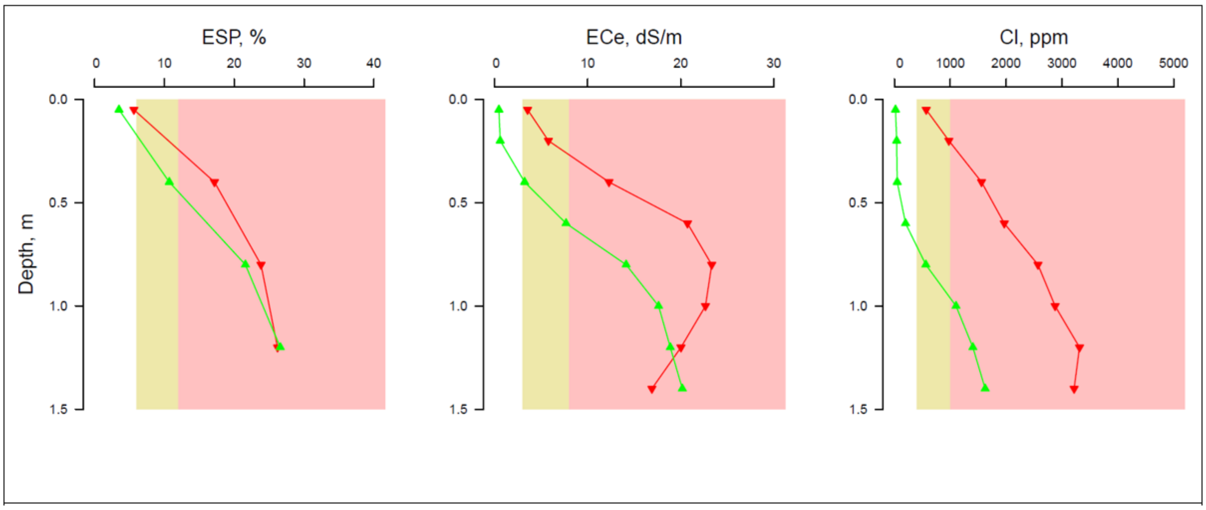


Figure 3. Soil profiles within the areas with consistently high crop yield index values (green - line to left) and consistently low values (red – line to right). More severely constrained zones are delineated by colour coding and are to the right side of each graph.

Web-based ConstraintID (http://constraintid.com.au/)

The web-based interface of Constraint ID allows farmers and consultants to setup, save and share soil constraint analyses for different paddocks (Figure 4).

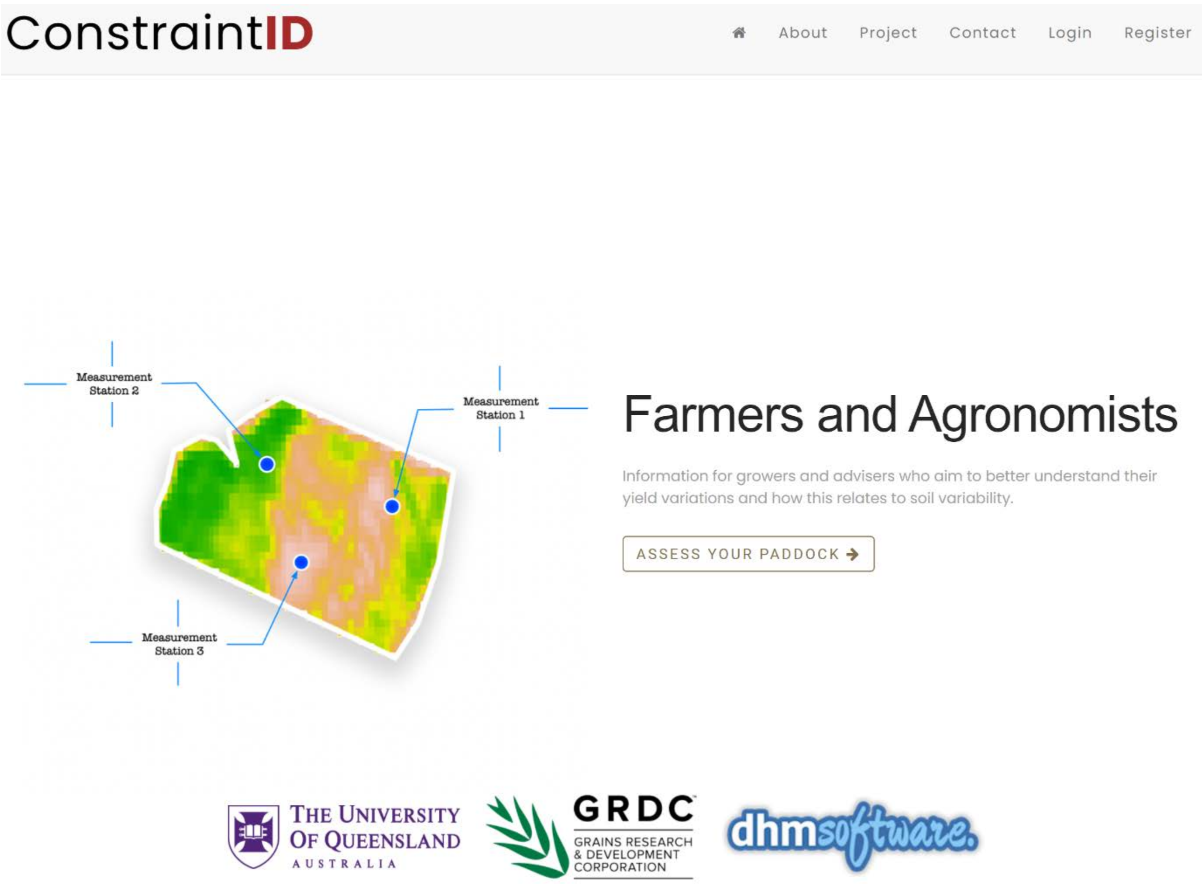
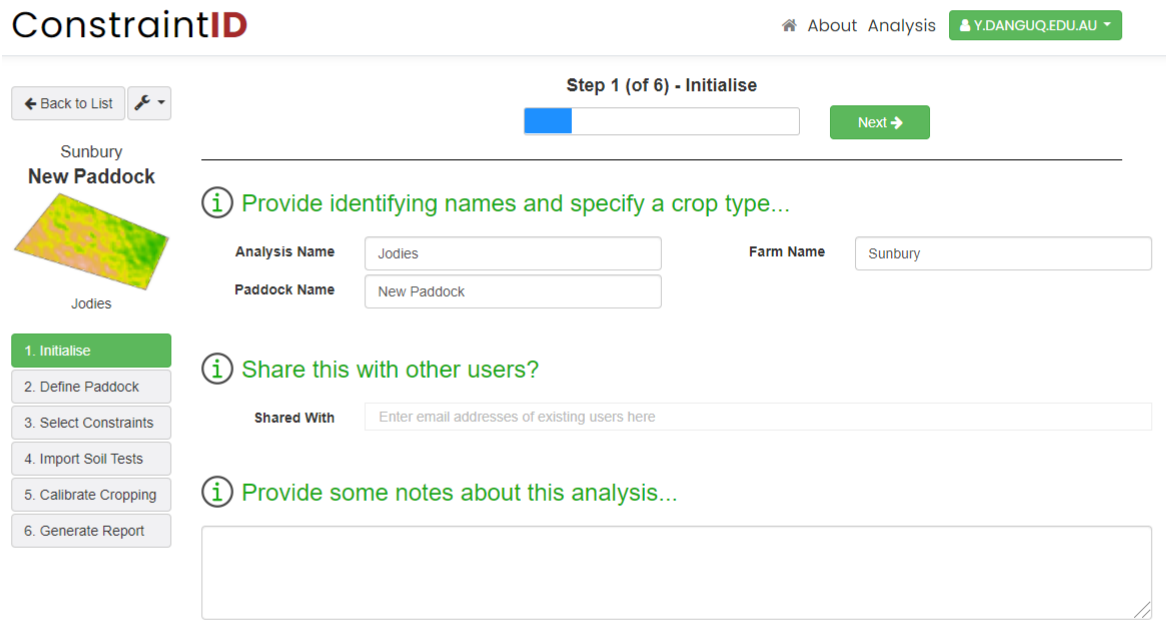


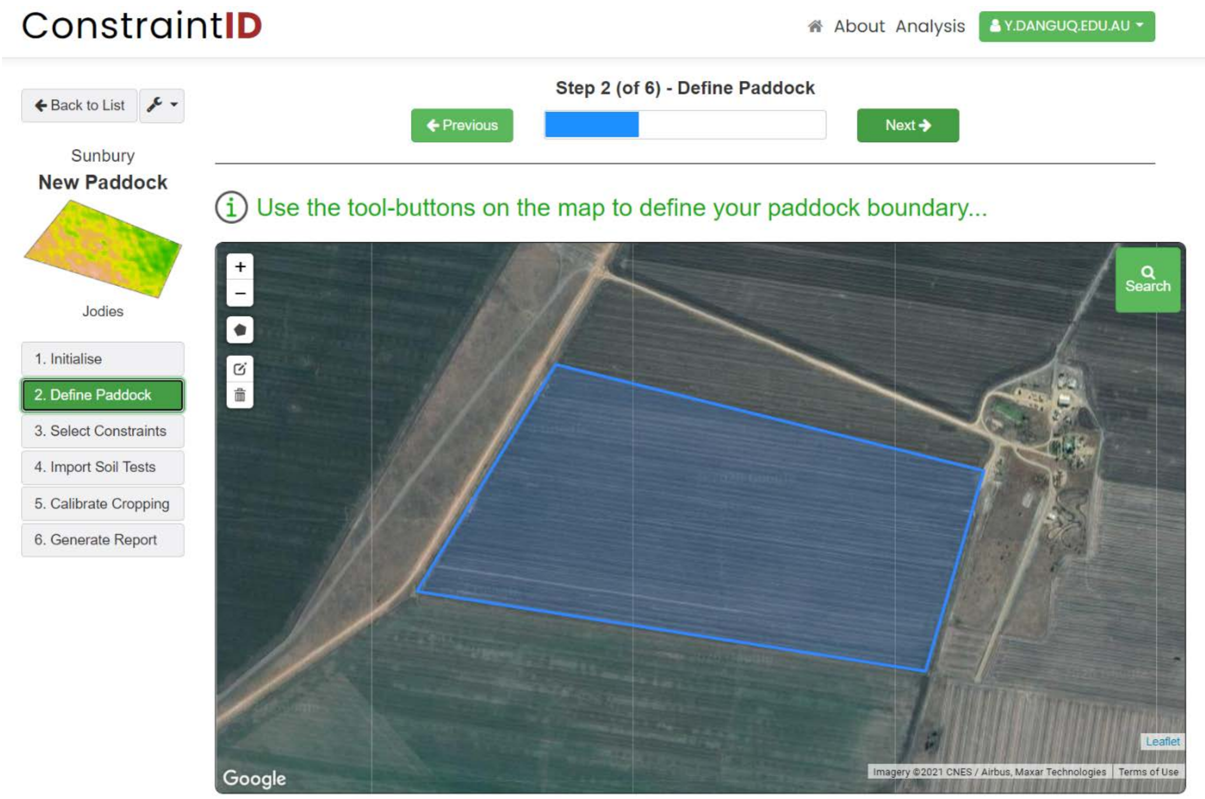
Figure 4. ConstraintID landing page

An analysis is broken down into 6 steps presented through the interface:

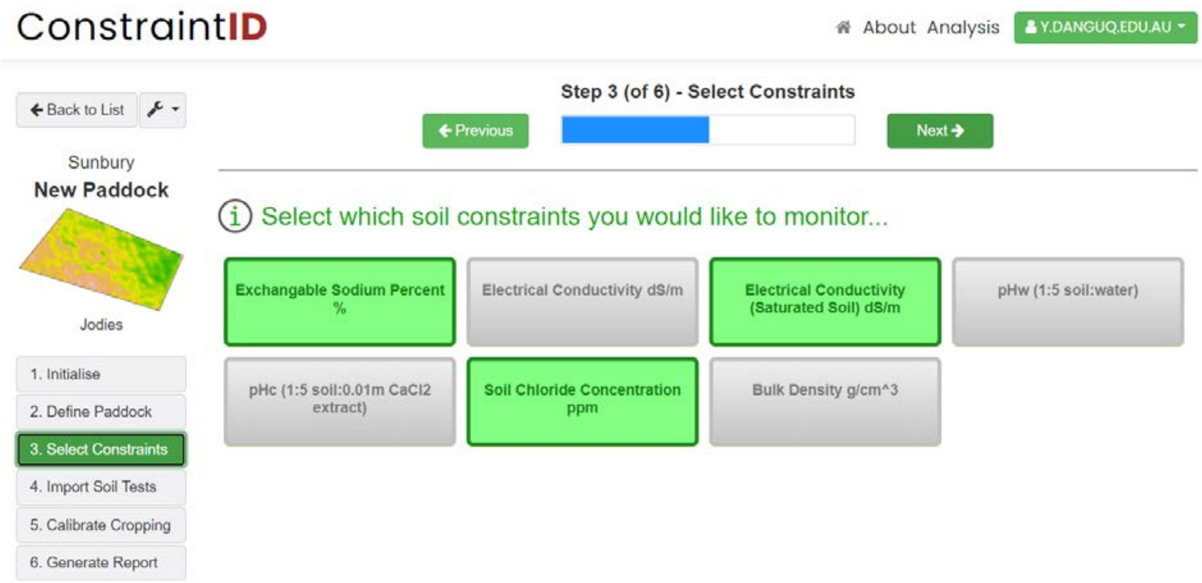
Step 1: Enter analysis details



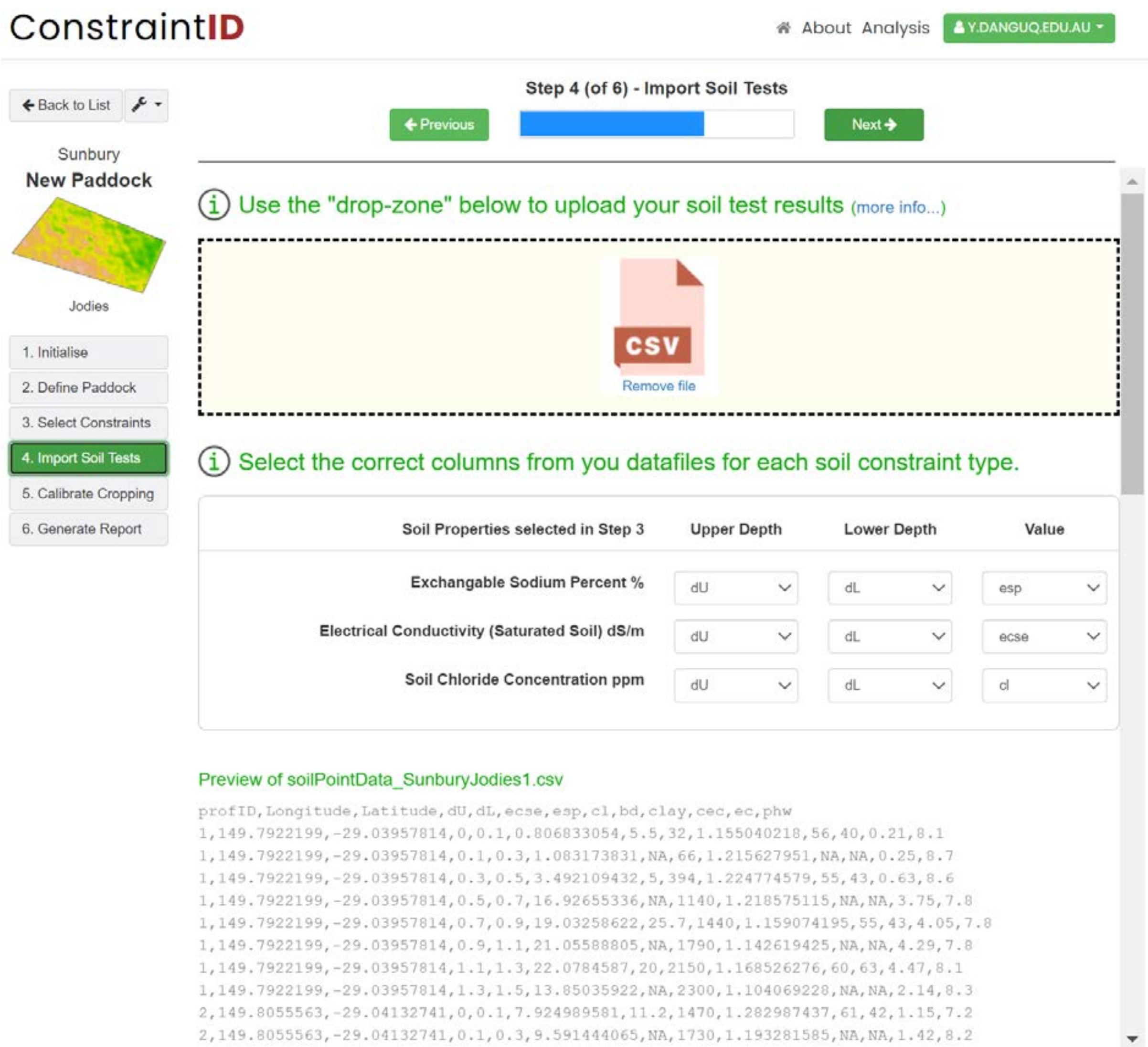
Step 2: Define paddock boundary



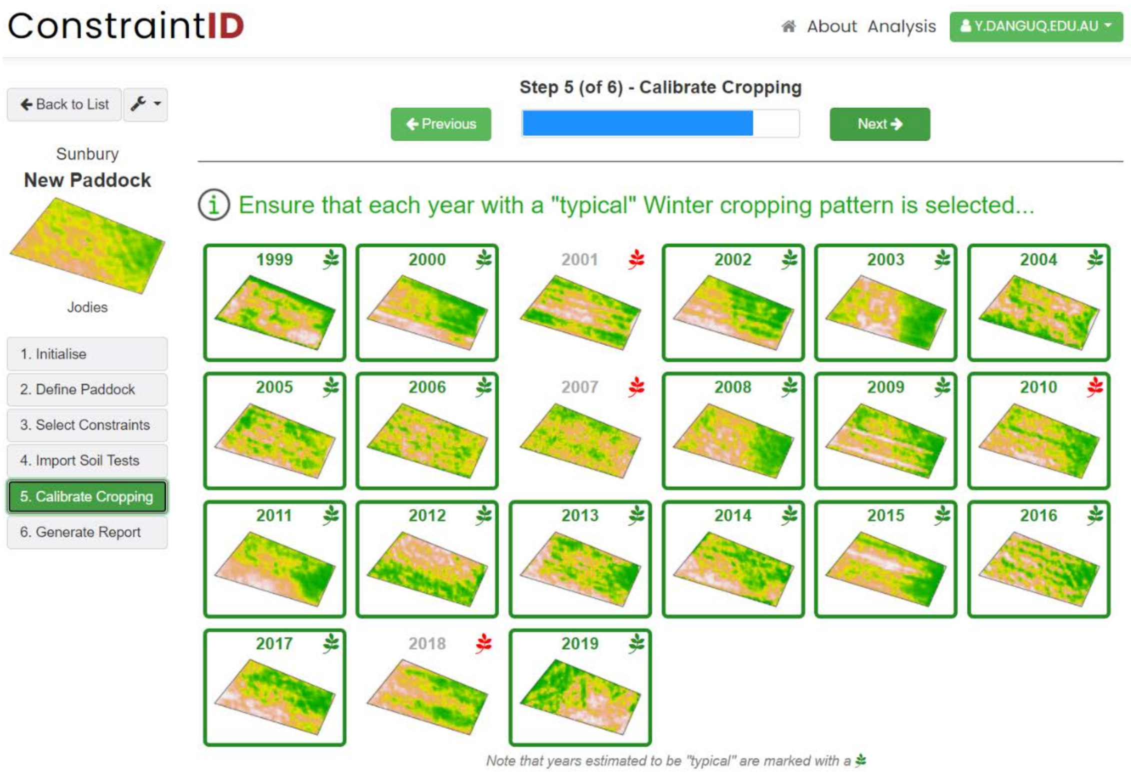
Step 3: Select soil constraints



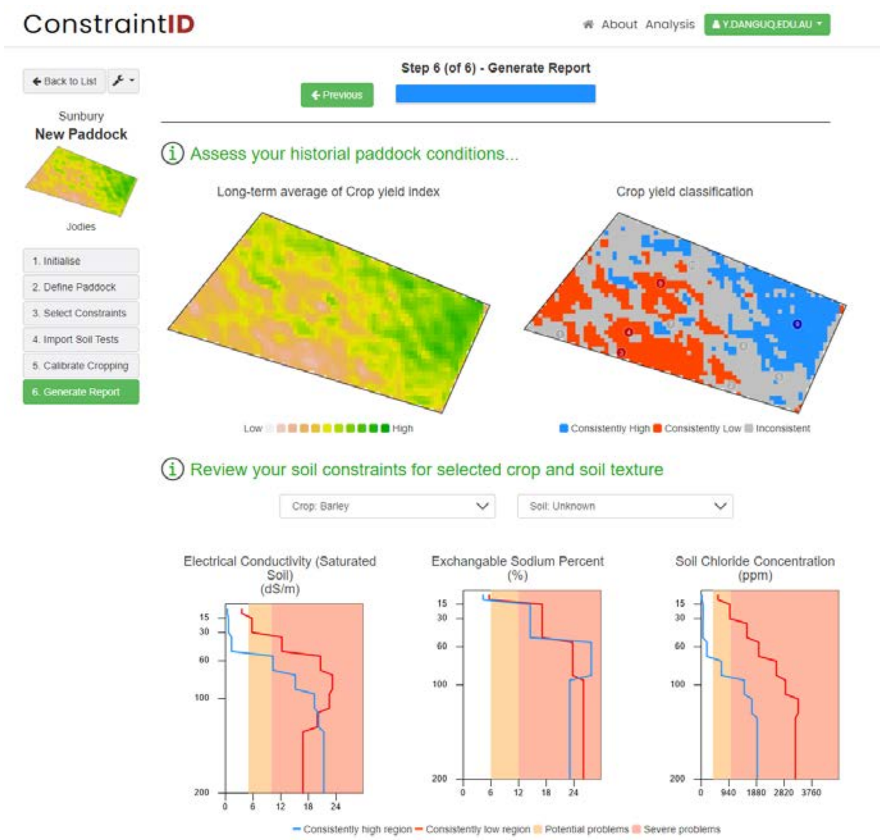
Step 4: Import soil test data



Step 5: Select cropping years



Step 6: Review results



For each analysis, the software requires the user to trace their paddock boundary over a Google Maps' satellite image, using tools provided in Step 2. This then initiates the start of the spatial analysis which occurs silently in the background on the server. In this process, a time-series of 'Enhanced Vegetation Index (EVI)' satellite images from 1999 to the present date are extracted which typically include up to 20 images (days) per year. These tiled images are then reprocessed to exclude any data outside of the paddock boundary. In some cases, multiple adjoining images may require stitching together when the paddock boundary extends past the tile boundary. The resulting paddock images are then filtered to remove any that might be affected by excessive cloud cover or are indicative of fallow conditions. Finally, the individual EVI pixel values are ranked in order across the paddock to differentiate between high vegetation and low vegetation areas of the paddock. A single image is then produced for each year, based on averaging the ranked EVI values for that year, which we designate as the Crop Yield Index (CYI). This process typically takes 10-20 seconds to complete.

