GRAINS RESEARCH UPDATE

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Bendigo

All Seasons Bendigo,
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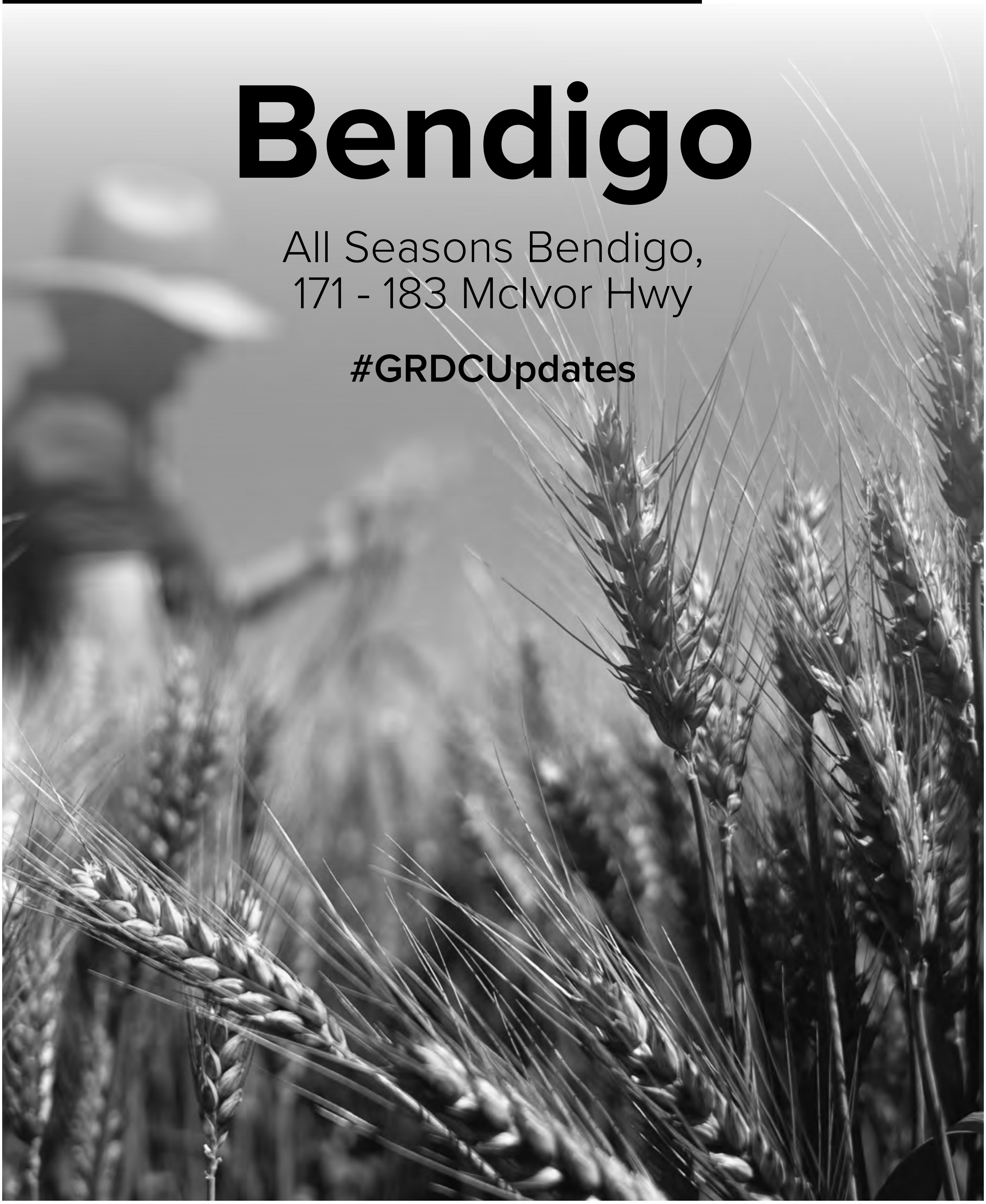
#GRDCUpdates



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Bendigo GRDC Grains Research Update convened by ORM Pty Ltd.