In the next steps (3 & 4), the user selects which soil constraints they wish to analyse and upload any measured soil test data they have relating to these constraints. Soil test data must be prepared in a comma-separated value format and uploaded to the server via dragging and dropping the data files into the user interface. Users must then identify which columns in the data files correspond to each soil constraint using in-built selection tools.

The second last step of the analysis involves the user being presented with a series of paddock images (generated in the second step) showing the Crop Yield Index across the paddock for each year. Each image is 'marked' to show whether or not the software thinks that that year was indicative of a typical cropping year. The user must then inspect each image to ensure that all typical cropping years are selected, and non-cropping years are de-selected. This in effect is calibrating the analysis in order to generate the final result.

In the final step of the analysis, all included cropping years are compiled into a single paddock map of Crop Yield Index values. A second image is then generated identifying those regions of the paddock that have demonstrated consistently high Crop Yield Index values (coloured blue) or consistently low values (coloured red). The locations of the soil test readings are then overlayed on these regions, allowing a graph of each soil constraint to be generated based on the soil test results, with different lines for high and low yielding areas.

Summary

The work presented here provides a snapshot of the Constraint ID software, which we think should provide growers with a valuable tool for investigating within-field variability and for making more informed management decisions. Further work to investigate and compare different management strategies once constrained areas have been identified is imperative.

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How heat tolerant are our current wheat varieties?

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Key words

wheat, heat tolerance, genomic selection, phenotyping, pre-breeding, current varieties

GRDC code

US00081

Take home message

Some Australian cultivars are significantly more heat tolerant than others when heat stress is applied at anthesis and grain filling growth stages. Materials identified and developed through this project provide new genetics for heat tolerance that can be used to improve the heat tolerance of current varieties.

Aims

This research compared the heat tolerance of current commercial wheat varieties under elevated day and night temperatures during anthesis (Zadok 60) and grain fill (Zadok 73) growth stages.

Introduction

Extreme heat events may become 85% more frequent and 57% longer in the coming decades due to the increasing impact of climate change (Syktus et al; 2020). Wheat is highly sensitive to extreme heat during anthesis (flowering) and grain fill growth stages. This can have a significant impact on final crop yield and quality. Heat stress at anthesis often affects pollen fertility which reduces the number of kernels produced by each spike. For every one degree rise in the average maximum temperature above the optimum (5°C to 28°C), it is estimated that kernel number decreases by 4% (NSW DPI, 2007). An extreme heat event at grain fill can negatively impact kernel size as it disrupts the translocation of nutrients and the synthesis and deposition of starch.

The most effective way of assessing the performance of a genotype and its range of physiological responses is to screen materials under stressful environmental conditions. Screening methods for heat tolerance often involve single tiered techniques, usually in a glasshouse setting, which can lack relevance to farming environments and does not always represent the most relevant materials. This paper discusses the findings of the second tier of a three-tiered technique developed specifically to screen for heat tolerance (Thistlethwaite et al., 2020). This method evaluates germplasm by combining natural and controlled conditions using in-field controlled environment chambers.

Methods

Twenty-three current commercial bread wheat cultivars and two breeding lines were screened under in-field controlled environment chamber conditions at The University of Sydney Plant Breeding Institute, Narrabri in 2020. Each line was sown in 12 m^2 replicated plots. Treatments involved a heated chamber that adjusted its internal conditions to be consistently 4°C above the ambient temperature. Anthesis treatments consisted of an average increased temperature of 30.7°C between 10:00-14:00h and grain fill treatments consisted of an average increased temperature of

15.3°C between 19:00-07:00h. Chamber units were deployed at the same growth stage at the same time of day for each genotype.

The hidden costs associated with a rise in global minimum temperatures, especially late in the season, is the reason a nighttime heat treatment was imposed at grain fill. Different physiological processes occur within a plant during the night compared with during the day. Some varieties could be more efficient at recovering during the night which would then allow them to cope much better when the temperature was high during the day. The physiological basis of this phenomenon remains limited; however, evaluations such as this are a step towards a better understanding of why, rather than how, varieties differ from each other.

In-field controlled environment chambers, designed to fit over a 4 m^2 of a plot, were used to increase the maximum ambient temperature for three consecutive days at anthesis and increase the minimum ambient temperature for three consecutive nights during grain fill (Figure 1). Each chamber unit was 2 m x 2 m x 1.5 m (length x width x height) in dimension. Chamber units consisted of a galvanised steel frame covered in clear polycarbonate. HOBOware® weatherproof temperature and humidity data loggers with a temperature measurement range of -40 °C to 70 °C with ±0.2 °C accuracy and a relative humidity (RH) measurement range of 0 to 100% with ±2.5% accuracy was installed in all units and fitted with a radiation shield.

Figure 1. In-field controlled environment chambers in the field at The University of Sydney Plant Breeding Institute, Narrabri 2020.

A positive temperature coefficient (PTC) thermistor with resistance increasing with temperature was installed with output fed to a SPLat HVAC26A AC controller. Each individual chamber was fitted with a domestic reverse cycle air conditioning (AC) unit rated to 3.9 kW heating and 3.6 kW cooling with a maximum full load current of 8.5 amps and ducting ran from the AC unit to the chamber. A 15 kVA 3-phase diesel generator was used to provide in-field power to the chamber units.

Spikes that were deemed to be at the correct stage for treatment were tagged and subsequently harvested to ensure the accuracy of plant growth stage. Yield, yield components and targeted phenological and physiological traits were assessed at key growth stages. Irrigation was applied based on Goanna moisture (capacitance) probe readings to ensure well-watered conditions throughout the season.

Ideally, this evaluation of commercial varieties should be repeated across multiple years and sites due to potential variation in environmental conditions and to allow for the best representation of the germplasm. In previous years, in-field controlled environment chambers were used primarily to assess new heat tolerant material rather than commercial varieties due to the availability of chambers.

Results

Overall, in-field controlled environment chambers significantly impacted the yield and kernel weight of most lines evaluated when a heat shock was applied at anthesis and during grain fill (Table 1). An average decrease in yield of 14% and kernel weight of 9.7% was observed between control and heated plots when a heat shock was applied during the day at anthesis. When minimum temperatures were increased at night during grain fill, yield and kernel were not as greatly impacted with yield and kernel weight decreases of 4.8% and 5.8% observed, respectively.

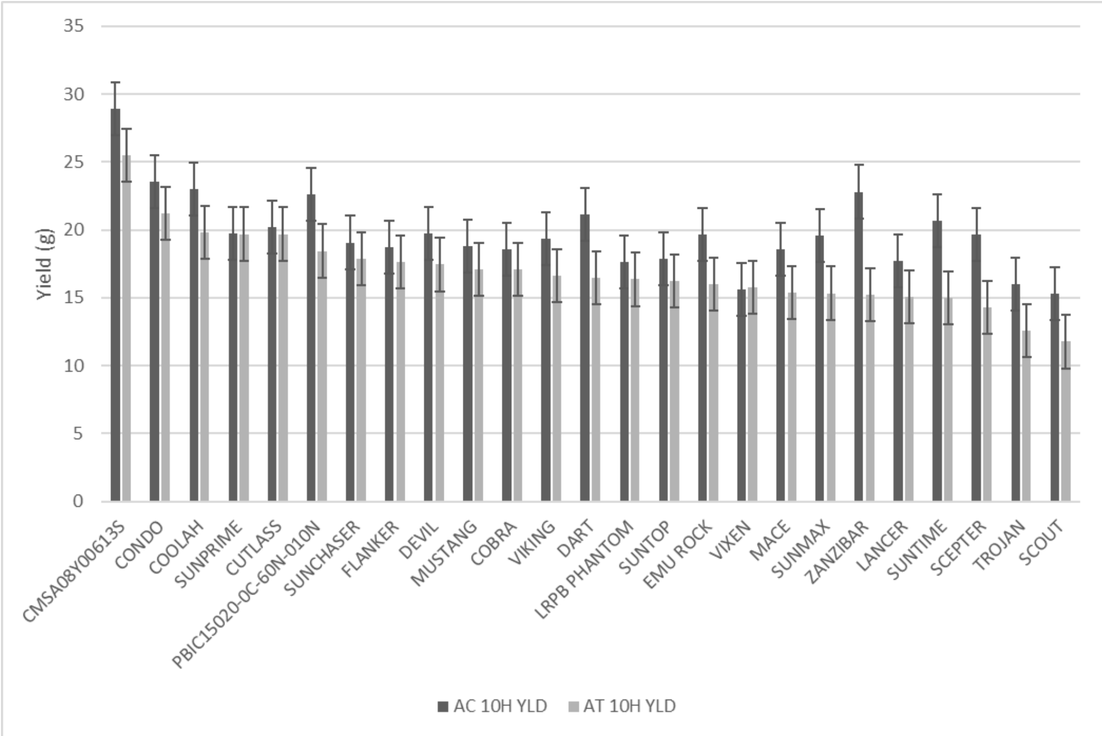
Table 1. The impact of heat chambers on yield and kernel weight (TKW) of ten heads selected at anthesis (Zadok 60) and mid-grain fill (Zadok 73) respectively.

Trait	Anthesis Control	Anthesis Treated	Grain Fill Control	Grain Fill Treated	Prob.
Yield of 10 heads (g)	19.78 a	16.95 b	19.28 a	18.35 c	<0.001
TKW of 10 heads (g)	38.28 a	34.57 b	37.86 a	35.67 b	<0.001

Note: means in rows followed by the same letter are not significantly different at P<0.05

Recent Australian varieties performed well under anthesis heat treatment with the best performing varieties AGT Condo⦸, Coolah⦸, Sunprime⦸ and Cutlass⦸ combining yield potential and heat tolerance, closely followed by AGT Sunchaser⦸, LRPB Flanker⦸ and Intergrain Devil⦸. Varieties such as LRPB Dart⦸, RGT Zanzibar⦸ and AGT Scepter⦸ showed good yield potential and performed well under controlled conditions but were greatly affected by heat treatment. Intergrain Vixen⦸ seemed to be unaffected by heat treatment as the difference between control and treatment yield was negligible. CIMMYT breeding line (CMSA08Y00613S-050Y-050ZTM-050Y-59BMX-010Y-0B) significantly outperformed all current varieties for yield (56% better than AGT Suntop⦸) and kernel weight under control and heat treatments (Figure 3).

(a)



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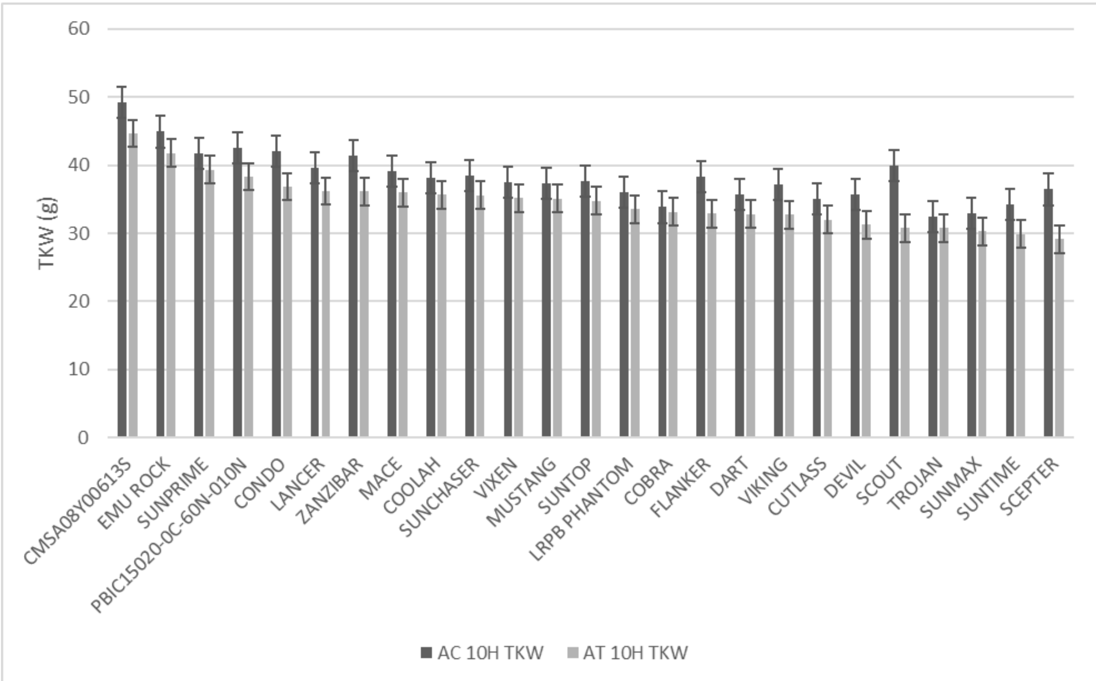


Figure 2. Yield (a) LSD ≤0.05 =3.98 (AC 10H YLD - Anthesis control 10 head yield, AT 10H YLD – Anthesis treatment 10 head yield) and kernel weight (b) LSD ≤0.05 =4.42 (AC 10H TKW - anthesis control 10 head thousand kernel weight, AT 10H TKW - anthesis treatment 10 head thousand kernel weight) of Australian cultivars under elevated day temperatures treatment and associated control at anthesis, Narrabri 2020.

(All the named varieties in the graphs above are protected under the Plant Breeders Rights Act 1994)

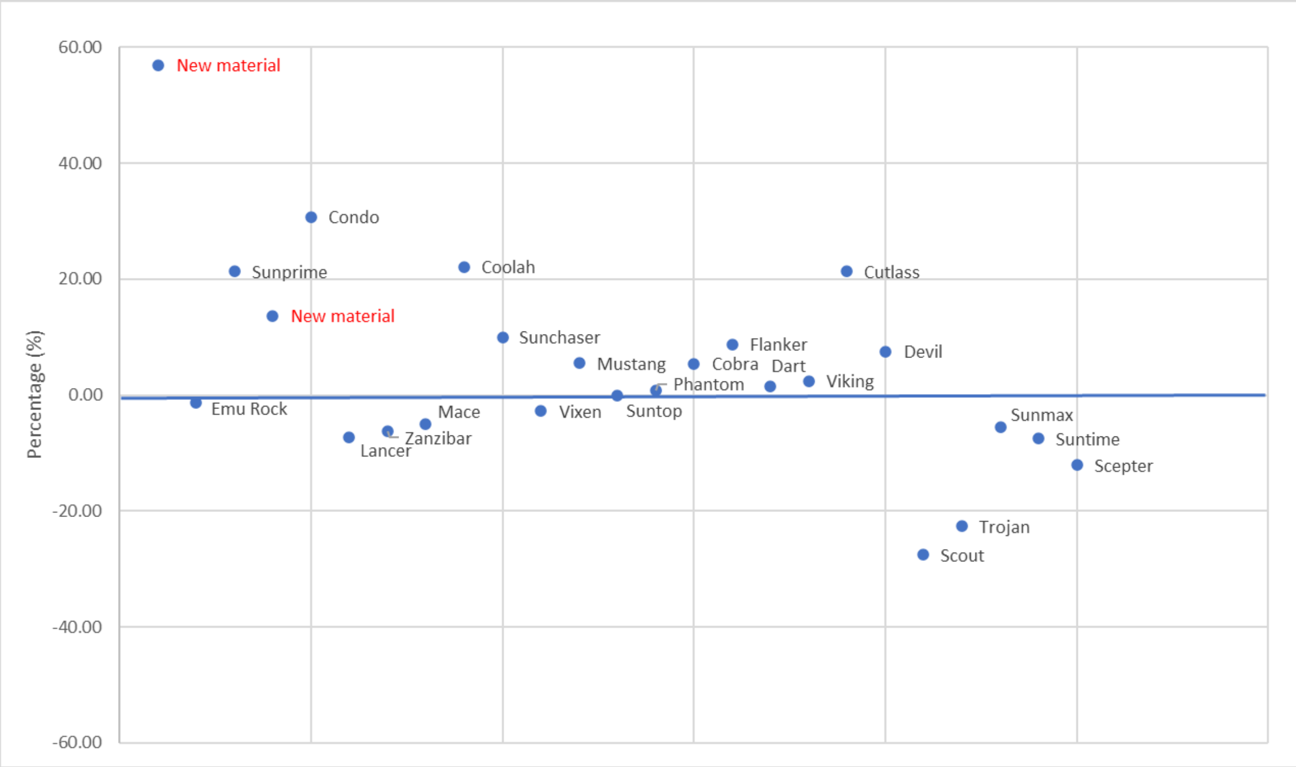
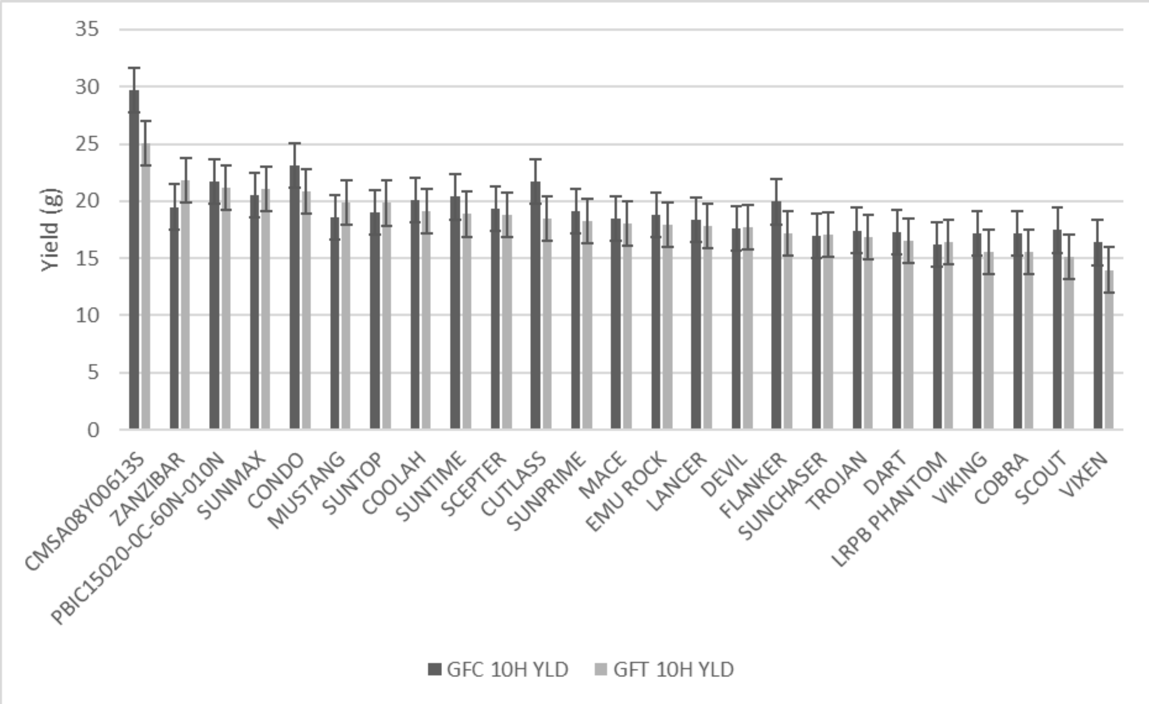


Figure 3. Yield of 10 heads for anthesis treatment of current cultivars under elevated day temperature treatment as a percentage (%) of Suntop⫽ which is represented by the x-axis (0.00%). (All the named varieties in the graphs above are protected under the Plant Breeders Rights Act 1994)

This was closely followed by AGT Suntop⫽, Coolah⫽, Suntime⫽ and Scepter⫽ (Figure 4). In some cases, as with RGT Zanzibar⫽, AGT Sunmax⫽ and Suntop⫽ and LRPB Mustang⫽, the heat treatment slightly outperformed the control. The varieties that were the most stable between treatments included Intergrain Devil⫽, AGT Sunchaser⫽ and LRPB Phantom⫽ although they didn't have as high a yield potential. CIMMYT breeding line (CMSA08Y00613S-050Y-050ZTM-050Y-59BMX-010Y-0B) surpassed all current varieties for kernel weight.

(a)



(b)

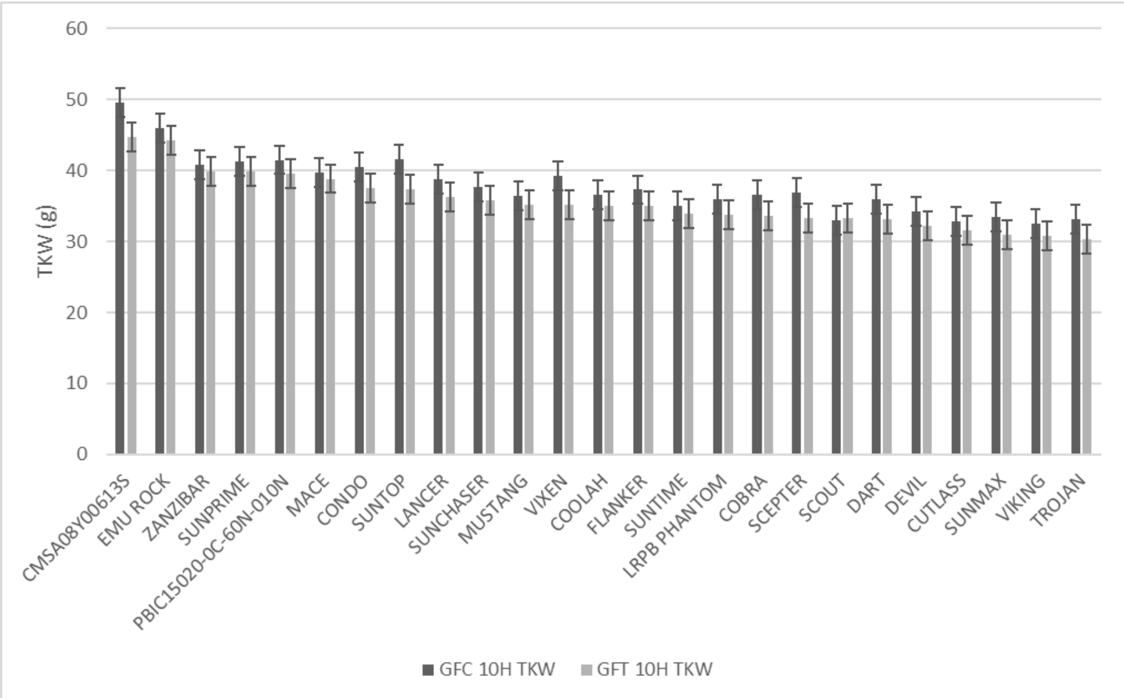


Figure 4. Yield (a) LSD ≤0.05 = 3.57 (GFC 10H YLD – grain fill control 10 head yield, GFT 10H YLD – grain fill treatment 10 head yield) and kernel weight (b) LSD ≤0.05 = 3.81 (GFC 10H TKW – grain fill control 10 head thousand kernel weight, GFT 10H TKW – grain fill treatment 10 head thousand kernel weight) of Australian cultivars under elevated minimum ambient temperatures treatment and associated control at grain fill, Narrabri 2020.
(All the named varieties in the graphs above are protected under the Plant Breeders Rights Act 1994)

Conclusion

Current and emerging Australian cultivars have a good degree of heat tolerance, however there is still more that can be achieved. This research identified and developed new sources of heat tolerance that can be used by wheat breeders to improve yield in our increasingly variable climate.

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Russian wheat aphid thresholds - Insect density, yield impact and control decision making

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Key words

Russian wheat aphid, yield loss, action threshold

GRDC code

UOA1805-018RTX: Russian wheat aphid risk assessment and regional thresholds

Take home message

- Russian wheat aphid (RWA) risk from 'natural invasion' (as opposed to inoculated insect pressure) was nonsignificant in all 28 trials in 2018 and 2019
- RWA yield impact is 0.28 % yield loss per percent of tillers with RWA (%TwRWA)
- After GS30 (start of stem elongation), the number of tillers with RWA doubles about every 35 days, thus doubling %TwRWA'
- The RWA action threshold calculator is now available on-line and supports adoption of an IPM approach.

Background

This project studied the risk of infestation by the Russian Wheat Aphid (RWA, *Diuraphis noxia* Kurdjimov) and its effect on yield to develop best management practices in an Australian context of winter cropping of short cycle cereals (e.g. spring wheat). Risk of yield loss depends on aphid invasion, subsequent pest development and sensitivity of the crop to the pest.

Previously, there were no data available for quantitative and qualitative yield effects of RWA and the development of intervention thresholds in Australian cereal growing conditions. Overseas data, from North America and South Africa, where RWA has been present for many decades (Archer and Bynum 1992; Du Toit and Walters 1984; Du Toit 1986; Bennett 1990a,b; Kieckhefer and Gellner 1992; Girma et al 1990, 1993, Mirik et al 2009, Legg and Archer 1998, Chander et al 2006), report a wide range of potential damage levels (yield loss and qualitative losses) and derived economic injury levels. Losses of around 0.5% of yield loss per percentage of RWA infested tillers during stem elongation and grain filling are most frequently reported (Archer and Bynum 1992).

These knowledge gaps were addressed through

1. 28 natural RWA infestation field trials in 2018 (15) and 2019 (13) in South Australia, Victoria, New South Wales and Tasmania (Table 1)
2. 15 RWA inoculated field trials in 2018 (5) and 2019 (10) where 50 RWA/m^2 (500,000 RWA/ha) were applied at GS15-20 (2-4 leaf stage, Table 1)
3. Green Bridge sampling of grasses during the non-cropping period in both years in all states and extensive continuous sampling of grasses in SA over 26 months (March 2018-May 2020).

Table 1. Location of trial sites in 2018 and 2019

Site Name	State	Lat	Long	Inoculation	Irrigation
		2018			
Birchip	VIC	-35.9666	142.8242	Y	N
Cummins	SA	-34.3050	135.7189	N	N
Griffith	NSW	-34.1902	146.0920	Y	N
Hillston	NSW	-33.5482	145.4408	N	Y
Inverleigh	VIC	-38.1805	144.0390	N	N
Keith	SA	-36.1299	140.3233	Y	N
Lockhart	NSW	-35.0837	147.3280	N	N
Longerenong	VIC	-36.7432	142.1135	N	N
Loxton	SA	-34.4871	140.5891	Y	N
Minnipa	SA	-32.8398	135.1642	N	N
Nile DRY	TAS	-41.6759	147.3140	N	N
Nile IRR	TAS	-41.6759	147.3140	N	Y
Piangil	SA	-35.0519	143.2758	N	N
Riverton	SA	-34.2193	138.7350	Y	N
Yarrawonga	NSW	-36.0484	145.9833	N	N
		2019			
Birchip	VIC	-35.9666	142.8242	Y	N
Bundella	NSW	-31.5851	149.9064	N	N
Cressy	TAS	-41.7854	147.1134	Y	N
Eugowra	NSW	-33.4944	148.3192	N	N
Griffith	NSW	-34.1902	146.0920	Y	N
Horsham	VIC	-36.7432	142.1135	Y	N
Inverleigh	VIC	-38.0497	144.0104	Y	N
Loxton	SA	-34.4871	140.5891	Y	N
Minnipa	SA	-32.8398	135.1642	Y	N
Mildura	VIC	-34.2627	141.8535	Y	N
Pt Broughton	SA	-33.5757	137.9987	Y	N
Thule	NSW	-35.6491	144.3914	Y	N
Yarrawonga	NSW	-36.0484	145.9833	N	N

Outcomes

Risk of RWA invasion of crops: Overall RWA risk was very low during these two (very dry) years with no significant RWA infestation occurring in any of the non-inoculated field trials. This shows that the largely adopted use of prophylactic seed treatments against RWA was not justified.

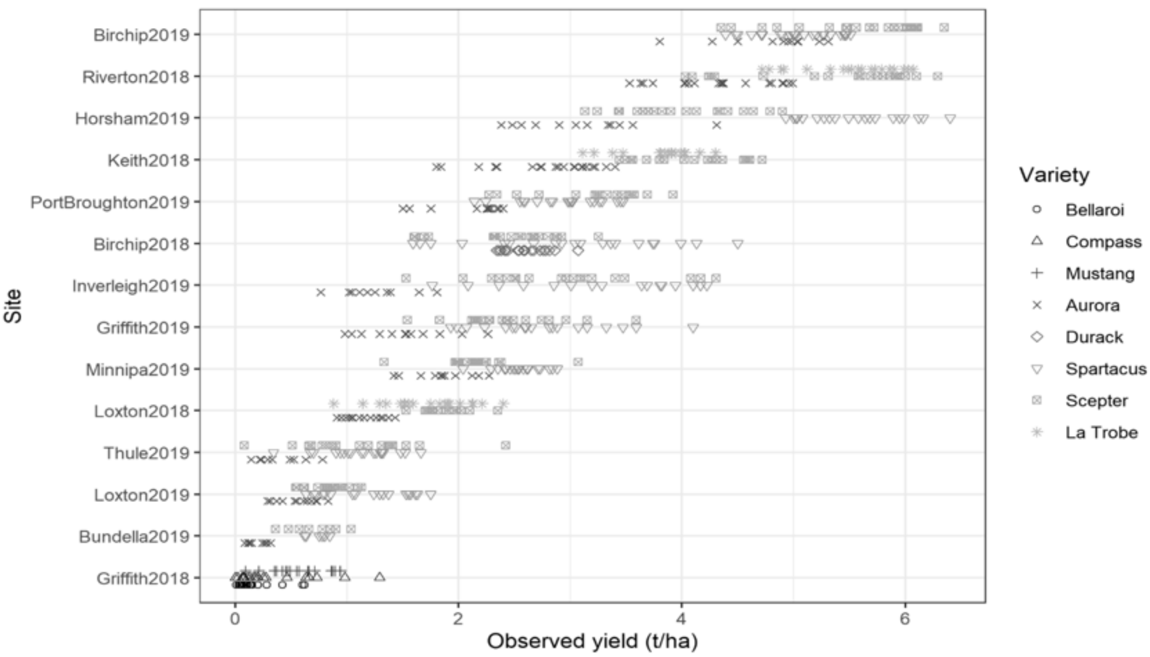

Figure 1. Yield across all trial sites and years with different cereal type/variety denoted by different markers. Varieties used: Barley: Compassⓓ; Spartacus CLⓓ, La Trobeⓓ; Durum wheat: EGA Bellaroiⓓ, DBA Auroraⓓ; Wheat: Scepterⓓ, Mustang ⓓ; Oat: Durackⓓ.

Yield loss in inoculated trials: Regional and varietal differences were large (Figure 1). In some, but not all, of the inoculated field trials RWA populations reached population levels (maximum observed between GS40 and 50) resulting in yield loss. The best predictor of yield loss of various aphid pressure metrics was the maximum percentage of tillers with RWA present (%TwRWA) and a percentage of the potential yield loss with a 0.28% yield loss observed for every %TwRWA. This simple relationship applied to all the different cereal types (wheat, barley, durum wheat), years and regions (through the adjustment of potential yield), oat did not allow RWA development. This yield impact is significantly lower than described for the USA (0.46-0.48% for every %TwRWA, Archer and Bynum 1992).

From this equation, the economic threshold (the break-even point of yield loss and control measures) can be calculated depending on the costs of control (pesticide, applications costs), the expected yield (region and year dependant) and the farm-gate price of the crop as parameters (Figure 3).

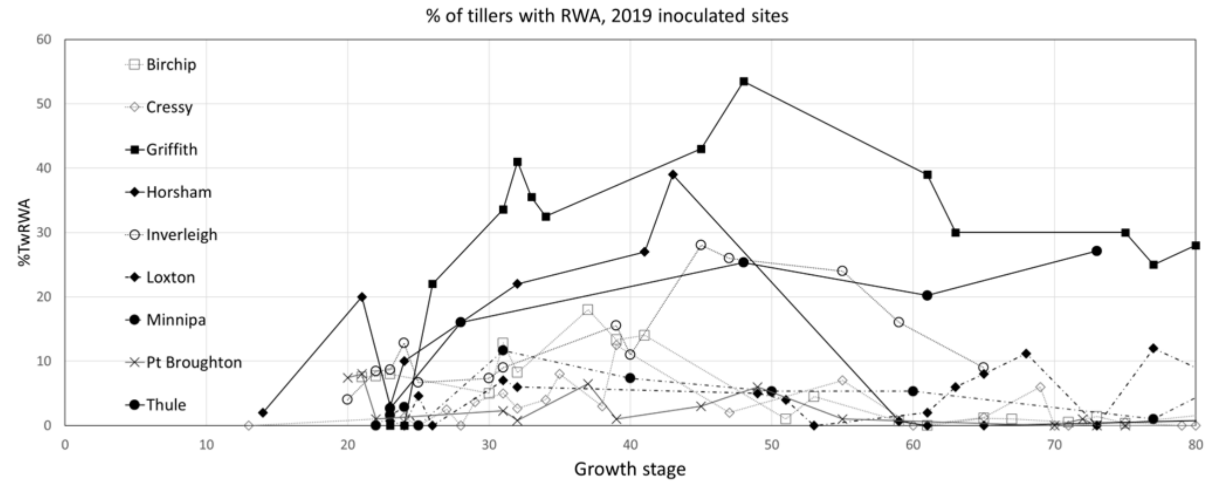

Figure 2. Percentage of tillers with RWA **(**%TwRWA) against growth stage for the RWA inoculated untreated control plots (AI-UTC) in all inoculated trial sites in 2019.

RWA population development: After inoculation with RWA, the highest RWA populations developed in drier regions, through a combination of increased RWA establishment during inoculation and increased rates of subsequent population increase. Less tillering in dry areas also contributed to a higher %TwRWA. The maximum population of RWA and the maximum %TwRWA was reached between GS40 and 50 (Figure 2) followed by a decrease. Between the end of tillering (GS30) and GS50 an increase in the %TwRWA of 0.021%/%/day was observed. This would result in a doubling of the %TwRWA every 35 days.

Action threshold calculator: Based on these observations and equations, we propose a decision rule (action threshold, Figure 3) for RWA management using an observation of the percentage of tillers with symptoms and the %TwRWA at GS30. This observation and the expected increase in %TwRWA (based on the expected time to ear emergence GS50), inform the need for management action, which can (if needed) be combined with existing treatments at GS32-35, thus reducing application costs. Growers and advisers are directed to the GRDC calculator (see additional resources) to calculate thresholds for their growing conditions"

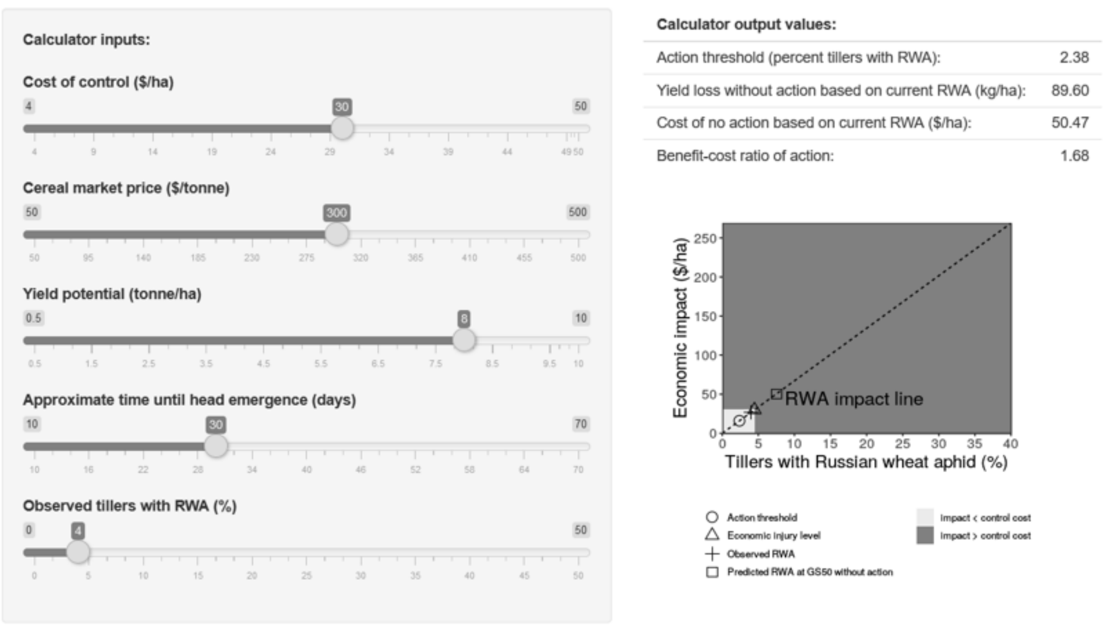

Figure 3. RWA action threshold calculator (example)

Green bridge risk: The environmental conditions over summer that form a 'green bridge' of suitable (grass) habitat between winter crops were expected to determine the risk of early colonisation events.

Field surveys during the spring to autumn periods demonstrated RWA detections being particularly common and with high populations during spring in the warm dry grain growing regions of northern Victoria, southern New South Wales and South Australia. During the summer, growing crops and green vegetation for most grass species disappeared and RWA populations declined (Figure 4). Apart from volunteer cereals (wheat and barley), the majority of RWA detections were on five grass genera (barley grass, *Bromus* sp., phalaris, ryegrass and wild oat.

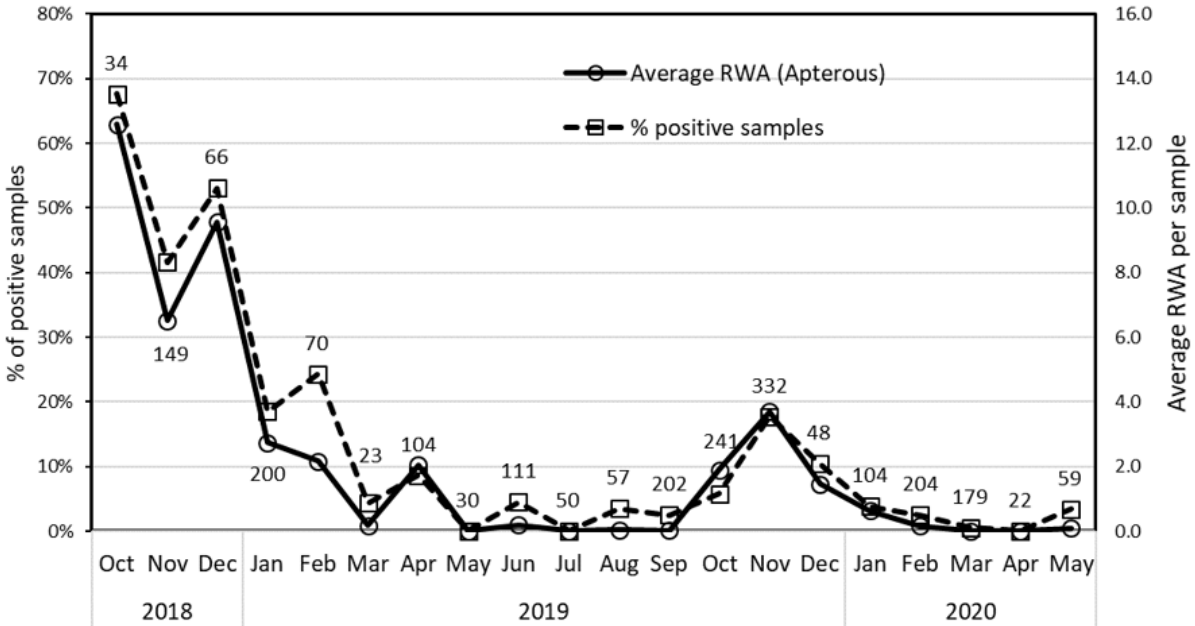

Figure 4. Dynamics of the percentage of positive samples (dotted line, left axis) and average RWA per sample (Solid line, right axis) over time in SA. Samples were 2 litres of grass extracted in a Berlese funnel. Numbers above markers show number of samples taken per month. n = 2285

Barley grass (*Hordeum leporinum*) and (to a lesser extent) Brome grasses (*Bromus* sp.) were the host plants that showed the highest combination of abundance, positive RWA detection frequency and aphid numbers. These introduced species are not summer active in low rainfall areas. In low rainfall areas, the native *Enneapogon nigricans* (bottle-brush) is the most important summer refuge because of its widespread distribution (207 samples collected from 135 sites) and summer growth pattern. Grazing and water availability (irrigation) can make some host grass populations, including prairie grass, couch grass, ryegrass and volunteer cereals, persist in summer. The presence of irrigated crops increased the likelihood of RWA detections 1.6-fold over the green bridge.

Early rainfall in late summer/autumn, 2-3 months before sowing, could cause RWA population to build up on grasses and cereal regrowth, potentially exacerbating early crop invasions. A 250 mm high rainfall event in the Birchip area (Vic) in December 2018 did cause significant development of a green bridge, but did not seem to result in increased RWA risk. Reports in 2020 from the Port Augusta area (SA), where a significant summer rain occurred on February 1st, suggested an increase in RWA pressure. This shows that observations, especially in early break years and better understanding of aphid population dynamics and migration on the green bridge before and after sowing, are needed to obtain more precision on the impact of the green bridge and the risk and timing of crop invasion.

A ‘wetter’ year with a higher green bridge, or if immigration of aphids occurs at a higher level for some other reason, might increase aphid colonisation, but will not automatically result in higher impact of RWA. Wetter and colder conditions are less favourable for RWA development in the crop (as can be seen from the Tasmanian trials), through a combination of slowing down population development, improving the crop development which will better resist RWA, and more tillering (diluting the aphid numbers over a lower % of tillers. The two experimental years experienced generally low levels of growing season rainfall, so RWA development in the crop (after inoculation) was probably maximal on these often drought stressed crops.

Crop sensitivity: Similar yield impact and aphid population *development* was observed for all crops tested, except for oats which is known not to be an RWA host. However, crop and varietal differences in RWA *establishment* are likely to exist and have been reported. Also, the crop condition (growth stage, level of tillering, drought stress, nutritional stage) will play a role in RWA *development* and could change the probability of reaching above threshold populations.

Conclusions

RWA ecology and yield impact in Australia are now somewhat better understood. This allows growers and agronomists to manage RWA more sustainably and economically. Management based on observations and regionally adapted decision rules, rather than an over-reliance on prophylactic seed treatments, will increase profitability, minimise chemical inputs and reduce off-target risks and resistance development.

The two years during which this study was done were very dry, with hot summers and growing seasons, and were generally unfavourable for RWA survival over summer, but favourable for the development of RWA in the inoculated trials (Baugh and Phillips 1991, De Farias et al. 1995). Some anecdotal observations in 2020, and in the few years that RWA is known to be present (since 2016, Ward et al 2020, Yazdani et al 2018), do suggest that the population levels will be very different (but not necessarily more damaging) with different rainfall patterns. More experience and research are needed to better understand RWA ecology and would enable further improvement to management guidelines.