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GRDC Welcome

GRDC 2021 Bendigo Grains Research Update Welcome

It is sometimes said that rather than procrastinating on making the right decisions, we should instead focus on making informed and timely decisions – and own and learn from the decisions we make.

Countless decisions collectively contribute towards a sustainable and profitable grains enterprise, but have you ever found yourself asking what really drives good decision making? Our decisions are informed by numerous and often complex factors (insert psychology and behavioural sciences disclaimer here) but key to sound decision making is access to relevant information and knowledge, supported by credible, trusted advice.

At the GRDC we pride ourselves in helping to inform the key profit driving decisions confronting grain growers and their advisers through investment in world-class science. Real impact, however, does not come from excellence in research alone but requires a focus upon awareness, extension and adoption of relevant solutions that demonstrate a clear value proposition. Success is highly dependent upon proper interpretation and excellence in implementation of new knowledge, practices and technologies by people like you. The GRDC Grains Research Updates provide a platform for this journey to begin or perhaps continue.

Whilst the past year has been extremely challenging for all Australians, the grains industry has demonstrated an outstanding ability to respond and work through the circumstances that have come with a global pandemic and associated challenges to trade, travel, access to labour and farm inputs. Perhaps this should not come as a surprise based on the ongoing resilience of grain growers in dealing with the unexpected through a requirement to anticipate, plan and respond to seasonal variability and risks that have become the 'new normal'.

While COVID-19 has also necessitated some significant changes to the traditional Grains Research and Farm Business Updates series over the past year, this has brought with it opportunities to try new formats and methods of delivery. We trust that you appreciate the intent and need for these changes including constraints on attendance and a greater reliance on live streaming of presentations to ensure the information is available to all who need it regardless of personal circumstance and no matter where they are located.

Each year, the Bendigo Update presents the very latest from the world of grains research and development. And despite the limitations imposed in 2020, an abundance of new technology, insights and results has been delivered over the past 12 months to ensure growers have at their disposal additional means to make a difference in their farming systems.

Topics this year include an update on the current state of play around glyphosate resistance and tips to help optimise herbicide performance; the potential fit of new chemistries in different environments and farming systems; getting the best results from harvest weed seed control; and reversing the decline of soil nitrogen and organic matter. Other topics certain to be of interest are rules of thumb for nitrogen fertiliser use efficiency; the latest developments on blackleg infection in canola and economic benefits from foliar fungicide use; and soil amelioration practices to reduce the impact of subsoil constraints.

To ensure the RD&E investments made by the GRDC on behalf of growers answer the most pressing profitability and productivity questions from the paddock, we continue to work closely with growers, advisers, agribusiness and others to understand and respond to deliver greatest impact. Through regionally based staff, a dedicated Regional Panel and broad regional networks, we are now more closely linked and better connected to industry than ever. So, if you have concerns, questions or feedback regarding the program or more generally, please contact the Southern team directly on 08 8198 8400 or email southern@grdc.com.au.

Craig Ruchs

Senior Regional Manager South

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GRDC's podcast series features some of the grain sector's most pre-eminent researchers, growers, advisers and industry stakeholders sharing everything from the latest seasonal issues, to ground-breaking research and trial results with on-farm application.

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GRDC GROWNOTES

SPRAY APPLICATION GROWNOTES™ MANUAL

SPRAY APPLICATION MANUAL FOR GRAIN GROWERS

The Spray Application GrowNotes™ Manual is a comprehensive digital publication containing all the information a spray operator needs to know when it comes to using spray application technology.

It explains how various spraying systems and components work, along with those factors that the operator should consider to ensure the sprayer is operating to its full potential.

This new manual focuses on issues that will assist in maintaining the accuracy of the sprayer output while improving the efficiency and safety of spraying operations. It contains many useful tips for growers and spray operators and includes practical information – backed by science – on sprayer set-up, including self-propelled sprayers, new tools for determining sprayer outputs, advice for assessing spray coverage in the field, improving droplet capture by the target, drift-reducing equipment and techniques, the effects of adjuvant and nozzle type on drift potential, and surface temperature inversion research.

It comprises 23 modules accompanied by a series of videos which deliver 'how-to' advice to growers and spray operators in a visual easy-to-digest manner. Lead author and editor is Bill Gordon and other contributors include key industry players from Australia and overseas.