The geographical distribution of RWA is expected to increase further into northern NSW and Queensland (Avila et al. 2019), and RWA was detected in Western Australia in 2020. Different growing conditions (temperature, drought) and presence of other cereal crops, including summer cereals (rice, corn, sorghum, millet), and other grass hosts could alter the risk of RWA in those regions.

Acknowledgements

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Additional resources

https://grdc.com.au/resources-and-publications/resources/russian-wheat-aphid

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The potential role of companion and intercropping systems in Australian grain farming. Should we be considering them?

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Take home messages

- There is increasing grower interest in the use of companion and intercropping systems in Australia
- While there are real and recognised yield benefits from intercropping, farmers experimenting with these multispecies mixtures are seeking other system benefits
- Potential system benefits include rotational benefits, risk management, soil improvement and reduced input costs
- Overseas experience suggests that most of the challenges can be met with perseverance and innovation.

Aims

The aims of this study were to examine the potential role of mixed-species cropping systems in Australia, including intercrops and companion crops. We examined the potential benefits and limitations of these systems, the current use of these systems in Australia and discussed the research and adoption in Europe and Canada and the potential learnings that could be applied in Australia.

Introduction

Modern agricultural cropping systems are generally based on large areas of single species monocultures. Crop rotation (between seasons) is used to obtain diversity in these farm systems.

Monocultures are grown due to the reduced complexity and ease of management on large farms where labour is scarce and expensive. However, recently there has been increasing interest in the use of intercrop and companion crop systems in large-scale mechanised cropping.

The idea of growing more than one crop/species on the same land in a mixture is not new - these systems are often used in small holder and subsistence agricultural systems in the developing world and in organic systems. There is ample evidence that these intercrop and companion crop mixtures can give yield benefits in mechanised systems both in Australia, (e.g. Fletcher et al 2016) and overseas, (e.g. Lithourgidis et al 2011; Pelzer et al 2014). However, in addition to these yield benefits there may be a range of farming system benefits that are important but less easy to quantify. These could include rotational benefits, reduced inputs and soil quality benefits.

In this paper we review the potential use of both intercrops and companion crops in Australian farming systems. There are several reasons why it is timely to revisit these systems and their potential in Australian farming systems. There are potential farming systems benefits that need to be evaluated including rotational benefits; disease and weed suppression; improved harvestability; reduced erosion risk; improved soil fertility; and reduced production risk. There are several emerging technologies, (e.g. precision agriculture, robotics, herbicide tolerant crops) that could help to remove some of the barriers to adoption. Here, we collate and analyse historical and recent small plot experiments looking at the yield and potential profitability benefits of intercrops. We evaluate the production risks of these systems. We report the broad findings of case studies we have developed with Australian farmers who are currently experimenting with intercrops and companion crops and report on the overseas (Canada and Europe) research, development and farmer uptake of these systems.

In this paper we use the following definitions:

Intercrop: where two or more species are sown and harvested together with the objective of harvesting grain of both species.

Companion crop: Where two or more species are sown together with the objective of harvesting grain of a single species. The other species are either grazed out or terminated using herbicides.

Land equivalent ratio (LER): A measure of the yield-benefit and land-saving achieved by sowing an intercrop. A LER >1.0 indicates that the intercrop is more productive than the monocultures and less land area is needed to achieve the same grain yield of the two component species as an intercrop compared to two sole crops. The LER takes account of the relative yield of the component species.

Methods

Historical Australian research data

We undertook a literature search of experimental research that had occurred with intercropping in Australia. This built on an earlier review (Fletcher *et al* 2016). There was a significant amount of unpublished historical research on intercropping across Australia. Much of the research was in WA due to the ease of searching the DPIRD research database (https://researchlibrary.agric.wa.gov.au/). Not every trial had yield data available. The yields from these reports and papers were collated and analysed using the LER. This analysis only included those trials where grain was separated into the component crops. In contrast, there had been very little research with companion crops.

We also compared the risk of intercrops and monoculture crops. To do this we used the mean yield of each sole crop and the combined yield of the intercrop in each experiment. We then calculated the median yield and the 10th percentile yield. The median yield represented the typical expected combined yield across experiments and the 10th percentile yield represented the yield in the worst seasons.

Australia farmer case studies

We undertook 20 case studies from selected farm businesses across Australia that were currently trying or have previously tried intercropping or companion crop mixtures at commercial scale. This involved consultant-led deep interviews intended to establish the types of intercrops and companion crops being tried by farmers, and their motivation and barriers to adoption. We have not identified individual farmers but rather summarised the results across the 20 farmers in Australia.

Summary of international experiences (France and Canada)

In July 2019, we undertook a study tour to Canada to visit farmers who are currently using intercrops on broadacre farms and researchers currently experimenting with intercrops. This tour was organised by Western Ag Innovations and Farmlink. This tour also included several interested farmers from southern NSW.

The insights into recent intercropping research and adoption in Europe by the scoping team emerged from a recent CSIRO-INRA Exchange Programin 2017-2018 which supported exchange visits in July-August 2017 (French in Australia) and June 2018 (Australians to France).

We describe the experiences and insights from these trips along with other information we were able to obtain from our colleagues.

Results

Historical Australian experimental results

In total there were 19 experiments that investigated cereal-legume intercrops and 15 of these had yield data available. The main experimental crop combinations of cereal and legume examined were: oats and lupin (six experiments), oats and field pea (four experiments), wheat and field pea (five experiments), barley and lupin (three experiments). All other combinations were trialled in one or two experiments only.

For the cereal legume intercrops, the mean LER was 1.12 (Figure 1a) and the LER was greater than 1 for 49 of the 72 individual comparisons. This indicates a yield benefit from intercropping with 12% more land required to grow the same amount of grain in monocultures compared to intercrops. These are consistent with a range of cereal-legume experiments in Europe (Pelzer et al 2014).

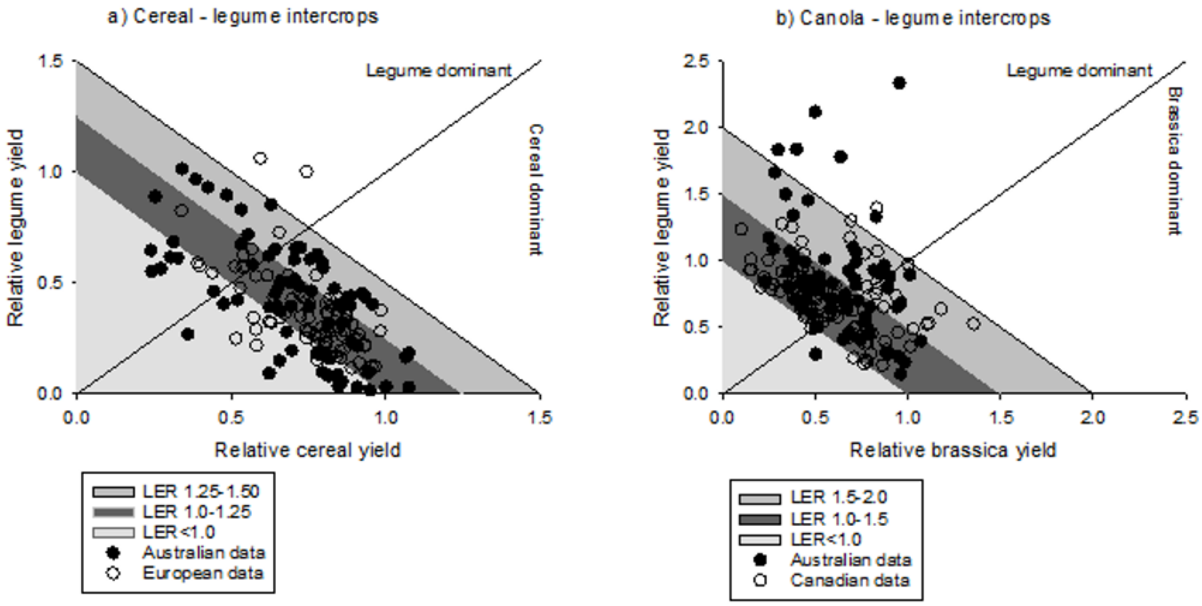

Figure 1. Summary of previous intercropping experiments in Australia (filled points) for wheat-legume (a) and brassica-legume (b) mixtures comparing the relative yields of each component species. Data from European and Canadian experiments are provided for comparison. Each data point is a separate experimental treatment. The total LER are indicated by the shaded areas in the background. The solid diagonal line is $y = x$ for comparison of the competitive abilities of each component crop in the mixture.

In total there were 22 experiments that investigated canola-legume intercrops but only 13 of these had yield data available. The LER was greater than 1 for all but one treatment. The mean overall LER was 1.49 (Figure 1b) which indicates 49% more land would be required to grow the same amount of grain in monocultures compared to intercrops. The LER's found here were consistent with a range of recent oilseed brassica-legume intercrop experiments in Canada.

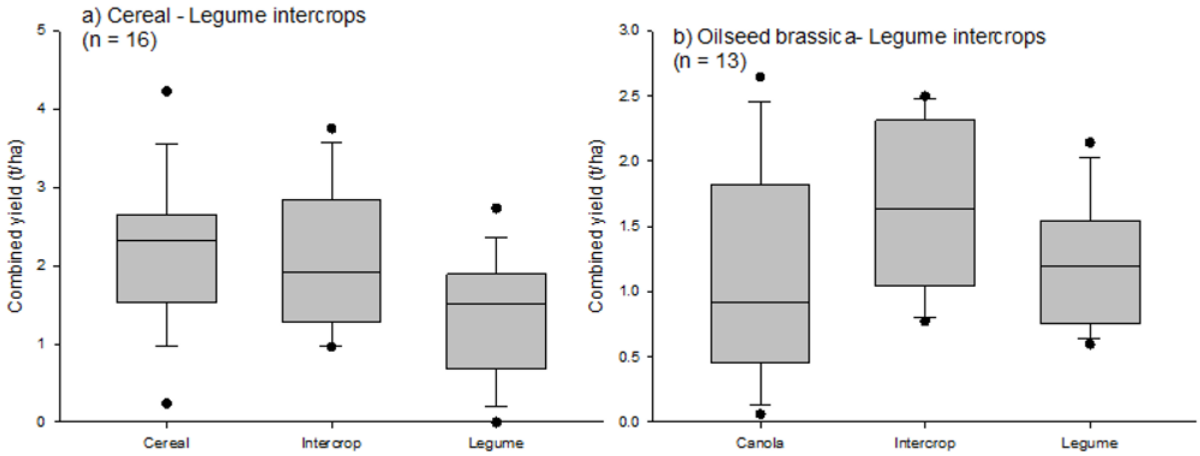

Figure 2. Box plot summarising the total yield of intercrops and component crops across a range of cereal legume (a) and canola-legume (b) intercropping experiments in Australia. To avoid biasing the result the means of each experiment were used in the analysis. The analysis thus represents the site to site variation rather than the within experiment variation. The boundaries of the box are 25th and 75th percentiles, the horizontal line in the box marks the median. The error bars represent the 90th and 10th percentiles and the data points represent the outliers.

There was reduced yield risk in the intercrops compared with the monocultures (Figure 2). In the cereal-legume intercrops the median yield was 2.3t/ha for cereal, 1.5t/ha for legumes and 1.9t/ha for intercrops. The 10th percentile yield was 1.4t/ha for cereals, 0.41t/ha for legumes and 1.1t/ha for intercrops. In the canola-legume intercrops the median yield was 0.9t/ha for canola, 1.2t/ha for legumes and 1.6t/ha for intercrops. The 10th percentile yield was 0.27t/ha for canola, 0.71t/ha for the legume crops and 0.89t/ha for the intercrops. This highlights that the overall risk is reduced because the other crop will still be able to produce some yield. This may help with the adoption of some crops that are perceived to have higher risk, such as the pulses.

As an example of the potential economic advantage of intercrops we re-analysed the data of Walton (1980). We calculated the gross return from each component of an oat-lupin intercrop assuming grain prices of $320/t for lupins and $390/t for oats. This showed that the intercrop always had a higher gross return than the mean of the two sole crops. Averaged across all sowing combinations the gross return was $191/ha greater in the intercrop. If the proportion of oats in the intercrop was greater than 50% there was greater economic return from the intercrop compared to the most valuable monoculture (Oats) (Figure 3). Of course, this will depend on the relative prices and yields of the two component crops. The economic advantage will be greatest when the two crops have similar prices and large amounts of overyielding. When one crop has a much higher return than the other the economics will show that this crop will be more profitable than the intercrop. However, prices vary from year to year and intercrops could help to reduce this economic risk as well as yield risk.

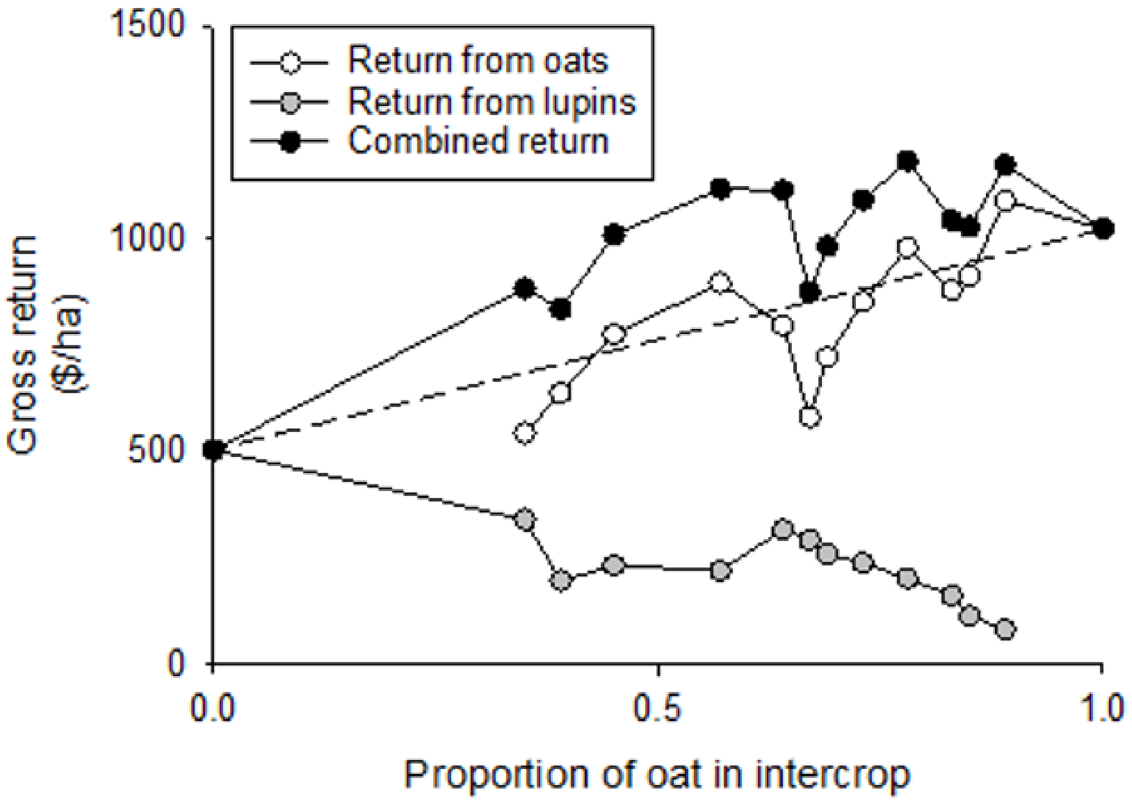

Figure 3. Economic return from the intercrop compared to the most valuable monoculture (Oats)

Insights from farmer cases studies - Australia

There were several key insights from the farmer case studies that were undertaken. These insights were consistent across Australia. **For most farmers the yield benefits of intercrops and companion crops were secondary motivations compared to the farming system benefits they were trying to achieve, (e.g. rotational, risk management, soil improvement and reduced input costs).** The farmers identified improving the logistics and agronomy of sowing, managing and harvesting the intercrops and companion crops to achieve the systems benefits as priority areas. These farmers were experimenting with a wide range of intercrops and companion planting systems, many of which have not been studied in formal experiments by researchers.

Overall there was a wide range of intercrops and companion crop systems planted. There was a range of canola-legume intercrops (including canola-pea, canola-faba beans, canola-vetch, and canola-lentil); many farmers were trialling companion crop mixtures where companion crops were either grazed-out or terminated to harvest a cereal crop; and at least three farmers had tried chickpea-linseed intercrops. In contrast, there was only a few that had trialled cereal-legume intercrops.

Insights from international experiences- Canada and Europe

There has been a recent resurgence in the adoption and research of intercrops in Canada. Despite important previous plot-scale research on intercrops this resurgence has largely been driven by farmers. Most farmers reported significant overyielding (5-40%) from intercrops compared with sole crops. This is consistent with most of the small plot research (Figure 1b). However, **this overyielding was not necessarily a driver for adoption; it was a bonus. The key motivations for adoption have been reduced input use and costs, improved soil health and higher profit.** Reducing risk on variable soils at the landscape scale due to the adaptation of different crops to different conditions was another driver. Risk associated with price and yield variations was also offset in intercrops.

Table 1. Area and type of intercrops insured in 2018 and 2019 in Canada.

Intercrop mixture	2018 area (ha)	2019 area (ha)
Oilseed-legume		
Canola-pea	2 350	7 220
Mustard-pea	810	620
Chickpea-linseed	2 300	1 620
Lentil-linseed		210
Lentil-mustard		540
Cereal-legume		
Wheat-lentil		6 880
Barley-pea	810	1 150
Oat-pea	1 050	4 250
Oat-linseed		80
Oat-lentil		540
3 crop mixes (mustard, Pea, lentil, camelina, oat, durum)	4 610	5 380
Total area	15 580	29 300
Total growers		140

The area of intercrops has increased rapidly in the prairie provinces of Canada. For example, the area has doubled in Saskatchewan from 2018 to 2019 (from 15,600 to 29,300ha). In 2019 there were a total of 140 growers with insured intercrops, indicating that this was more than a few growers with large areas. One farmer that we visited had more than half his 2500ha cropping farm planted to intercrops.

The permanent adopters of intercropping that we visited in Canada took time (~10 years) to develop successful systems, overcoming practical and logistical barriers and innovating as necessary (with machinery, agronomy and markets). All of them identified seed separation at harvest as a major hurdle to adoption at scale. Due to differences in seed moisture, mixed species cannot be stored together. Furthermore, the speed of harvest cannot be compromised. For this reason, peaola (pea and canola intercrops) was often an entry point to intercrops (Table 1). The large differences in seed size meant that they could be separated at harvest using a rotary screen. Chickpea-linseed intercrops were also emerging as a popular combination because of reduced disease in the chickpea component and the ease of separation.

There has been renewed interest in intercropping in Europe. However, there is very little information on the actual area of intercrops and species mixtures being grown. Europe has been the centre of significant intercropping research for decades and the detailed crop physiological understanding on species mixtures is well published and reviewed (Pelzer et al 2014; Brooker et al 2015). Previous research has been 'researcher-led' and 'policy-driven' (EU agricultural policies), i.e. focus on crop diversification, biodiversity, soil health, ecosystem services; less by farmer demand. Higher support and adoption of organic farming systems in Europe, along with subsidies have made some aspects of crop mixtures feasible in certain cases, (e.g. higher prices for organic cereals-legume mixtures can offset lower yields). A recent large investment in intercropping ReMIX project (https://www.remix-intercrops.eu/) has initially focussed on better understanding of farmer decision making towards intercropping and the barriers to adoption.

Conclusion

There is increasing interest in the use of mixed species systems (both intercrops and companion crops) in both Australia and overseas. There are potentially large yield benefits from growing mixtures of two species. However, any future adoption of these approaches is likely to be driven by the farming systems benefits associated with intercrops and companion crops.

There are several logistical issues that need to be overcome before the use of these systems can be widespread. These include (1) sowing, when the two crops require different sowing depths (2) the range of herbicides available for some mixtures could be limited (3) intercrops could require different harvester settings, and (4) the separation of harvested grain. Despite these issues, the evidence in Canada is that most can be resolved with persistence and innovation.

There is potential for these systems to be included in large mechanised cropping systems in Australia. This is highlighted by the Canadian experience where there has been a recent increase in adoption. In our tour we visited one farmer who was growing 2200ha of intercrops. In 2019 there were at least 30,000ha of intercropping in Canada. As in Canada, Australian growers and consultants are leading the impetus for renewed research on intercrops and calling for appropriate supporting research to explore the most promising options within Australian farming systems. The future challenge is to see whether they have a fit in Australian systems and to identify any limits to adoption.

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Amelioration for sodicity - deep ripping and soil amendment addition across NSW and Qld. Engineering challenges. Yield responses to ripping, gypsum and OM placement in constrained soils

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Take home messages

- Benefits of subsoil amendments are more likely in poorer seasons
- Adjustment in agronomy may be necessary to take advantage of improved subsoil conditions
- Considerable challenges remain in identifying engineering solutions to deeper amendment applications.

Background

Model analyses suggest a yield gap between water-limited potential yield and currently achieved production exists across northern Australian grain regions. This yield gap is a function of physical, chemical and biological factors in each soil, including capacity of soil to store and release water for efficient plant use. Many regions where yield is constrained contain dispersive soil within the surface 50cm and deeper. Sodicity (a high exchangeable sodium percentage) is a major cause of aggregate dispersion and may compromise soil structure. Dispersive behaviour decreases both soil water availability and nutrient acquisition, increases risk of runoff and erosion, and impairs biological (soil microbial and plant root) activity. Acidity, salinity (presence AND absence) and compaction further constrain yield potentials. However this project focuses on sodicity as the major constraint with often related constraints considered as compounding and/or interacting factors.

Amelioration of subsoil constraints is an expensive process. The engineering challenges and energy requirements are significant. It is important to acknowledge that production benefits from subsoil amendment are more likely to be observed in poorer seasons. In good seasons, root function and activity, and soil moisture, will be able to sustain yield from surface activity and extraction where soils are often less constrained. However in poorer seasons where subsoil moisture is required to finish a crop, subsoil amelioration will have a proportionately larger impact on yield. Hence, we expect that the return on investment in subsoil amelioration to be larger in poorer seasons, than in higher decile seasons with more growing season rainfall.