Spray Application GrowNotes™ Manual – go to: https://grdc.com.au/Resources/GrowNotes-technical
Also go to https://grdc.com.au/Resources/GrowNotes and check out the latest versions of the Regional Agronomy Crop GrowNotes™ titles.

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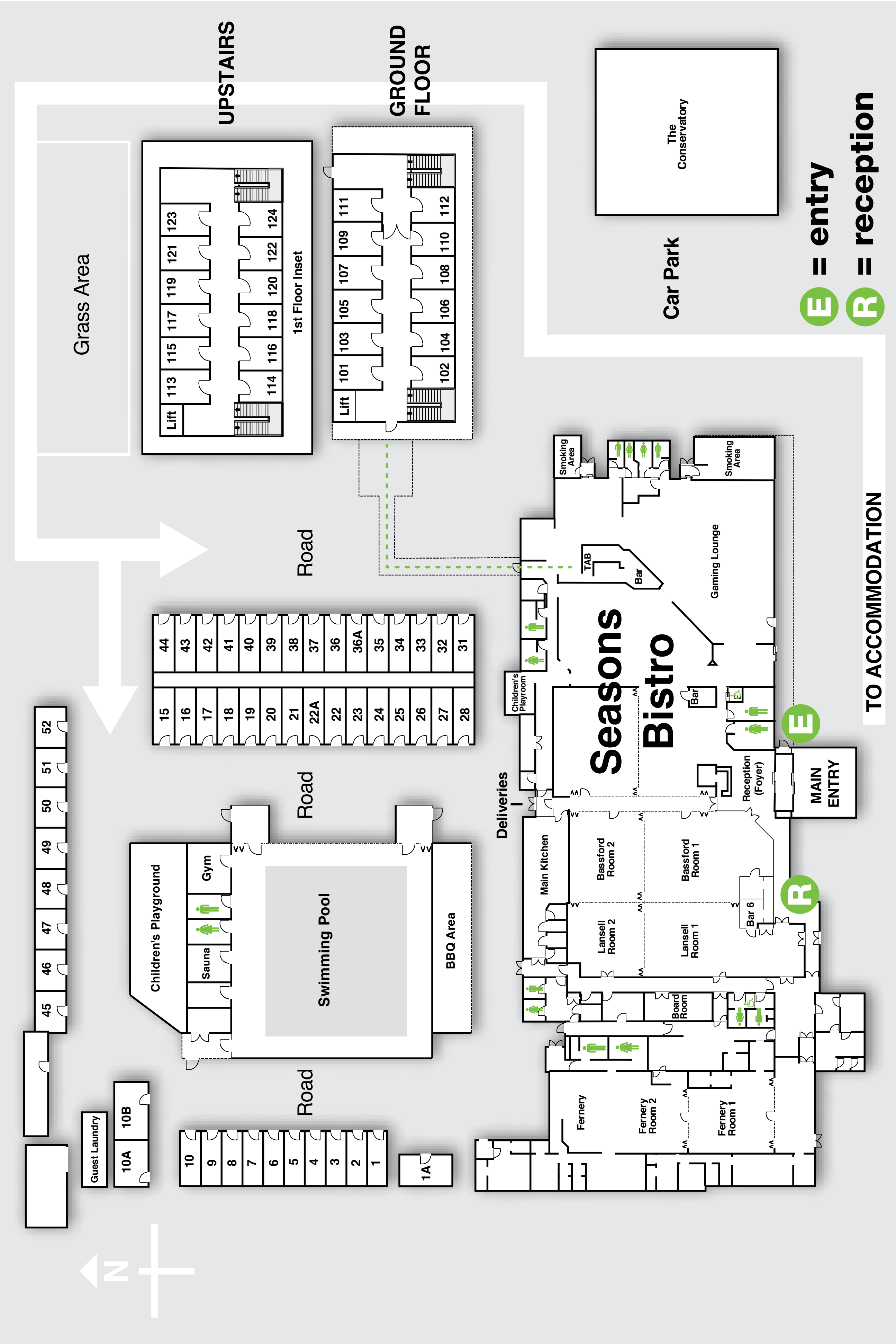
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1st Floor Inset
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The Conservatory
Car Park
E = entry
R = reception
TO ACCOMMODATION
Road
Road
Road
Smoking Area
Smoking Area
TAB
Bar
Gaming Lounge
Seasons Bistro
Bar
Children's Playroom
Reception (Foyer)
MAIN ENTRY
Deliveries
Main Kitchen
Bassford Room 2
Bassford Room 1
Lansell Room 2
Lansell Room 1
Bar 6
Board Room
Fernery
Fernery Room 2
Fernery Room 1
Children's Playground
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GRDC Grains Research Update
BENDIGO