A series of linked investments is assessing the economics of ameliorating constrained surface and sub-surface soils in the northern region. The program has four areas covering:

(i) Spatial soil constraint identification

(ii) Amelioration and management of soil constraints
(iii) Economics of adoption, and
(iv) An overarching communications and extension program.

The research into soil amelioration and management has two components led by the University of Southern Queensland (USQ). First is a set of six small-plot core experiments exploring detailed amelioration research. There are three sites in northern and central New South Wales (NSW) managed by the University of New England (UNE), and three sites in southern Qld managed by the Department of Agriculture and Fisheries (DAF).

This paper covers the challenges of core site implementation, describes the treatments being studied and the adaptations needed to deliver these treatments to depth in our constrained soils. It also extends to discussing the realities of attempting this process at a commercial scale. Finally it reports on the first season of field trial responses.

Core site selection

The USQ team undertook extensive surveying of 30 fields across central and northern NSW and southern Qld. The areas were clustered around 6 locations (Trundle, Armatree, Spring Ridge, Talwood, Millmerran and Meandarra), with 5 fields surveyed at each. Field surveying included capture of yield maps if available, satellite NDVI imagery, and soil mapping with EMI. Using a combination of yield, site elevation and EMI maps, bare soil colour imagery and grower experience, four survey points where selected for soil sample collection and analysis. After consolidating data 'core' experimental sites where selected in each of the six hub areas: three in NSW and three in Qld.

Core site characterisation

All sites were generally alkaline in the upper profile with an exchangeable sodium percentage (ESP) well over the 6% nominal threshold for healthy crop growth. Profile chloride (Cl) values were generally low, indicating that sodicity was likely to be the primary restriction.

Chemical characteristics of the six core experiments are below:

Location: Armatree
Soil type: Brown Sodosol, not dispersive (0-10cm) to dispersive (10-20) surface, to strongly alkaline and dispersive at depth, compact surface layers

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	6.0	5.3	0.20	3.7	3.4	0.91	1.00	9.0	10		58
10-20	7.8	6.8	0.20	8.5	7.9	2.63	0.83	19.9	13		7
30-40	9.3	8.3	0.45	13.1	12.6	5.78	0.81	32.3	18		8
60-70	9.4	8.4	0.58	12.3	13.4	6.35	0.96	33.0	19		6

Location: Forbes
Soil type: Brown Vertosol, not dispersive (0-10cm) to dispersive (10-20) surface, to strongly alkaline and dispersive at depth

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	6.3	6.1	0.39	8.7	7.7	2.13	0.77	19.3	11		89
10-20	7.9	6.9	0.30	15.4	10.2	4.76	0.55	30.9	15		12
30-40	9.1	8.2	0.64	12.5	11.3	8.14	0.49	32.5	25		4
60-70	9.1	8.3	0.85	11.3	10.4	9.57	0.56	31.9	30		1

Location: Spring Ridge

Soil type: Black Vertosol, moderate ESP and salinity in surface, increasing to high ESP and salinity at depth, but both are non-dispersive due to the salinity

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	8.2		0.54	31.7	41.7	3.3	2.4	79.1	4		100
10-20	8.2		0.62	37.2	43.5	5.2	1.4	87.3	6		
30-40	8.3		1.94	31.0	51.5	13.9	1.0	97.4	14		
60-70	8.3		2.52	28.7	56.7	19.5	1.1	106	18		

Location: Dulacca

Soil type: Grey/Brown Vertosol (nominally Ulimaroa). Surface soils not spontaneously dispersive, subsurface highly dispersive.

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	8.5	7.7	0.21	18.1	8.0	2.73	0.93	29.8	9	43	9
10-20	8.8	7.8	0.25	15.8	9.8	3.99	0.61	30.3	13	53	14
30-40	8.1	7.3	0.46	15.4	12.3	7.10	0.45	35.3	20	102	4
60-70	6.8	6.7	0.66	12.0	12.8	8.83	0.48	34.1	26	275	8

Location: Millmerran

Soil type: Grey/Brown Vertosol (nominally Moola). Surface and subsurface soils not spontaneously dispersive, very compact soil through the profile.

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	6.6	6.3	0.15	8.4	6.6	2.37	0.31	17.7	13	153	38
10-20	8.7	7.4	0.24	10.6	9.0	3.36	0.20	23.2	14	330	5
30-40	6.9	6.2	0.38	9.5	15.	6.82	0.14	31.4	22	428	3
60-70	6.4	5.5	0.43	10.2	16.4	8.79	0.18	35.5	25	457	2

Location: Talwood

Soil type: Red/Brown Vertosol (nominally Arden). Surface soils not spontaneously dispersive, subsurface highly dispersive at 60-70cm.

Depth	pH	pH	EC	Ca	Mg	Na	K	ECEC	ESP	Cl	P
(cm)	(H_2O)	($CaCl_2$)	(1:5)	(cmol/kg)					%	(mg/kg)	(mg/kg)
0-10	8.3	7.6	0.17	27.5	4.7	1.8	1.3	35.5	11	22	18
10-20	8.7	7.9	0.23	27.8	7.0	3.8	0.7	39.3	10	26	3
30-40	8.9	7.8	0.36	22.5	9.4	7.0	0.4	39.4	18	73	2
60-70	9.2	7.9	0.44	20.3	9.9	9.9	0.5	40.7	24	163	2

Experiment treatments

This research focussed on eliminating sodium as a constraint for the upper 50 cm of a soil profile. It was 'proof-of-concept' research, intended to explore effects on soil water storage and grain yields under gypsum application rates to remediate the ESP to ≤ 3% in either or both of the top 20 cm of soil and half of the soil volume in bands from 20 cm down to 50 cm depth. Organic matter (OM) also acts to limit aggregate dispersion (as well as providing nutrients at depth) and, whilst not reducing ESP, may act to improve water holding capacity and pore stability. Gypsum rates (often ≥ 15 t/ha) were compared against a high rate subsoil (≈ 20 cm deep) compost (Qld)/lucerne pellet (NSW) application (≈ 10 t/ha), and the application of elemental sulfur to dissolve calcium carbonate to produce gypsum in-situ and lower alkalinity.

The rates chosen are considerably higher than the likely economically viable rates and were deliberately chosen to determine if subsoil remediation to remove dispersive constraints would result in improved production outcomes beyond the first year. With that in mind, it is worth considering that the cost in diesel of ripping to depth without adding the necessary amendment is unlikely to be recovered. Repeated, smaller gypsum/OM applications coupled with deep ripping to place them is cost prohibitive. Hence, single, large, additions may ultimately be best practice.

Similar treatment structures are used in both NSW and Qld, with both physical and chemical ameliorants, a range of options exploring impacts and/or interactions between tillage (shallow and deep), deep placement of nutrients (as inorganic or organic forms), surface and subsurface applications of gypsum to reduce ESP to < 3%, incorporating organic amendments (lucerne pellets in NSW and composted feedlot manure in Qld), and applying elemental sulfur (ES) to decrease soil pH and generate gypsum in situ (Table 1).

Surface gypsum treatments were spread onto the soil, and then incorporated by ripping to 20 cm. Actual application rates for gypsum varied with each site based on calculations that capture the required Ca to lower the ESP to <3%, but the overall structure of the experiment stayed the same.

The applied gypsum rate for subsurface placement was banded with 50% of the total needed for the whole 20 to 50 cm layer of soil. For example, if a total of 20 t/ha of gypsum was theoretically needed to remediate the entire 20 to 50 cm layer, in this application 10 t/ha was applied to ensure the right amount of gypsum within each band (assuming the band covers 50% if this zone). In NSW, it was assumed that the band only treated 25% of the profile, so only 25% of the total gypsum needed was applied – 5 t/ha in the example. Further details on how it was applied are outlined later in this paper.

Table 1. Treatment structure for core soil constraints sites in southern Queensland

Treatment	Rip (≈ 20 cm)	Surface Gyp	Deep NP(K)Zn (≈ 20 cm)	Rip > 20 cm	Deep Gyp (≈ 20 cm)	Deep OM (≈ 20 cm)	Deep ES (≈ 20 cm)
1							
2	Y						
3	Y		Y				
4	Y	Y	Y				
5	Y		Y	Y			
6	Y		Y	Y	Y		
7	Y	Y	Y	Y	Y		
8	Y	Y	Y				
9	Y	Y	Y	Y			Y
10	Y	Y	Y (*)	Y			
11	Y	Y		Y		Y	
12	Y	Y		Y		Y	Y
13	Y	Y		Y	Y	Y	Y

Deep NP(K)Zn rate is 50 kg N, 30 kg P, 50 kg K and 1.5 kg Zn apart from * rate which matches N and P addition from deep compost application. Gyp = Gypsum, OM = Organic matter ES = elemental sulfur

Engineering and application challenges

Application rates for all ameliorants are substantial, with rates often greater than 6-10 t/ha being applied. With such large amounts of product required, logistically it is challenging to source, transport and apply the treatments at each site, especially with deep (~20 cm) applications.

Applicators are not going to be universally capable machines for putting ameliorant at depth – it is very challenging to engineer something to measure and distribute all manner of materials. The deep placement machine used in Qld required amendments with the physical characteristics of being relatively fine and easily flowable in order to be metered and delivered to depth. This was achieved by using 6 mm screened feedlot compost, and air drying natural mined gypsum to reduce moisture content. All materials were screened at the top of the applicator bin through a 12mm screen to further exclude lumps. In NSW, flow problems were resolved by using pellets and prills – a more expensive solution.

Metering of products was achieved through fluted rollers (Figure 1). Further changes were undertaken adapting it for use in the soil amendment experiments. Modifications included 75 mm chutes for amendment delivery down the back of the applicator tine and inclusion of a crumble roller for smoothing the surface slightly.

Figure 1. Metering unit for amendment application on the Qld research machine, with ruler for scale.

Given the 'proof-of-concept' intent of much of the research, interpretation of individual specific effects is challenging. What the research outcomes do confirm is there exists a significant upside in yield achievable with combinations of physical and chemical inputs.

Grain yield

Millmerran was planted to sorghum for 2019-20, while Dulacca, Armatree, Forbes and Spring Ridge all had winter crops in 2020. While experiments are similar across the Qld and NSW components, the results for the different states are reported separately.

Grain yield responses in Qld

In Qld, yield increases have been recorded at both the harvested sites. At Millmerran (Table 2), grain yields increased up to ≈25% or 750 kg/ha. In general, treatments with combinations of surface gypsum and subsurface NPK (i.e. trt 4, 7, 8 and 13) had the largest yield gains.

Table 2. 2019-20 Grain yield (GY) for sorghum at Millmerran

Trt		Yield	SE	Delta GY	Rel GY%	LSD*	Protein
1	Control	2970	133	0	0	a	11.1
2	Shallow rip	2910	188	-60	-2	a	10.7
3	Banded fert	3300	188	330	11	abcd	10.7
4	Surface gyp + shallow rip	3580	133	610	21	bcd	10.4
5	Deep rip	3430	188	460	15	abcd	10.6
6	Deep gyp	3120	188	150	5	ab	10.9
7	Surface + deep gyp	3750	133	780	26	d	10.7
8	Surface gyp + deep rip	3750	188	780	26	cd	10.2
9	ES + surf gyp	3250	188	280	10	abc	10.6
10	Nutrient control	3500	188	530	18	bcd	11.0
11	Surface + deep OM	3370	188	400	13	abcd	10.4
12	ES+OM	3360	188	390	13	abcd	10.5
13	All	3700	188	730	25	cd	10.5

* Treatments with the same letter do not significantly differ ($P<0.05$)

At Drillham (Table 3), grain yields increased up to ≈60% or 1,250 kg/ha. Three treatments in particular provided the largest increases, treatments 10, 12 and 13. Commonality of these treatments is all have tillage to 30 cm, and either have high nutrient supplies from the high NP rates (treatment 10), or the composted feedlot manure (12 and 13). Deeper ripping (to 30cm) and lower nutrient inputs (50N,30P) increased yields by 800 kg/ha (40%), but it appears the higher nutrient supply plots allowed greater yields to be recorded.

Table 3. 2020 Grain yield (GY) for wheat at Drillham

Trt		Yield	SE	Delta GY	Rel GY%	LSD*	Protein
1	Control	2110	66	0	0	a	13.7
2	Shallow rip	2200	133	90	5	ab	13.5
3	Banded fert	2520	133	410	20	bcd	14.4
4	Surface gyp + shallow rip	2320	133	210	10	abc	14.0
5	Deep rip	2990	133	880	42	fgh	13.3
6	Deep gyp	2860	133	750	35	defg	13.8
7	Surface + deep gyp	2580	133	470	22	bcde	13.8
8	Surface gyp + deep rip	2910	133	800	38	efg	13.8
9	ES + surface gyp	2690	133	580	27	cdef	13.5
10	Nutrient control	3310	133	1200	57	hi	13.9
11	Surface +deep OM	3010	133	900	43	fgh	13.7
12	ES + OM	3200	133	1090	52	ghi	13.6
13	All	3420	133	1310	62	i	13.6

* Treatments with the same letter do not significantly differ (P<0.05)

Grain responses in NSW

The Armatree site produced a 4.5t/ha crop at around 15% protein and had significant differences between treatments in both grain yield, and biomass at flowering (Table 4). In general, deep ripping and the addition of nutrients, as banded fertiliser or contained in the organic amendment, increased growth and yields by approximately 20%. However, the organic matter treatments (11-13) ran out of water during grain fill due to the very large biomass produced, resulting in similar yields to the controls, with higher protein and screenings levels.

Table 4. 2020 Grain yield (GY) for wheat at Armatree

Trt		Yield	SE	Delta GY	Rel GY%	LSD*	Protein	Screenings
1	Control	4470	188	0	0	abcd	15.5	0.8
2	Shallow rip	4740	210	270	6	abcde	15.8	1.2
3	Banded fert	5040	210	570	13	abcde	14.8	0.9
4	Surface gyp + shallow rip	5210	210	740	17	bcde	15.4	1.2
5	Deep rip	5390	210	920	21	cde	14.7	1.1
6	Deep gyp	5460	210	990	22	cde	15.0	1.1
7	Surface + deep gyp	5110	188	640	14	bcde	14.6	1.2
8	Surface gyp + deep rip	5330	188	860	19	cde	15.0	1.0
9	ES + surface gyp	5630	210	1160	26	e	14.9	1.0
10	Nutrient control	5340	210	870	19	bcde	14.8	1.1
11	Surface + deep OM	4390	210	-80	-2	abc	16.3	2.1
12	ES + OM	4570	210	100	2	abcde	17.0	3.1
13	All	4340	188	-130	-3	ab	17.1	2.2

* Treatments with the same letter do not significantly differ (P<0.05)

Forbes had no significant differences in canola grain yield, but the organic treatments did increase protein and reduce oil content (Table 5). The site was waterlogged for most of winter, and still had moisture in the profile at harvest, so any differences in plant available water capacity, or root penetration to depth, were unlikely to have shown up in this season. The plant population was also extremely variable due to the surface roughness from the ripping and waterlogging from 70mm of rain immediately after sowing. This variation has been included in the statistical analysis, but also suggests that small-seeded canola may not be the best crop for growing immediately after a ripping program.

Table 5. 2020 Grain yield (GY) for canola at Forbes

Trt		Yield	SE	Delta GY	Rel GY%	LSD*	Protein	Oil
1	Control	2470	194	0	0	ns	19.9	44.9
2	Shallow rip	2530	222	60	2	ns	19.9	44.3
3	Banded fert	3070	193	600	24	ns	20.3	43.9
4	Surface gyp + shallow rip	2710	192	240	10	ns	20.4	45.0
5	Deep rip	2680	176	210	9	ns	20.8	43.2
6	Deep gyp	2650	193	180	7	ns	21.4	42.7
7	Surface + deep gyp	3010	172	540	22	ns	20.6	43.7
8	Surface gyp + deep rip	2840	192	370	15	ns	20.4	44.0
9	ES + surf gyp	2700	193	230	9	ns	20.4	43.7
10	Nutrient control	2750	193	280	11	ns	20.2	44.2
11	Surface + deep OM	2630	173	160	6	ns	22.4	40.6
12	ES + OM	2570	192	100	4	ns	22.5	40.4
13	All	2590	192	120	5	ns	21.6	41.7

* Treatments with the same letter do not significantly differ (P<0.05). ns = not significant difference

Spring Ridge also had no significant differences in biomass at flowering, or barley grain yield (Table 6). The high yield reflects the good season in 2020 and suggests that the site may not be as constrained as originally thought. We are uncertain if this lack of observed yield constraint is long term, or due to the above average rainfall in early 2020 which may have resulted in short term leaching of the salinity found in the initial sampling.

Table 6. 2020 grain yield (GY) for barley at Spring Ridge

Trt		Yield	SE	Delta GY	Rel GY%	LSD*
1	Control	6520	226	0	0	ns
2	Shallow rip	6030	253	-490	-8	ns
3	Banded fert	6170	256	-350	-5	ns
4	Surface gyp + shallow rip	6410	254	-110	-2	ns
5	Deep rip	6320	256	-200	-3	ns
6	Deep gyp	6360	256	-160	-2	ns
7	Surface + deep gyp	6700	227	180	3	ns
8	Surface gyp + deep rip	6050	227	-470	-7	ns
9	ES + surf gyp	5760	256	-760	-12	ns
10	Nutrient control	6460	254	-60	-1	ns
11	Surface + deep OM	6170	256	-350	-5	ns
12	ES + OM	6270	254	-250	-4	ns
13	All	6310	227	-210	-3	ns

* Treatments with the same letter do not significantly differ (P<0.05) ns = no significant difference.

Conclusions

We present one year of results, after a very wet summer/autumn which allowed all plots to refill after treatment application except for the Talwood site which has been planted in mid-January 2021. The 2021 crop will give a better indication of long term effects of treatments, and (possibly) under more typical conditions. Increases in yield as a result of the ripping may also require extra nutrients to achieve the increased yield potential.

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

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Take home messages

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

Background

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

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

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

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

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

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

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

Method

Rand amendment site

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

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

Depth (cm)	pH (H_2O)	EC (1:5) (μS/cm)	Nitrate N (mg/kg)	Exchangeable cations (cmol/kg)	Exchangeable sodium percentage (%)	Bulk density (g/cm^3)	Volumetric water content (θv)
0–10	6.6	132.1	20.6	16.1	3.8	1.40	0.120
10–20	7.8	104.0	5.8	22.6	7.3	1.52	0.163
20–40	9.0	201.5	4.1	26.7	12.5	1.50	0.196
40–50	9.4	300.5	3.0	27.5	18.1	1.48	0.232
50–60	9.5	401.3	3.0	28.8	21.8	1.53	0.237
60–100	9.4	645.0	2.9	29.7	26.4	1.55	0.218

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

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

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

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

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

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

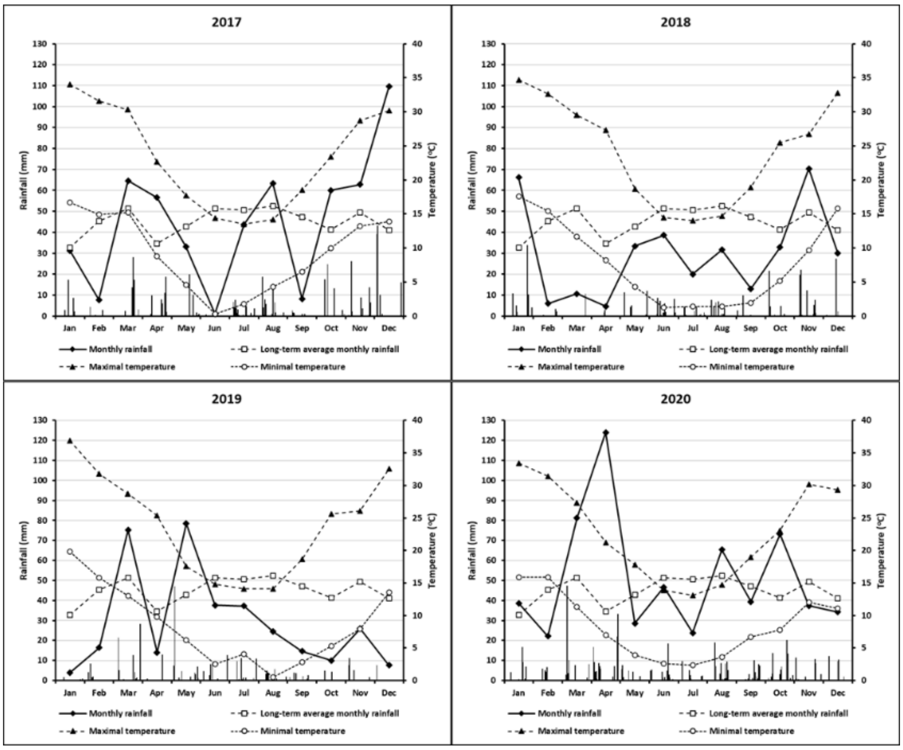

Figure 1. Long-term average monthly rainfall, and average monthly maximum and minimum temperatures, daily (bars) rainfall events and monthly rainfall at the Rand experimental site located at Urangeline East, NSW.