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PROGRAM DAY 1 - FEBRUARY 24th

Day 1 Agronomist Commentary Panel

Bec Marshall, *Grower and Consultant (LRZ);* ***Matthew Sparke,*** *SparkeAG (MRZ)*
and ***Craig Drum,*** *Dagro (HRZ)*

Note: Each topic session will include 15 mins dedicated to questions and interaction with the Agronomist Commentary Panel.

8.55 am	**Welcome**	***GRDC representative***
9.10 am	**Current market drivers and opportunities for Australian grain**	***Pat O'Shannassy,*** *Grain Trade Australia*
9.55 am	**Glyphosate resistance – state of play and optimising chemical performance**	***Peter Boutsalis,*** *Plant Science Consulting*
10.35 am	**MORNING TEA**	
11.05 am	**Key tips on fitting the new chemistries into the farming system**	***Chris Preston,*** *The University of Adelaide*
11.50 am	**Getting the best results from harvest weed seed control**	***Chris Davey,*** *WeedSmart*
12.35 pm	**Addressing the decline of soil nitrogen and organic matter**	***Mark Farrell,*** *CSIRO*
1.15 pm	**LUNCH**	
2.05 pm	**Nitrogen fertiliser use efficiency rules of thumb put to the test**	***Roger Armstrong,*** *Agriculture Victoria*
2.50 pm	**Hyper Yielding Crops Focus Farms – achieving the big yields**	***Jon Midwood,*** *TechCrop Services*
3.35 pm	**Key take homes from pest infestations in 2020**	***Paul Umina,*** *cesar*
4.15 pm	**Complimentary drinks and food in trade display area**	

PROGRAM DAY 2 - FEBRUARY 25th

Day 2 Agronomist Commentary Panel

Brad Bennett, *Agrivision (LRZ);* ***Greg Toomey,*** *Nutrien Ag Solutions (MRZ) and* ***Annieka Paridaen,*** *Premier Ag Consultancy Group (HRZ)*

Note: Each topic session will include 15 mins dedicated to questions and interaction with the Agronomist Commentary Panel.

8.55 am	**Welcome**	***GRDC representative***
9.10 am	**Cereal disease wrap up**	***Grant Hollaway & Mark McLean,*** *Agriculture Victoria*
9.55 am	**Blackleg infection of canola – latest developments and yield impacts from foliar fungicide**	***Steve Marcroft,*** *Marcroft Grains Pathology*
10.35 am	**MORNING TEA**	
11.05 am	**Soil amelioration practices to alleviate subsoil constraints**	***Roger Armstrong,*** *Agriculture Victoria*
11.50 am	**Faba bean agronomy update**	***Jason Brand,*** *Agriculture Victoria &* ***James Manson,*** *SFS*
12.35 pm	**Pulse disease update**	***Josh Fanning,*** *Agriculture Victoria*
1.15 pm	**LUNCH**	
2.05 pm	**Measuring the impact of inoculation with a new rhizobia testing tool**	***Ross Ballard,*** *SARDI*
2.50 pm	**Maximising the benefits of growing vetch in our farming systems**	***Stuart Nagel,*** *SARDI*
3.35 pm	**Know the 'new lingo' – new classification and scoring of cereal crop development**	***James Hunt,*** *La Trobe University*
4.15 pm	**CLOSE**	

LOOK AROUND YOU.

1 in 5 people in rural Australia are currently experiencing mental health issues.

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The GRDC supports the mental wellbeing of Australian grain growers and their communities. Are you ok? If you or someone you know is experiencing mental health issues call *beyondblue* or Lifeline for 24/7 crisis support.

beyondblue
1300 22 46 36
www.beyondblue.org.au

beyondblue
Depression. Anxiety.