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

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

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

Grogan genotypes screening experiment

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

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

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

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

Results

Rand amendment trial

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

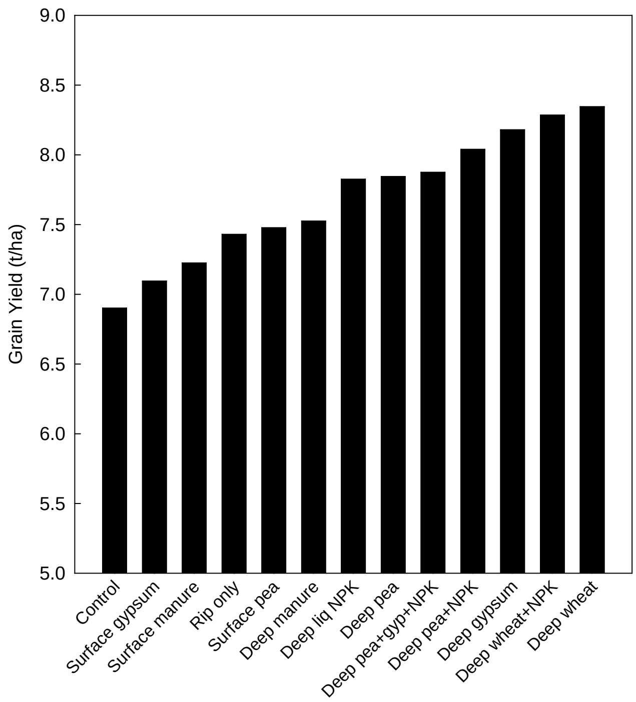

Figure 2. The mean effect of surface or deep-placed amendments on grain yield of wheat (cv. Scepter⚬) grown in an alkaline dispersive subsoil in Rand, SNSW in 2020. Values are mean (n=4). $LSD_{0.05}$ = 0.67.

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

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

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

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

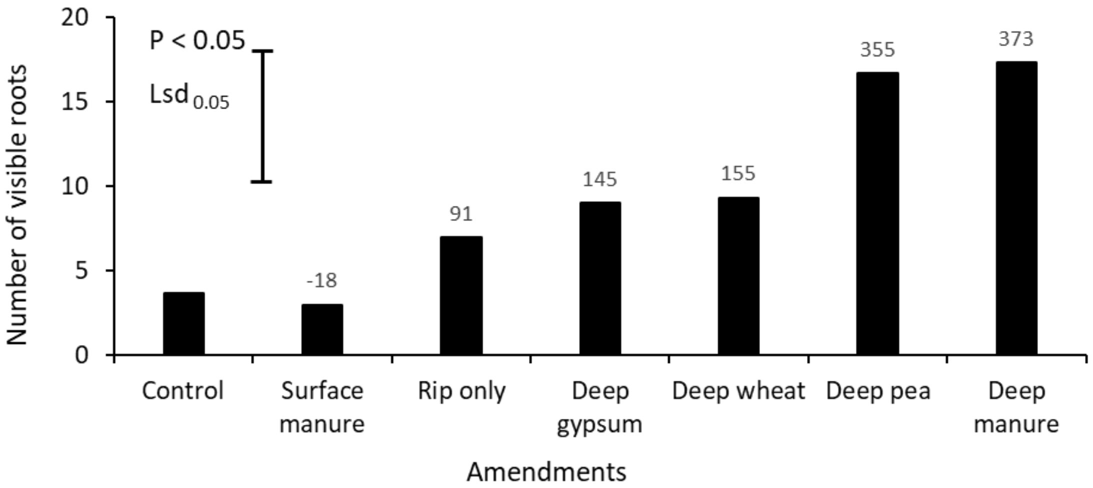

Figure 3. The mean effect of surface or deep-placed amendments on the number of visible roots at 30cm at late flowering of canola (cv. Pioneer® 45Y91CL) grown in alkaline dispersive subsoil in Rand, SNSW in 2019. Values on the top of each bar is representing percent change of visible roots compared to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

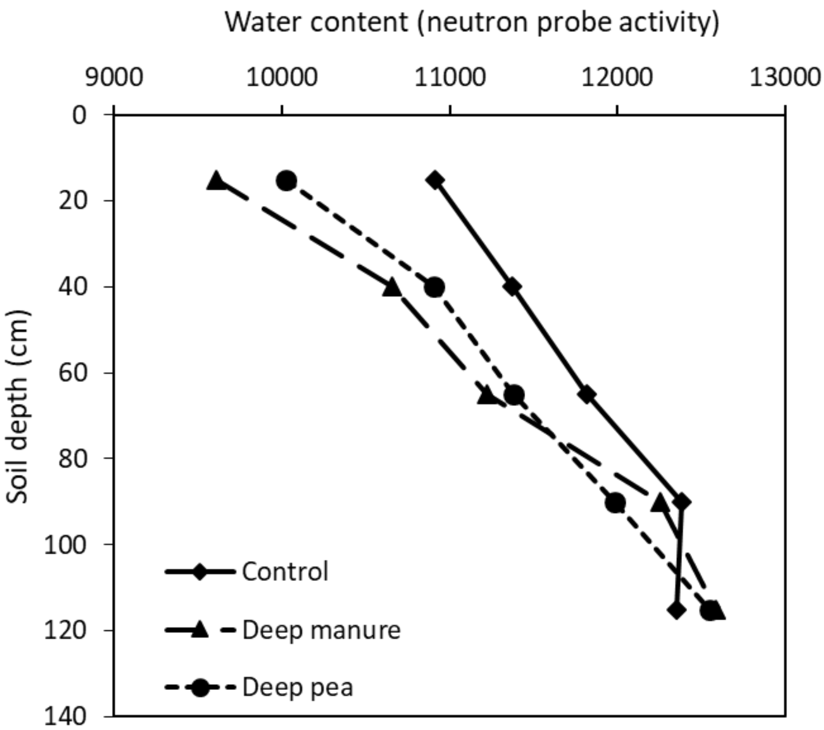

Figure 4. Neutron probe readings taken in September at the Rand amendment site for contrasting treatment comparisons. Results are based on the neutron activity (raw data) where higher values represent higher water content in the soil profile. Values are averages (n = 4).

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

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

Grogan genotypes screening trial

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

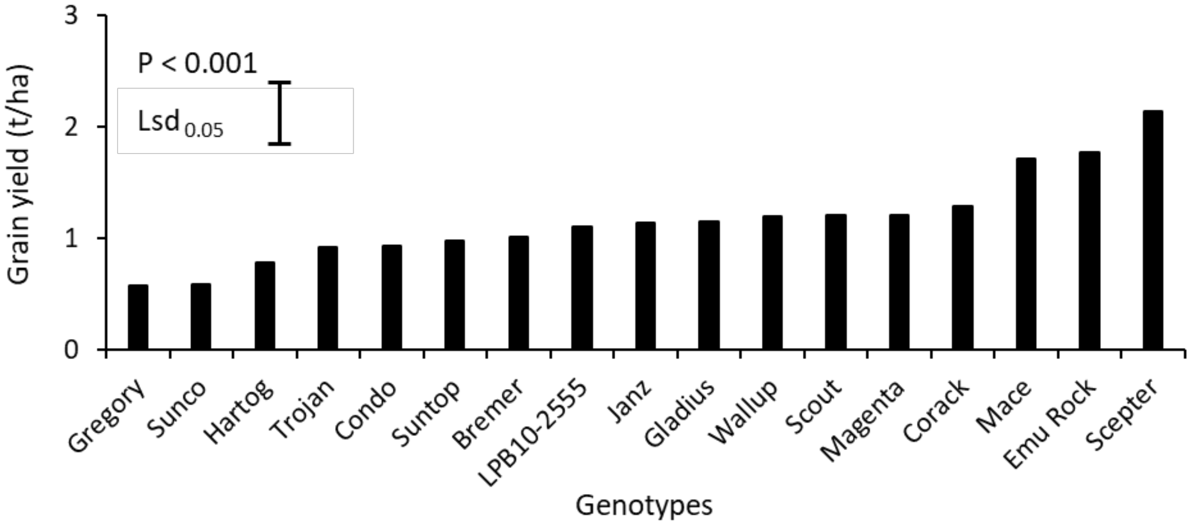

Figure 5. Variations in grain yield of 17 wheat genotypes grown in alkaline sodic dispersive subsoil in Grogan, SNSW in 2019. Each data point is mean values of n = 4.
(Varieties Gregory, Trojan, Condo, Suntop, Bremer, Gladius, Wallup, Scout, Magenta, Corack, Mace, Emu Rock and Scepter are protected under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

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

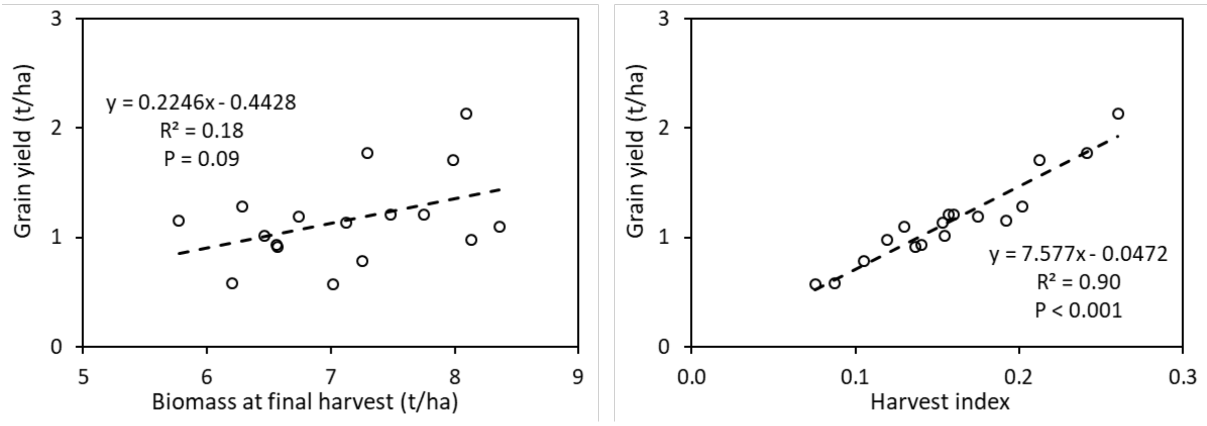

Figure 6. Linear regressions between grain yield and biomass at final harvest (left) and harvest index (right) of 17 wheat genotypes grown in alkaline sodic dispersive subsoil at Grogan, SNSW in 2019.

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

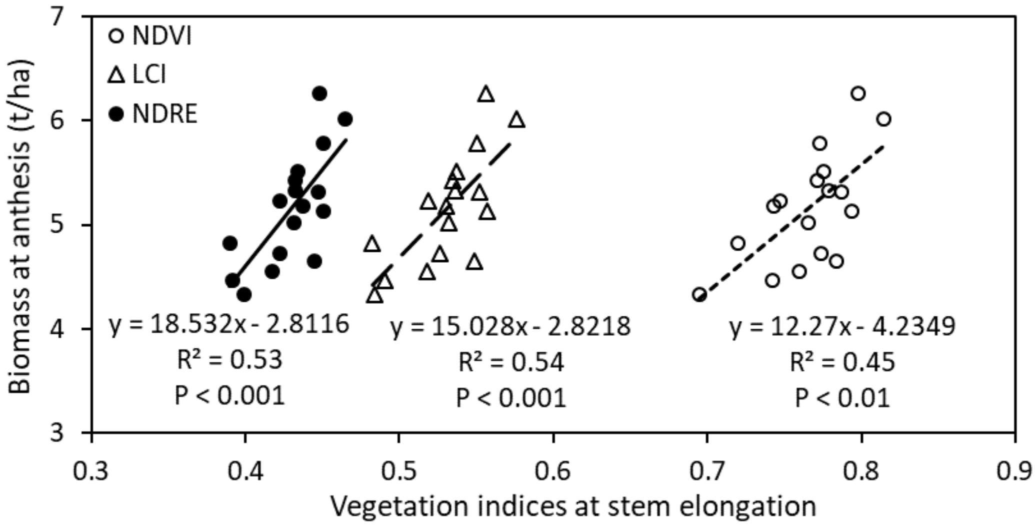

Figure 7. Linear regressions between vegetation indices (measured at stem-elongation) and anthesis biomass of 17 wheat genotypes grown in alkaline sodic dispersive subsoil at Grogan, SNSW in 2019. NDVI = normalised differences in vegetation index; LCI = Leaf chlorophyll index; NDRE = Normalised difference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

Discussion

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

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

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

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

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

Conclusions

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

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CBA Captain⊕: a new desi variety for the northern region

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Key words

chickpea variety, desi, yield, disease resistance, Ascochyta blight, Phytophthora root rot, phenology, grain quality

GRDC code

DAN00094, DAN00151, DAN00176, DAN00212, BLG205, BLG209, BLG111, 9177999

Take home message

CBA Captain⊕ is a new broadly adapted desi chickpea variety for the northern region and other chickpea growing areas of Australia. The variety was evaluated as CICA1521 and has higher yields in northern NSW and southern QLD than PBA HatTrick⊕. CBA Captain⊕ has a medium seed size and is expected to have similar disease ratings to PBA HatTrick⊕. Seed of CBA Captain⊕ is available in the northern region for the 2021 season from the following seed partners; Galleon Grains, PB Agrifood, PB Seeds and Woods Seeds.

Significant yield advantage over PBA HatTrick⊕

CBA Captain⊕ has been included in National Variety Trials (NVT) since 2015. During this six-year period there have been two favourable seasons in north west NSW (2016 and 2020) and a number of dry seasons (2018 and 2019). CBA Captain⊕ has shown great consistency in yield despite the highly variable seasons. In the southern areas of north-west NSW, CBA Captain⊕ has consistent yield gains over PBA HatTrick⊕ (Table 1). At the time of writing this paper, the long term yield reporter using 2020 trials were not available. Readers are encouraged to visit nvtonline.com.au.

Table 1. Long term yield (2015-2019) of CBA Captain⊕ and current chickpea varieties, expressed as a % of the mean yield, in NVT in Trangie, Narromine and Coonamble. The mean yield of all varieties in each of the 5 contributing trials was used to assign that trial to a 'yield grouping'. This enables varietal performance to be better evaluated in different yield situations

		Yield group (t/ha)			
		1	**1.5**	**2.0**	**3.0**
	Mean yield (t/ha)	0.91	1.25	1.84	2.96
Variety	No trials in total & for each yield group	2	1	1	1
CBA Captain⊕	**5**	**108**	**110**	**110**	**112**
Kyabra⊕	5	113	98	97	68
PBA Boundary⊕	5	110	101	103	89
PBA Drummond⊕	1	107			
PBA HatTrick⊕	5	101	95	96	88
PBA Seamer⊕	5	95	102	102	115

Source: https://app.nvtonline.com.au/lty/table/chickpea-desi/nsw/nw/trangie,narromine,coonamble/?lty-type=yield&stacked=1

Table 2. Long term yield (2015-2019) of CBA Captain⊕ and current chickpea varieties, expressed as a % of the mean yield, in NVT at Bellata, north west NSW. The mean yield of all varieties in each of the 4 contributing trials was used to assign that trial to a 'yield grouping'. This enables varietal performance to be better evaluated in different yield situations

		Yield group (t/ha)		
		1.0	**1.5**	**2.0**
	Mean yield (t/ha)	0.96	1.18	1.65
Variety	No trials in total & for each yield group	2	1	1
CBA Captain⊕	**4**	**109**	**121**	**104**
Kyabra⊕	4	113	68	96
PBA Boundary⊕	4	104	95	96
PBA Drummond⊕	1	115		
PBA HatTrick⊕	4	97	86	96
PBA Seamer⊕	4	96	116	102

Source: https://app.nvtonline.com.au/lty/table/chickpea-desi/nsw/ne/bellata/?lty-type=yield&stacked=1

Ascochyta blight

CBA Captain⊕ has undergone Ascochyta blight (AB) testing in the field at Tamworth and Horsham as well as single isolate testing under controlled conditions in Adelaide and Tamworth.

An increase in the aggressiveness of the AB pathogen has been observed both in the northern and southern regions (Ford et al., 2018). Increased levels of disease have been recorded on CBA Captain⊕ and other varieties such as PBA Seamer⊕ from these isolates collected in 2017 compared to isolates collected in 2015 (Table 3). The distribution of the more aggressive isolates in the northern region is currently unknown, due to the reduced chickpea area and dry seasons over the past two years, however a cautious disease rating from the NVT pulse disease rating system for CBA Captain⊕ is expected. For northern isolates this is likely to be a Moderately Susceptible rating for Ascochyta blight. At the time of writing this paper the 2021 NVT pulse disease ratings were unavailable. Readers are encouraged to visit nvtonline.com.au for updated AB ratings.

Table 3. Mean disease index of chickpea varieties in single isolate AB screening conducted at Adelaide. The index is calculated as the sum of (% main stems broken + % of stems with lesions + % side branches with disease + % leaves with disease) divided by 4. (0 = healthy plant, 100 = heavily diseased plant)

	Isolate collection location and year							
Name	Yallaroi NNSW 2015	Curyo VIC 2015	Graman NNSW 2016	Curyo VIC 2016	Gurley NNSW 2017	Pt Broughton SA 2017	Gurley NNSW 2017	Curyo VIC 2018
CBA Captain⊕	**40**	**50**	**77.1**	**76.3**	**29.2**	**26.7**	**67.9**	**89.6**
Kyabra⊕			100	100	100	100	100	100
PBA Boundary⊕	81.3	67.9	100	100	77.1	55.4	90	100
PBA Drummond⊕	97.1	100	100	100	66.7	97.5	83.3	100
PBA HatTrick⊕	87.5	61.7	86.3	94.2	66.7	48.8	67.9	68.3
PBA Seamer⊕	31.7	37.5	83.8	90.8	29.2	39.2	65.4	84.6
Lsd	*20.6*	*27.2*	*18.1*	*16.2*	*24.7*	*19.2*	*26.6*	*28.6*

Phytophthora root rot

CBA Captain⊕ was included in Phytophthora root rot (PRR) yield loss trials conducted at Warwick QLD, over several years (Table 4). Yield losses for CBA Captain⊕ from PRR in these trials have ranged from 38.7 to 93.4 %. Similar variability in yield loss has also been observed for PBA HatTrick⊕; an explanation of the seasonal impacts on yields and varietal PRR disease rankings is provided in Bithell et al., 2018. In 2020, NVT pulse disease rating testing was conducted for PRR for the first time. It is expected that a review of all variety ratings for PRR will be conducted to align with the NVT disease rating definitions. The 2020 ratings were not available at the time of writing this report, please see nvtonline.com.au for updated ratings.

Table 4. Yield (t/ha) in the absence of PRR and yield loss (%) from PRR across 2016 to 2018 for CBA Captainⓟ and other current chickpea varieties. Adapted from Bithell et al., 2018, Bithell et al., 2019

	2016		2017		2018	
Name	Yield (t/ha) in the absence of PRR	% yield loss from PRR	Yield (t/ha) in the absence of PRR	% yield loss from PRR	Yield (t/ha) in the absence of PRR	% yield loss from PRR
CBA Captainⓟ	**4.06**	**75.1**	**2.74**	**93.4**	**1.94**	**38.7**
PBA Boundaryⓟ	3.98	95.2	2.63	82.5		
PBA Drummondⓟ					2.49	68.1
PBA HatTrickⓟ	4.02	90.0	3.31	78.2	2.28	40.5
PBA Seamerⓟ	4.08	76.7	3.23	90.4	2.81	61.5
Yorker	4.06	68.3	3.50	97.3	2.84	40.1

Phenology and other agronomic traits

CBA Captainⓟ is early flowering when sown in the mid-May to mid-June sowing window, approximately six days earlier than PBA HatTrickⓟ (Table 5). Flowering data collected from early May sown chilling tolerance trials (BLG111) indicates that CBA Captainⓟ can flower up to 24 days earlier than PBA HatTrickⓟ depending on winter daytime temperatures. An increased understanding of the drivers of chickpea phenology is expected with new GRDC investments in this area. Although there is some data indicating that CBA Captainⓟ may produce pods earlier in some environments (e.g. Kingaroy, 2019), it is expected that days to first pod is similar to current varieties.

Table 5. Phenology data (2017-2020) collected for CBA Captainⓟ and current chickpea varieties from breeding and chilling tolerance trials in northern NSW and southern QLD

		CBA Captainⓟ		Kyabraⓟ		PBA Drummondⓟ		PBA HatTrickⓟ		PBA Seamerⓟ	
Sowing date	Location	DTF	DTP	DTF	DTP	DTF	DTP	DTF	DTP	DTF	DTP
15/6/2017	Spring Ridge	**102**		103				103		102	
23/5/2018	Moree	**91**		96		97		98		97	
7/5/2018	Tamworth	**101**	**134**	112	134	120	134	125	135	126	134
12/6/2018	Tamworth	**96**	**108**	99	108	97	108	102	108	99	
13/5/2019	Narrabri	**77**	**108**	83	106			80	108		
15/5/2019	Breeza	**106**	**122**	105	123			105	122		
17/5/2019	Kingaroy	**79**	**91**	82	95			81	96		
10/06/2020	Narrabri	**86**		88		88		89		88	

DTF = days to flower from sowing
DTP = days to pod from sowing

CBA Captainⓟ has early to mid-maturity, earlier than PBA HatTrickⓟ. CBA Captainⓟ has an erect plant type with good height to lowest pod and plant height. Under the high biomass producing conditions of 2016 and 2020, CBA Captainⓟ had less lodging than PBA HatTrickⓟ at seven sites across northern NSW and southern QLD (Table 6).

Table 6. Mean lodging score at northern NSW and southern QLD breeding sites in 2016 and 2020 for CBA Captain and current chickpea varieties. 1 = erect, 9 = flat.

Location	**Year**	**CBA Captain**	Kyabra	PBA Drummond	PBA HatTrick	PBA Seamer
Edgeroi	2016	**3.7**	2.3		5.3	5.3
North Star	2016	**4.3**	3.0		7	3.3
Rowena	2016	**5.3**	5.3		6.7	6.3
Warwick	2016	**6.0**	6.3		6.3	5.3
Warra	2016	**3.3**	2.0		6.0	2.7
Roma	2016	**3.7**	3.0		6.0	4.7
Rowena	2020	**1.7**	1.3	1.3	3.0	1.0

In December 2020, Tamworth Agricultural Institute received more than 240 mm of rain. Plots of CBA Captain were observed to have remained standing with good harvestability compared to PBA HatTrick which had lodged considerably.

In 2019 and 2020, large seed multiplications and demonstration blocks of CBA Captain were harvested by commercial harvesters throughout the northern region. No negative feedback regarding the harvestability of CBA Captain were reported.

Grain quality

CBA Captain has a yellow-brown seed coat and angular seed shape, not unlike PBA HatTrick. The seed size of CBA Captain is larger than PBA HatTrick, similar to PBA Seamer and PBA Drummond but smaller than Kyabra (Table 7). CBA Captain has a higher or similar split yield than PBA HatTrick and PBA Drummond at six sites across southern QLD and northern NSW.

Table 7. Seed size (grams per 100 seeds) and split yield % (SY%) for CBA Captain and other current chickpea varieties at six sites in northern NSW and southern QLD

	CBA Captain		Kyabra		PBA Drummond		PBA HatTrick		PBA Seamer	
Site Year	100 SW	SY%	100 SW	SY%	100 SW	SY%	100 SW	SY%	100 SW	SY%
Roma 2017	**19.8**	**52.9**	21.9	72.5			20.1	40.8	20.8	44.8
Spring Ridge 2017	**22.5**	**53.2**	24.6	45.1			18.9	44.3	21.3	55.7
Warra 2017	**21.7**	**72.3**	24.2	67.5			22.5	70.5	24.1	73.7
Moree 2018	**21.5**	**41.2**	25.1	46.9	22.2	36.7	20.2	42.9	21.5	42.0
North Star 2018	**23.7**	**46.0**	27.2	64.1	24.0	39.7	22.0	39.2	23.5	45.3
Warra 2019	**22.3**	**50.7**	24.2	32.6	22.4	38.0	21.8	37.4	22.2	38.7

100SW = grams per 100 seeds
SY% = split yield % (yield of dhal using a standard SKE milling method without pre-conditioning seeds; Wood et al 2008).

Seed partners

CBA Captain⦸ will be delivered to the northern region through the following seed partners; Galleon Grains, PB Agrifood, PB Seeds and Woods Seeds to distribute seed to QLD and NSW.

Acknowledgements

CBA Captain⦸ was developed by the PBA Chickpea program (led by NSW Department of Primary Industries). The partners of the PBA Chickpea program were: GRDC, NSW DPI, Department of Agriculture and Fisheries (QLD), Agriculture Victoria and the South Australian Research and Development Institute.

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The economics of managing Ascochyta in chickpea when disease occurs at different growth stages and implications for spray timing

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Key words

chickpea, Ascochyta, management, gross margin, profitability

GRDC codes

GAPP, Grains Agronomy & Pathology Partnership - A strategic agreement between GRDC and NSW DPI (DAN00213): BLG209 Pulse Integrated Disease Management – Northern NSW/QLD

Take home messages

- Impact of Ascochyta at different growth stages was investigated in a 2020 field experiment at Trangie with varieties Kyabra⁽ᴰ⁾, PBA HatTrick⁽ᴰ⁾ and PBA Seamer⁽ᴰ⁾
- Ascochyta caused yield losses from 100% to nil depending on when the disease occurred, and the variety grown
- Highest gross margin (GM)'s (> $800/ha) occurred with the lowest incidence of Ascochyta and also with the least susceptible variety, i.e. PBA Seamer⁽ᴰ⁾
- Manage Ascochyta early and grow varieties with best resistance to minimise impact of Ascochyta
- Follow current Ascochyta advice to maximise enduring profitability.

Why did we do this research?

Current management of chickpea Ascochyta in north central/northern NSW and southern QLD is based on results of field trials conducted mostly at Tamworth, grower experiences and feedback from agronomists. The Tamworth experiments have tried to simulate what happens in most farmers crops, i.e. initial infection occurs during the first post emergence rainfall event – accordingly, all the Tamworth experiments have established Ascochyta during that event. But what is the impact if infection occurs at later stages of growth and how does that affect management? The Trangie Agricultural Research Centre provided an opportunity to address that question – the soil and climate are typical of the Macquarie valley, a major chickpea production region. Overhead irrigation (lateral) and inoculation with conidia and infected spreader plants optimised infection and disease development.

Experiment details

Treatments

Aim: to assess the impact of Ascochyta blight (AB) disease occurring at three different growth stages, on yield of three chickpea varieties with different levels of AB resistance.

Ascochyta treatments (5):

1. **LOW (NIL)**: un-inoculated (NIL disease = CONTROL) plus foliar chlorothalonil fungicide (1.0 L/ha, chlorothalonil 720g/L) applied before rain or irrigation events
2. **HIGH**: inoculated with disease twice (at seedling (SDG, 3-4 nodes) and vegetative (VEG, 7-8 nodes) growth stages); NIL fungicide applied

3. **SDG**: inoculate with disease at seedling stage (3-4 nodes), allow disease to progress for 2-3 rain events to 7-8 nodes, then control disease for rest of season with chlorothalonil
4. **VEG**: protect plants from emergence to vegetative stage (7-8 nodes) with chlorothalonil; inoculate with disease and allow to progress for 2-3 rain events to first pods, then control disease with chlorothalonil
5. **POD**: protect plants from emergence to reproductive stage (first pods) with chlorothalonil, inoculate with disease and allow disease to progress through to harvest.

Variety treatments (3, and level of AB resistance):

1. **Kyabra**ᶲ VS = Very susceptible
2. **PBA HatTrick**ᶲ MS = Moderately susceptible
3. **PBA Seamer**ᶲ MR = Moderately resistant

Replication: 4 reps

Method

The experiment was conducted at Trangie Agricultural Research Centre in central west NSW, on a grey vertosol soil with access to overhead (lateral) irrigation. The experiment was sown as a randomised block design using a small plot seeder, with each plot 2m x 10m. Buffer plots were sown (with PBA Seamerᶲ) at the same plot size between each treatment plot, to reduce the impact of inter-plot interference from Ascochyta inoculation and fungicide application. A back-pack sprayer with a 2m wide hand-held wand and 015 110 degree flat fan nozzles @ 50cm, was used to apply both Ascochyta inoculum and fungicide. Buffer plots received the full set of six fungicide applications.

Ascochyta disease was generated in treatment plots by a combination of two inoculation methods:
1. Ascochyta applied to whole plot as conidial suspension (600,000 conidia/mL), and
2. Ascochyta infected spreader plants transplanted to centre of plot.

Ascochyta treatments for each growth stage were applied just prior to either a forecast rain event, or irrigation.

Ascochyta treatment and fungicide were applied as follows:

up to 1 July	NIL fungicides applied prior to first disease treatment
1 July	**inoculation 1 - SDG & HGH treatments (pre-irrigation)**
9 July	fungicide 1 pre-rain - applied to LOW, VEG & POD (not SDG or HGH)
5 August	**inoculation 2 - VEG & HGH treatments (pre-rain)**
13 August	fungicide 2 pre-rain – applied to LOW, SDG & POD (not VEG or HGH)
9 September	fungicide 3 pre-rain – applied to LOW, SDG & POD (not VEG or HGH)
19 September	**inoculation 3 - POD treatment (pre-rain)**
29 September	fungicide 4 pre-rain – applied to LOW, SDG & VEG plots (not POD or HGH)
7 October	fungicide 5 pre-rain – applied to LOW, SDG & VEG plots (not POD or HGH)
21 October	fungicide 6 pre-rain – applied to LOW, SDG & VEG plots (not POD or HGH)

Site details & agronomy management

Sowing date: 26 May 2020
Harvest date: 27 November 2020
Seed treatment:
PBA Seamerᶲ pre-treated with thiram at purchase
Kyabraᶲ & PBA HatTrickᶲ treated with P-Pickel T® pre-sowing
Fertiliser at sowing: Granulock® Z @ 80 kg/ha

Inoculant: Group N, liquid inject at sowing
Target plant density: 30 plants/m^2
Actual establishment achieved:
    Kyabra⟮ & PBA Seamer⟮ = 31 plants/m^2 (new seed)
    PBA HatTrick⟮ = 21 plants/m^2 (retained seed ex 2019 harvest, poor storage conditions)
Buffers between treatment plots: PBA Seamer⟮ at 30 plants/m^2

Herbicide management:
    pre-sow: TriflurX® (trifluralin 480 g/L) @ 1.7 L/ha
    PSPE: Terbyne® Xtreme® (terbuthylazine 875 g/kg) @ 0.86 kg/ha
    in-crop: haloxyfop 520 @ 100 mL/ha + clethodim 240 @ 250 mL/ha
Fungicide application:
    up to 6 chlorothalonil 720g/L @ 1.0 L/ha for LOW (NIL disease) treatment; total number of applications varied for each growth stage treatment
Insecticide & mouse management:
    17 Sept Affirm® (emamectin) insecticide @ 300 mL/ha (by plane)
    6 Oct Altacor® (chlorantraniliprole) insecticide @ 70 g/ha (by plane)
    12 Oct Zinc phosphide mouse bait @ 1.0 kg/ha (by plane)
Harvest management:
    desiccation not required due to heatwave conditions from 15 November on
    experiment harvested at 9% moisture content.
Pre-sowing rainfall (1/01/20 to 25/05/20): 351 mm
In-crop rainfall (26/05/20 to 27/11/20): 201 mm in 49 events
Plus in-crop irrigations: 20 mm (as 2 x 10 mm events)

Table 1. Summary of dates of disease inoculations and fungicide applications for 2020 Trangie chickpea Ascochyta management trial, relative to dates of subsequent rain or irrigation events.

2020 date	Disease inoculation	Fungicide application	Rain > 2.0mm	Irrigation (mm)	Cumulative >2.0mm # Events	Cumulative >2.0mm (mm)
01 Jul	SDG & HIGH		0.0	10.0	1	10.0
09 Jul		LOW, VEG & POD				
10-13 Jul			31.6		2	41.6
25-27 Jul			35.8		3	77.4
05 Aug	VEG & HIGH					
06-12 Aug			19.2		4	96.6
13 Aug		LOW, SDG & POD				
14-22 Aug			18.8		5	115.4
09 Sep		LOW, SDG & POD	3.8		6	119.2
14 Sep			0.0	10.0	7	129.2
19 Sep	POD					
19-25 Sep			33.8		8	163.0
29 Sep		LOW, SDG & VEG				
7 Oct		LOW, SDG & VEG	6.8		9	169.8
17 Oct			3.4		10	173.2
21 Oct		LOW, SDG & VEG				
23-25 Oct			17.6		11	190.8
4-5 Nov			7.8		12	198.6

Table 2. Log of operations for 2020 Trangie experiment on managing chickpea Ascochyta when disease occurs at different growth stages: Inoc = inoculation, DAS = days after sowing, DAI = days after inoculation.

	Ascochyta treatment			
Operation	**HIGH**	**SDG**	**VEG**	**POD**
Sow date	26/05/2020	26/05/2020	26/05/2020	26/05/2020
1st Inoc date	1/07/2020	1/07/2020	5/08/2020	19/09/2020
2nd Inoc date	5/08/2020	not done	not done	not done
1st Inoc DAS	36	36	71	116
2nd Inoc DAS	71	not done	not done	not done
Score 1 date	26/08/2020	26/08/2020	26/08/2020	26/08/2020
Score 2 date	1/10/2020	1/10/2020	1/10/2020	1/10/2020
Score 3 date	14/10/2020	14/10/2020	14/10/2020	14/10/2020
Score 1 DAI	56	56	21	na
Score 2 DAI	92	92	57	12
Score 3 DAI	105	105	70	25

Results

The effects of Ascochyta treatment, Variety and Ascochyta x Variety were highly significant (P<0.001) for all variables measured.

Disease incidence

The seedling, (SDG) and HIGH Ascochyta treatments were inoculated on 1 Jul 20, 36 days after sowing, DAS (Table 2). The HIGH treatment was inoculated a second time on 5 Aug (71 DAS) to maximise disease development (Table 2). This resulted in severe early disease (assessed on 26 Aug) in Kyabraᶲ, moderate disease in PBA HatTrickᶲ and demonstrated the improved Ascochyta resistance in PBA Seamerᶲ (Table 3). The vegetative, VEG treatment was inoculated on 5 Aug (71 DAS), prior to which plants had been protected with foliar fungicide applied on 9 Jul. This regime produced low disease in Kyabraᶲ and PBA HatTrickᶲ at the 1st and 2nd assessments (26 Aug, 1 Oct) and nil in PBA Seamerᶲ (Table 3). The podding, POD treatment was inoculated on 19 Sep (116 DAS), prior to which plants had been protected with foliar fungicides applied on 9 Jul, 13 Aug and 9 Sep. This regime produced nil disease in all three varieties at the 1st assessment (26 Aug) and low disease at the two subsequent assessments (1 Oct, 14 Oct) (Table 3). We assign the low incidence of Ascochyta with the POD treatment as a consequence of the three fungicide sprays applied before inoculation and less favourable seasonal conditions.

Table 3. Incidence of Ascochyta (% plot with disease) in Kyabra⒫, PBA HatTrick⒫ and PBA Seamer⒫ chickpeas when disease was established at different growth stages but controlled before and after; l.s.d. (P=0.05) for Scores 1, 2 & 3 = 13.26%, 8.63% & 11.74%, respectively.

Variety	Ascochyta treatment	Score 1 26 Aug 20	Score 2 01 Oct 20	Score 3 14 Oct 20
Kyabra ⒫	LOW	1.3	0.0	5.2
PBA HatTrick ⒫	LOW	0.0	0.0	11.2
PBA Seamer ⒫	LOW	0.0	0.0	3.0
Kyabra ⒫	SDG	92.0	57.5	70.0
PBA HatTrick ⒫	SDG	37.5	22.5	40.0
PBA Seamer⒫	SDG	0.0	0.0	2.8
Kyabra ⒫	VEG	8.8	12.5	31.2
PBA HatTrick ⒫	VEG	5.0	8.8	22.5
PBA Seamer⒫	VEG	0.0	0.0	3.0
Kyabra ⒫	POD	0.0	0.5	7.8
PBA HatTrick ⒫	POD	0.0	2.5	5.2
PBA Seamer⒫	POD	0.0	0.0	3.8
Kyabra⒫	HIGH	88.8	100.0	100.0
PBA HatTrick ⒫	HIGH	32.5	52.5	57.5
PBA Seamer ⒫	HIGH	0.0	0.0	4.0

This approach, i.e. inoculating Ascochyta at different times and protecting before and after, allowed us to determine the impact of disease at those stages on yield.

Impact on yield

Table 4. Effect of Ascochyta on grain yield, gross margin (GM) and yield loss for three chickpea varieties when disease occurs at different growth stages; l.s.d. (P=0.05) yield 286 kg/ha. GM is based on chickpea price of $600/t, fungicide product $16/ha/application, fungicide ground rig application $5/ha, other production costs $300/ha.

Variety	Ascochyta Treatment	Yield (kg/ha)	GM ($/ha)	% Yield Loss (kg/ha)
Kyabra ⒫	LOW	1878	701	0
PBA HatTrick ⒫	LOW	1840	678	0
PBA Seamer ⒫	LOW	2138	857	0
Kyabra ⒫	SDG	10	-399	99
PBA HatTrick ⒫	SDG	965	174	48
PBA Seamer⒫	SDG	2080	843	3
Kyabra ⒫	VEG	1483	506	21
PBA HatTrick ⒫	VEG	1504	518	18
PBA Seamer ⒫	VEG	2211	943	-3
Kyabra ⒫	POD	2041	862	-9
PBA HatTrick ⒫	POD	1880	765	-2
PBA Seamer ⒫	POD	2101	898	2
Kyabra ⒫	HIGH	0	-300	100
PBA HatTrick ⒫	HIGH	234	-160	87
PBA Seamer ⒫	HIGH	1903	842	11

Grain yield (Table 4) ranged from nil (Kyabra⒫ HIGH) to over 2 t/ha (all PBA Seamer⒫ treatments). For the very susceptible Kyabra⒫, lowest yields occurred with the SDG and HIGH treatments with yield losses of 99% and 100% respectively. The moderately susceptible PBA HatTrick⒫ also had lowest yields for SDG and HIGH treatments, with losses of 48% and 87% respectively (Table 4). The least susceptible variety PBA Seamer⒫ only lost 3% and 11% yield from SDG and HIGH treatments.

Gross Margins, GM

The highest GM's occurred with the lowest incidence of Ascochyta (LOW) and also with the least susceptible variety PBA Seamer⒫ (Table 4). All PBA Seamer⒫ treatments, including the one with most Ascochyta, (HIGH) had GM over $800/ha (Table 4). However, the experiment showed that controlling Ascochyta in the very susceptible Kyabra⒫ is profitable with a GM of $701/ha and $862/ha for the LOW and POD treatments respectively.

Conclusions

Generating chickpea Ascochyta at different stages of growth showed when and how disease affects yield. The impact of disease on a chickpea crop depends primarily on when the disease occurs, how it is managed, and the variety grown. Allowing Ascochyta to establish early in the life of your crop results in greatest impact on yield and lowest profitability, even if the disease is subsequently controlled with foliar fungicides. This is especially true for very susceptible and moderately susceptible varieties. Your best option for minimising impact of Ascochyta on chickpea production and maximising profitability is to follow current recommendations (Moore and Heuston, 2020) by controlling disease early and growing the least susceptible variety. This approach will also reduce the build-up and carryover of Ascochyta inoculum for your and your neighbour's future chickpea crops.

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Viral diseases in faba bean, chickpeas, lentil and lupins. Impacts, vectors/causes and management strategies for 2021

Joop van Leur and Zorica Duric, NSW DPI

Key words

faba bean viruses, *Bean yellow mosaic virus*, *Alfalfa mosaic* virus, aphids

GRDC codes

DAN00202, DAN00213/BLG209, DAN00213/BLG204

Take home messages

- The severe virus epidemic in faba bean in northern NSW during 2020 was initiated by early and massive flights of aphids (mainly cowpea aphids) that carried *Bean yellow mosaic virus* (BYMV) into the crops
- After a 2-year drought, heavy January and February rains in north-west NSW triggered the emergence of naturalised medics and other pasture legumes, which allowed a build-up of aphids and virus prior to the emergence of faba bean crops
- Most faba bean crops were sown into bare ground as cereal stubble was lacking after the extended drought. Lack of standing cereal stubble or uneven emergence makes pulse crops particularly vulnerable to early aphid infections
- Relatively mild and dry conditions during the start of the season favoured aphid multiplication in the faba bean crops and a fast spread of virus from initial infection foci
- Co-infections of BYMV and *Alfalfa mosaic virus* (AMV) caused particularly severe symptoms in several crops
- Both BYMV and AMV are non-persistently transmitted viruses that require only a short probing period by a viruliferous aphid to infect a plant. Slow-acting insecticides like imidacloprid applied to seed will not prevent infection of non-persistently transmitted viruses by incoming, winged, aphids . However, they may help in slowing the multiplication of aphids in the crop and subsequent spread of the virus by wingless aphids
- Further work is needed to investigate how long an imidacloprid seed dressing remains active and whether a foliar application of a pulse registered product (pirimicarb) after aphids are found in a crop is more practical, economic or effective
- There are no indications that transmission of BYMV to faba bean seed occurs at significant levels
- Virus control strategies are all based on preventing infection, particularly during the early growth stages of the crop. Poorly emerging crops or crops sown into bare ground are particularly vulnerable to infection. Sowing in standing cereal stubble and using high quality seed with good seedling vigour has shown to be the most reliable management option to avoid virus infections.

Pulse viruses and pulse virus vectors

Pulses are far more vulnerable to virus infection than winter cereals with over 20 viruses considered to be of economic importance on pulse crops worldwide. All major pulse viruses require an insect vector (mostly an aphid species) to transmit the virus to a healthy plant. The mode of transmission can be non-persistent, which means that the aphid only needs a short probe of the plant in order to acquire or to transmit the virus, while persistently transmitted viruses require a longer feeding period by the aphid. Plants can be infected by most non-persistently transmitted viruses under experimental conditions through rubbing a virus suspension into the leaf ('mechanical inoculation'), while a viruliferous vector is always needed for the persistently transmitted viruses. Viruliferous aphids will lose a non-persistently transmitted virus after probing a healthy plant, but aphids that carry a persistently transmitted virus remain viruliferous.

The difference in the time needed to transmit a virus has implications for the effectiveness of aphicides to control virus infections; infection by a persistently transmitted virus like *Bean leafroll virus* (BLRV) can be prevented by a timely foliar application of an insecticide or by seed dressing with a systemic insecticide, but most aphicides are not fast enough to prevent infection by a non-persistently transmitted virus like *Bean yellow mosaic virus* (BYMV).

Virus epidemiology and the prediction of severe virus epidemics is complicated as aphid numbers and movements depend on numerous factors, both during and preceding the growing season. A few viruses can survive in seed, but most require a 'green bridge' of living host to survive between cropping seasons. Pulse viruses are not host species specific and naturalised pasture legumes, like medics or sub clovers, or perennial legumes, like lucerne or white clover, can be infected with a range of viruses that can be harmful to grain legumes like faba bean or chickpea. Viruses like BYMV and AMV can be seed transmitted in several pasture legume species and viruses and their vectors can build up in pastures, roadside weeds or stock routes prior to the emergence of pulse crops. Also, a virus that can devastate grain legumes might have little or no impact on a pasture legume or a weed; e.g. *Bean leafroll virus* (BLRV) kills pulses like faba bean, field pea, lentil and field pea, but is symptomless on lucerne, its main summer host.

Different aphid species have different temperature optima, but generally mild weather favours aphid multiplication. Aphids can multiply very fast and host plant population can become rapidly overcrowded, particularly if the host plants are still in an early stage of development (as with naturalised pasture legumes during late summer-early autumn). Overcrowding or deterioration of the host plant will trigger the development of winged aphids who can, largely through wind currents, migrate over long distances. Large peaks in movements of winged aphids can be observed during autumn and can be harmful for early sown crops like faba bean and lupins. Aphid activity generally slows down during winter but picks up again with rising temperatures and major aphid flights can be again observed in spring. Later-sown pulse crops like chickpeas generally escape the autumn aphid flights but are vulnerable to the spring flights.

Faba bean viruses in northern NSW

Within Australia 12 viruses have been reported to infect faba bean, but not more than five have caused serious yield reductions in the past (Table 1). Surveys in northern NSW over the last two decades identified *Bean leafroll virus* (BLRV) as the most important faba bean virus. Severe symptoms, like stunting and plant death, were found after infection by BLRV and (less frequently) by the closely related *Soybean dwarf virus* (SbDV). Heavy yield losses by BLRV were recorded in the early 2000's on the highly susceptible cultivar Fiord, particularly in paddocks close to lucerne, the major BLRV summer host. Germplasm screening for resistance was successful in identifying good sources of BLRV resistance, which were used in the breeding program to develop varieties with improved resistance.