Lifeline
13 11 14
www.lifeline.org.au

Lifeline
13 11 14

Looking for information on mental wellbeing? Information and support resources are available through:

www.ifarmwell.com.au An online toolkit specifically tailored to help growers cope with challenges, particularly things beyond their control (such as weather), and get the most out of every day.

www.blackdoginstitute.org.au The Black Dog Institute is a medical research institute that focuses on the identification, prevention and treatment of mental illness. Its website aims to lead you through the logical steps in seeking help for mood disorders, such as depression and bipolar disorder, and to provide you with information, resources and assessment tools.

www.crrmh.com.au The Centre for Rural & Remote Mental Health (CRRMH) provides leadership in rural and remote mental-health research, working closely with rural communities and partners to provide evidence-based service design, delivery and education.

Glove Box Guide to Mental Health

The *Glove Box Guide to Mental Health* includes stories, tips, and information about services to help connect rural communities and encourage conversations about mental health. Available online from CRRMH.

www.rrmh.com.au Rural & Remote Mental Health run workshops and training through its Rural Minds program, which is designed to raise mental health awareness and confidence, grow understanding and ensure information is embedded into agricultural and farming communities.

www.cores.org.au CORES™ (Community Response to Eliminating Suicide) is a community-based program that educates members of a local community on how to intervene when they encounter a person they believe may be suicidal.

www.headsup.org.au Heads Up is all about giving individuals and businesses tools to create more mentally healthy workplaces. Heads Up provides a wide range of resources, information and advice for individuals and organisations – designed to offer simple, practical and, importantly, achievable guidance. You can also create an action plan that is tailored for your business.

www.farmerhealth.org.au The National Centre for Farmer Health provides leadership to improve the health, wellbeing and safety of farm workers, their families and communities across Australia and serves to increase knowledge transfer between farmers, medical professionals, academics and students.

www.ruralhealth.org.au The National Rural Health Alliance produces a range of communication materials, including fact sheets and infographics, media releases and its flagship magazine *Partyline*.

ifarmwell growing farmers' wellbeing | Black Dog Institute | Centre for Rural & Remote Mental Health | CORES™
Rural & Remote Mental Health | Heads up Better mental health in the workplace | National Centre for Farmer Health | National Rural Health Alliance Ltd

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Day 1

In the wake of the China barley tariffs

Pat O'Shannassy.

Grain Trade Australia.

Keywords

- barley, China, exports, Grain Trade Australia, anti-dumping, supply chain..

Take home messages

- China's 80% tariffs on Australian barley exports stops an annual trade flow worth $A1.2 billion.
- Prior to the tariffs, China was Australia's largest destination market for barley exports accounting for around 58% of Australian barley exports.
- Estimated cost to industry is $2.5 billion over the initial five-year period of the tariffs.
- There has been significant work to build demand for lost barley exports, including focus on farm returns, other grains and modernising the grain supply chain.
- In developing policy to improve the position of the Australian agricultural industry, trade is just one, albeit important, policy consideration. Other factors, such as the supply chain, should also be considered in order to improve competitiveness and extract economic value.

Grain Trade Australia (GTA)

Grain Trade Australia (GTA) is a national association and is the focal point for the commercial grains industry within Australia. Grain Trade Australia provides an industry driven self-regulatory framework across the grains industry to facilitate and promote the trade of grain. This framework consists of Trading Standards, Standard Form Contracts, Trade Rules, Arbitration and Dispute Resolution, Professional Development and international and domestic advocacy for Market Access.

Grain Trade Australia members are responsible for over 95% of all grain storage and freight movements made each year in Australia. The overwhelming majority of grain contracts executed in Australia each year refer to GTA Grain Trading Standards and/or Trade Rules.

Grain Trade Australia provides industry stewardship through its specialist industry codes, including:

1. Australian Grains Industry Code of Practice,
2. Grain Transport Code of Practice, and
3. Technical Guideline Documents.

These codes outline the base practices expected in the Australian grains industry supply chain and are critical to ensuring confidence of governments, regulators and consumers of the quality assurance systems and processes in place in the supply chain. The Australian Grains Industry Code of Practice is critical for our grain exports and is endorsed by the Australian Government Department of Agriculture. Australia is the only major grain exporting country that has an industry Code of Practice.