In 2004 and 2005 high incidences of the thrips transmitted *Tomato spotted wilt virus* (TSWV) were found in faba bean paddocks north of Moree. The sudden occurrence of TSWV was likely a result of the recent incursion of the western flower thrips (*Frankliniella occidentalis*), a highly effective vector. TSWV has a very wide host range and is lethal on faba bean. However, although infections of up to 10% were found in some crops, infected plants remained randomly scattered through paddocks and, surprisingly, no secondary spread could be noticed. TSWV was rarely found in more recent surveys.

Other viruses that can cause plant death, but only occur sporadically, are *Sub clover stunt virus* (SCSV) and *Clover yellow vein virus* (CYVV).

Table 1. Faba bean viruses in Australia (in alphabetical order)

Virus	Abr.	Transmission	Major vectors	Seed transmission[1]	Occurrence in NSW faba bean crops	Impact on plants
Alfalfa mosaic	AMV	non-persistent	many aphid species	medics, lucerne, lupin	low incidences every year	moderate
Bean leafroll	BLRV	persistent	pea, cowpea aphid	no	very high occasionally	high
Bean yellow mosaic	BYMV	non-persistent	many aphid species	medics, sub clover, (faba bean)	high incidences regularly, normally at end of season	high after early infection
Broad bean wilt	BBWV	non-persistent	green peach aphid and others	no	very rare	high
Cucumber mosaic	CMV	non-persistent	many aphid species	lupin, lentil	very rare	low
Clover yellow vein	CYVV	non-persistent	cowpea aphid	no	rare	high
Pea seed-borne mosaic	PSbMV	non-persistent	many aphid species	field pea, (lentil)	rare	low
Phasey bean mild yellows	PBMYV	persistent	cowpea aphid	no	?	?
Sub clover stunt	SCSV	persistent	cowpea aphid	no	generally rare, widespread occasionally	high
Soybean dwarf	SbDV	persistent	pea aphid and others	no	low incidences regularly	high
Turnip yellows[2]	TuYV	persistent	green peach aphid	no	high incidences regularly at end of the season	moderate
Tomato spotted wilt	TSWV	persistent	Western flower thrips and other thrips	no	occasionally low incidences	high

[1] Seed transmission of host species listed between brackets is reported, but unlikely to be of significance

[2] TuYV was previously known as *Beet western yellows virus* (BWYV)

While survey results indicated that BLRV was the most important virus because of its impact on yield, BYMV was always the most frequently identified virus throughout northern NSW. Generally, infections appeared late in the season and symptoms consisted only of a relatively mild mosaic in the top leaves above the pod setting nodes and no serious impact on yield was noticeable in commercial crops. However, yield loss trials comparing BYMV inoculated with non-inoculated plots (using mechanical inoculation at the 3-4 leaf stage) demonstrated that early infections could have a major impact on yield with over 50% yield reduction on PBA Warda⑪ and PBA Nasma⑪ (the two most common varieties in northern NSW) and close to 70% yield reduction on the highly susceptible southern variety Fiesta VF. Large numbers of breeding lines and germplasm accessions were evaluated in BYMV inoculated screening trials over the years, but no lines with high levels of resistance were identified. Unlike with BLRV, no plant death was observed in the yield loss or resistance screening trials, except for several germplasm accessions from Ecuadorian origin that showed hyper-sensitive reactions.

The 2020 faba bean virus epidemic in northern NSW

By early June 2020 serious symptoms in early sown faba bean crops were reported in several sites in northern NSW. Patches of necrotic and stunted plants in the affected paddocks resembled severe early infections by BLRV, SCSV or TSWV seen in earlier years. However, testing of symptomatic plants by Tissue Blot Immunoassay (TBIA) at the Tamworth Agricultural Institute (TAI) and by molecular tests at the QDAF virology laboratory in Brisbane (Dr Murray Sharman) showed the main virus to be BYMV, with co-infection by AMV in some paddocks (Table 2).

Table 2. Presence of three major faba bean viruses and one virus group in collected and submitted faba bean samples, northern NSW, 2020 [1]

Symptom type	Tested plants	% positive plants as determined by TBIA			
		BYMV	AMV	BLRV	Luteovirus[2]
Randomly collected	359	44.3	13.1	1.1	7.5
No symptoms	407	49.9	6.4	0.2	2.0
Not specified virus symptoms	279	58.4	15.4	2.5	9.0
Plant necrosis	329	81.8	26.4	0.3	2.4
Plant stunting	194	66.0	5.2	12.9	7.2
Leaf mosaic	234	88.9	11.5	0.0	3.8
Total plants tested	1802	62.7	13.3	2.1	5.0

[1] Minor incidences found for SCSV (7 plants out of 325 tested), CYVV (1 plant out of 991 tested) and *Cucumber mosaic virus* (CMV, 4 plants out of 682 tested)
[2] Luteoviruses other than BLRV

The early infections followed high populations of migrating aphids observed on aphid traps during autumn 2020 (Figure 1). The main aphid species found on the traps was cowpea aphid (*Aphis craccivora*), but other aphid species known to colonise pulse species were also found in high numbers: pea aphid (*Acyrthosiphon pisum*), blue-green aphid (*Acyrthosiphon pisum*) and green-peach aphid (*Myzus persicae*). Cowpea aphid is a highly effective vector of both persistently and non-persistently transmitted viruses, and - equally important - it colonises and multiplies on faba bean. Further surveys and testing during the season showed clear foci spreading from early infected plants, a pattern typical of colonising, wingless aphids.

Several agronomists expressed concern that green mirids (*Creontiades dilutes*), which were in abundance in faba bean crops during 2020, were capable of transmitting BYMV. We have undertaken two separate trials in which green mirids were left for 24 hours on BYMV infected faba bean plants in insect proof tents, before healthy faba bean plants were placed in the same tent. No

BYMV transmission from the infected to the healthy plants was observed, confirming numerous publications that only aphids can transmit this virus.

As the season progressed the virus spread through most faba bean paddocks in northern NSW, but severe symptoms generally remained restricted to early infected paddocks. Large differences in severity could be observed between paddocks that were at close distance, and paddocks close to the Queensland border and those south of Gilgandra were less affected (Figure 2). Virologists from QDAF confirmed the presence of BYMV in faba bean paddocks in Queensland, but severe symptoms were rare except for an irrigated crop near St George.

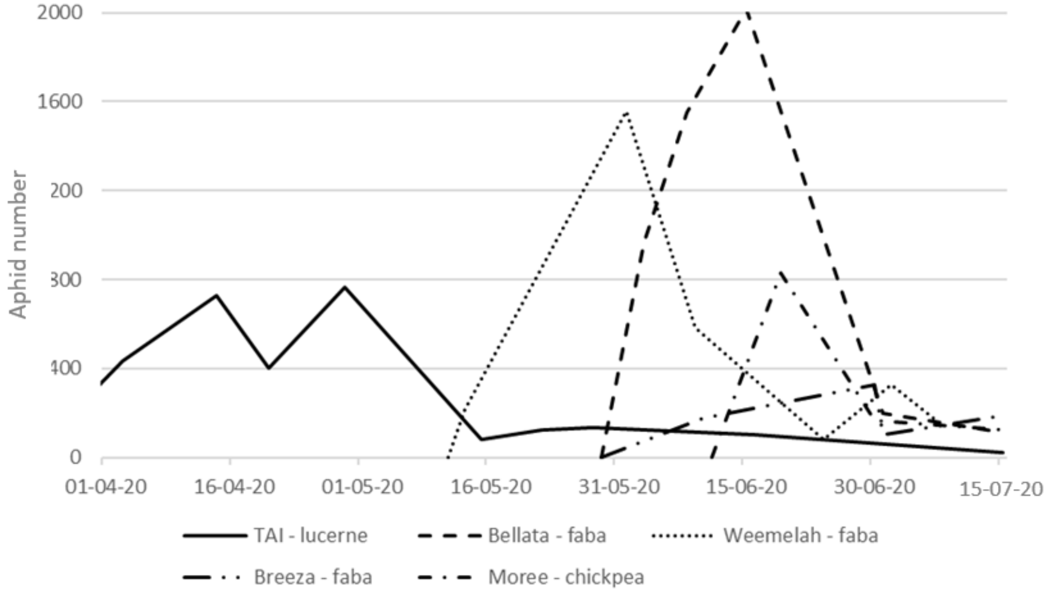

Figure 1. Aphids (number of aphids / m^2 yellow sticky trap / day) caught on yellow sticky traps in 5 sites in northern NSW, Autumn 2020

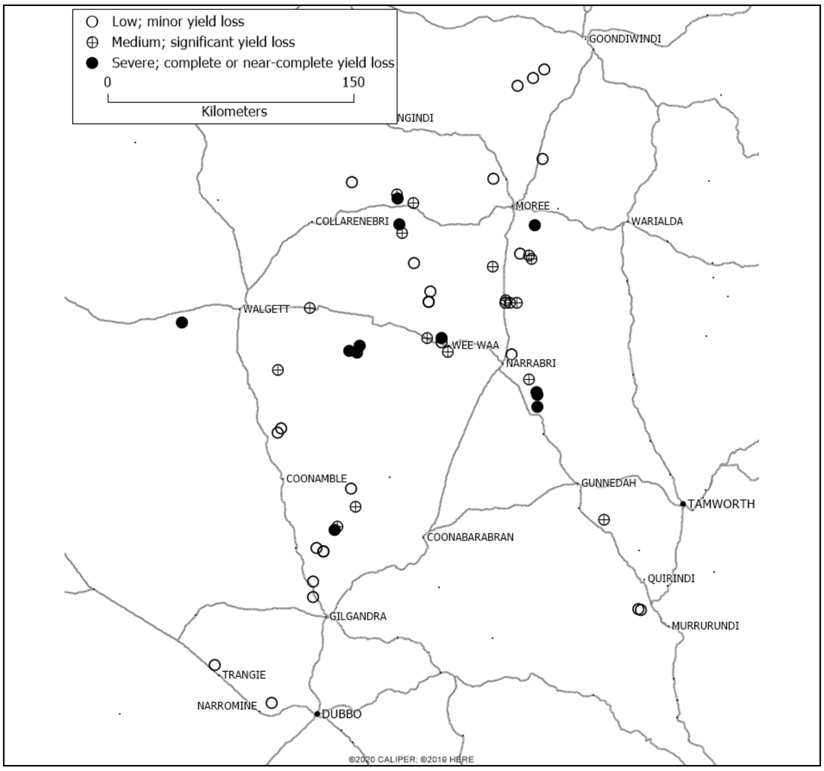

Figure 2. Severity of virus infections in 55 faba bean paddocks Northern NSW, 2020

The very high early aphid numbers and severe virus in north-western NSW points to a possible role of naturalised pasture legumes in the epidemiology of pulse viruses: After two very dry years, the January - February rains in the north-western part of the state would have triggered the emergence of large areas of medics and other potential virus hosts. Mild temperatures promoted a fast multiplication of aphids and when aphid populations on the medics became too crowded, winged aphids would have moved to newly emerged faba bean crops. BYMV (and AMV) are both transmitted in medic seed, so even with low seed transmission rates enough aphids could have picked up inoculum to establish infection foci in faba bean crops. Continuing mild temperatures during the start of the season allowed multiplication of aphids in the faba bean crops and spread of the virus from the initial infection foci. The preceding drought also had indirect effects on the high level of virus infections: Aphids tend to avoid crops sown in standing cereal stubble and with less cereal crops grown in 2019, more faba bean crops were sown into bare ground. Also, faba bean seed was in short supply and some seed used was rather old and less vigorous.

While the unusual severity of BYMV infection during 2020 was likely a direct result of very early infections and, in some cases, co-infection by AMV, it is also possible that more virulent BYMV strains were present. BYMV is known to be variable in pathogenicity and host species specificity. We have isolated a large number of strains this year and are in the process of evaluating these using pathogenicity testing and molecular tools.

Viruses in crops other than faba bean

Virus symptoms were observed in several chickpea crops in the Moree-Narrabri region that were bordering faba bean paddocks. The level of infection was high close to the border but diminished rapidly further from the faba bean crop. Testing of virus symptomatic plants showed that while the faba bean paddocks had high BYMV and minor AMV infection levels, symptomatic chickpeas were only infected by AMV. BYMV is reported to be capable of infecting chickpeas, but in our greenhouse tests chickpeas reacted as immune to the majority of BYMV strains isolated from faba bean.

Random samples taken from chickpea paddocks by Dr Kevin Moore as part of his yearly disease survey (Table 3), showed that the later sown chickpea crops generally escaped the aphid autumn flights. The absence of virus spread in chickpea paddocks also demonstrated that aphids rarely colonise chickpeas and infection is generally caused by incoming, winged aphids.

Table 3. Presence of four major pulse viruses and one virus group in collected and submitted samples of pulses (other than faba bean), NSW, 2020.

Species	Tested plants	% positive plants as determined by TBIA				
		BYMV	AMV	BLRV	Luteovirus[1)]	CMV
Chickpeas	1,329	0.0	5.5	0.3	1.1	1.1
Lentils	1,161	0.2	12.7	2.7	0.3	34.6
Lupins	227	1.3	28.6	0.9	0.0	90.3

[1] Luteoviruses other than BLRV

Both lupins and lentils are, unlike chickpeas, crops colonised by several aphid species and highly vulnerable to infection by a range of viruses. CMV caused severe symptoms in narrow-leafed lupin crops in the Gilgandra region with co-infection by AMV aggravating losses in several paddocks. CMV can be seed-transmitted in narrow-leafed lupins at high rates and testing of several seed lots that were used for the 2020 sowing showed dangerously high CMV levels. Narrow-leafed lupins in NSW are generally used as stockfeed on farm and most growers multiply their own seed stock for several years. While virus infections might remain unnoticed in most years, seed infection levels can build up slowly and cause a severe virus epidemic in an aphid favourable season like 2020.

Lentils are still an experimental crop in most of NSW, but the high levels of CMV and other viruses in lentil samples taken from trial sites (Table 3) showed that viruses may become a major factor limiting the expansion of lentils.

Virus control strategies

Virus control strategies will differ between crops and virus species, but all are aimed at avoiding infection as curative control of viruses is not possible.

Minimising numbers of incoming virus vectors

The most effective strategy currently is to minimise virus infection by promoting fast canopy closure through following optimal agronomic practices and use of high quality seed with good seedling vigour. Migrating aphids prefer landing in crops that show uneven emergence and bare ground, while sowing in standing stubble deters aphid landings. Early sowing increases the risk of virus infection as crops are exposed to the autumn aphid flights when plants are small and most vulnerable to virus infection. However, later sowing is often not a practical option for growers.

Virus-free seed

Several non-persistently transmitted viruses can be seed-borne in pulses. Sowing virus-infected seed will result in infection foci scattered randomly throughout a crop right after crop emergence and a rapid spread of the virus. Fortunately, for most virus / pulse host combinations, the levels of seed transmission are very low and, while still very important for quarantine, not of concern in commercial crops. The exceptions are CMV in narrow-leafed lupins and lentils and *Pea seed-borne mosaic virus* (PSbMV) in field peas. Growers who keep their own seed should have it tested and only use virus-free seed.

BYMV can be seed-transmitted in faba bean, but so far we haven't found any evidence of its presence in commercial or farmers' seed lots. However, new virus strains can develop that have a better ability to be seed transmitted, so our testing program is continuing.

Avoiding inoculum sources

Unlike most fungal pathogens, viruses don't survive in stubble or soil. Apart from those that are seed-transmitted all will be brought into the crop by vectors from outside sources. It is advisable to keep distance from known sources of infection like lucerne. Weed and volunteer legume crops within or near crops are also key virus sources and should be controlled before the crop emerges.

Chemical control of vectors

The effectiveness of aphicides to control virus infection differs between viruses. Viruses that are persistently transmitted, like BLRV or TuYV, require a relatively long feeding period and a seed treatment with a systemic insecticide can provide protection during early growth when plants are most vulnerable. Non-persistently transmitted viruses, like BYMV, CMV or AMV, only require a brief probing to transmit virus and the insecticides used for seed treatment act too slowly to prevent infection.

Imidacloprid is registered as a seed treatment for early aphid control on faba bean, field pea and lentils. The seed treatment will not stop initial BYMV infections from migrating aphids, but it could possibly delay the build-up of colonising aphids in a crop and thereby limit virus spread. Greenhouse trials in 2020 confirmed that imidacloprid seed treatment reduced the multiplication of cowpea and pea aphid numbers on faba bean, but it took more than one day to kill aphids. Field research is needed to determine how long an imidacloprid seed treatment remains effective and whether it will be more useful than a well-timed foliar aphicide application.

Resistance

Genetic resistance can be a very economical and environmentally friendly option for virus control. Over the years good resistance has been identified for several pulse / virus combinations and subsequently used in Australian pulse breeding programs.

Unfortunately, the search for high levels of BYMV resistance in faba bean has not been successful so far. There are differences among Australian faba bean varieties in symptom expression with some of the older varieties and lines developed for the southern region reacting as 'very susceptible'. There were no indications that the current northern region varieties differed in their BYMV reaction during the 2020 epidemic, but a few breeding lines yielded well in different sites under severe BYMV pressure. These lines will be tested during the 2021 season in inoculated trials.

All narrow-leafed lupin varieties are CMV susceptible, but a number of varieties are moderately resistant to CMV seed infection. While these varieties are still susceptible to CMV by aphid transmission, the build-up of inoculum in seed stock will be slower and the risk on CMV induced losses during virus favourable seasons will be lower.

References

There is a wealth of information on pulse viruses published on the internet by the agricultural departments of Western Australia (https://www.agric.wa.gov.au/), Queensland (https://www.daf.qld.gov.au/), Victoria (https://agriculture.vic.gov.au/) and New South Wales (https://www.dpi.nsw.gov.au/).

For more detailed information:

Makkouk KM, Kumari SG, van Leur JAG, Jones RAC (2014). Control of plant virus diseases in cool-season grain legume crops. Advances in Virus Research 90: 207-253.

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Panel discussion – agronomic strategies to optimise pulse productivity in 2021

Leigh Jenkins[1] & Garry Lane[2]

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Key words

pulse, agronomy, management, harvest, storage, marketing

Take home message

PLANNING is the key for successful and profitable pulse crops!

- plan now for 2021 production of pulse crops
- plan now for storage of harvested grain to suit marketing options
- know your marketing strategy now, before you even plant the crop.

Please bring your questions to the panel discussion. The following are just some of the topics we think are important to optimise pulse productivity in 2021.

Key agronomic/production strategies

- Paddock selection to suit pulse crop type – soil type & pH, previous crop rotation history, and was there a pulse crop right next door to that paddock in 2020 (disease risk?)
- Consider paddock history in terms of potential chemical residues either tied up in stubble or in the soil, particularly residual herbicides from Group I, Group C or any Group B products
- Also, consider paddock history in terms of weed control in 2021 – broadleaf herbicide options can be limited; and you may think grasses are easy to control in pulse crops but what if there is a herbicide resistance issue?
- Source high quality seed and have it tested for germination, vigour and disease levels; be particularly mindful of virus-infected seed from the 2020 crop for faba bean, narrow-leaf lupin and lentils
- Variety choice – don't just consider yield – think also about disease resistance, maturity to suit your environment, and quality of product for human consumption market premiums
- Sow on time for each pulse crop type – know the optimum sowing window in your district and be ready to sow as early as possible in that window
- All pulse seed should be inoculated with the right inoculant (no excuses, no sob stories!) – what is the best method on your farm to maximise survival of rhizobia so it works?
- In 2021 after a great season in 2020 – plan now for potential mice or locust plagues at sowing time in autumn and insect pressure in spring
- Hopefully 2021 will be as rainfall-reliant as 2020 – so plan now to have enough fungicide in stock (on farm) for foliar disease management, particularly for faba bean, chickpea and lentil crops
- Don't throw away all your hard work at harvest – harvest at the right time (when the crop is ready) to maximise seed quality and marketing potential; plan now to determine if you have the right gear and time available, or would finding a contract-harvester be better?

Harvest management strategies

- Desiccation/crop topping:
    - Can even up the crop for quicker harvest
    - Use only registered products
    - Ensure application timing meets label requirements for pre-harvest with-holding periods and Minimum Residue Limits.
- Harvest as soon as crop is ready to avoid:
    - Losses in field (wind, rain, hail)
    - Broken grain from being too dry
    - Quality downgrade due to rain
    - Losses at header front.
- Correct header set up:
    - Know the delivery specifications for the target market.

Storage strategies

- Know where your grain is going to be delivered as harvested
    - On-farm (aeration, insect control, running sample?)
    - Warehouse
    - End user or packer.
- Minimise the number of times you handle all pulses
- What is my backup plan if grain quality is compromised?
- Be mind-full of grain contaminants, stones, soil, faeces (most pulse products are going to human consumption markets)

Marketing strategies

- Pulses take patience to execute better prices - don't be a forced seller
- Understand market cycles and competitor supply cycles
- Liquidity:
    - What are your cash flow needs?
    - Can buyers take them when you want to deliver or sell?
- Buyer reliability:
    - Do they have good reputation?
    - Do they pay on time?
    - Are they helpful during the growing season?
    - Potential for overseas government interference in your target market?

Recommended references & website links

NSW DPI: Winter crop variety sowing guide:
available online at: https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/winter-crop-variety-sowing-guide
(note this publication contains multiple links to further references on specific topics for each pulse crop type, from many different organisations)

NSW DPI: Weed control in winter crops:
available online at: https://www.dpi.nsw.gov.au/agriculture/broadacre-crops/guides/publications/weed-control-winter-crops

GRDC website:
GrowNotes™ for all pulse crop types, see Northern region section at bottom of website page
https://grdc.com.au/resources-and-publications/grownotes/crop-agronomy

Pulse Australia website:
for all the latest info on pulse crops, including Growing Pulses and Marketing sections
http://www.pulseaus.com.au/

National Variety Trial (NVT) website:
including updated variety performance results, and further links to commercial variety guides
https://www.nvtonline.com.au/

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