Grain Trade Australia members are drawn from all sectors of the grain value chain from production to domestic end users and exporters. Grain Trade Australia has over 270 organisations as members. Their businesses range from regional family businesses to large national and international trading/storage and handling companies who are involved in grain trading activities, grain storage, processing grain for human consumption and stock feed milling.

Australian barley production

Australian grain is produced in a belt along the east coast of Australia (including the states of Queensland (Qld), New South Wales (NSW) and

Victoria (Vic)), South Australia (SA) and Western Australia (WA). The Australian grain market tends to operate in three distinct regions, with additional variances dependent on the Port Zone within each region. Domestic consumption for grain is concentrated on the East Coast states. Exporting is the dominant market pathway in SA and WA, as they account for around 50-60% of barley production. This means the major states for exports of both feed and malting quality barley to China are SA and WA.

Australia's position in the global barley market

Australia is a small global producer. As a net exporter and consequently a price taker, Australian barley prices are dominated by global markets, which have a high level of competition from other major exporters including the countries listed in Figure 4.

The five-year average global production of barley is around 144 million metric tonnes (mmt). Europe Union (EU) is the largest producer with around 60mmt, with Australia on average being the third largest producer of barley at around 9.5mmt. Global exports of barley are around 28.7mmt with Australia being the second largest global exporter of barley with around 6.2mmt behind the EU with 7.4mmt.

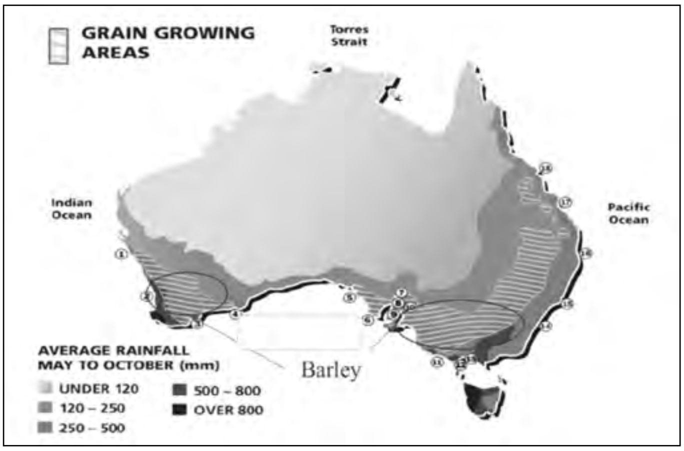

Figure 1. Australian barley production regions. (Source: AEGIC).

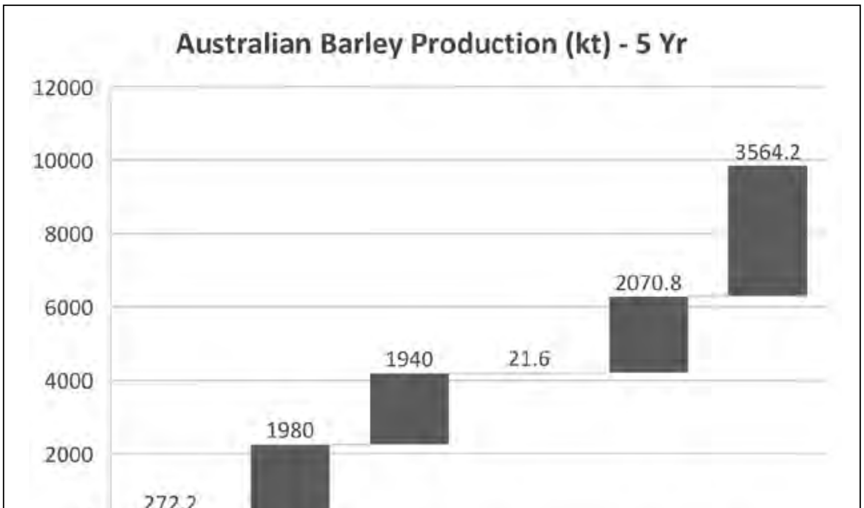

Figure 2. Australian barley production by state. (Source: ABARES).

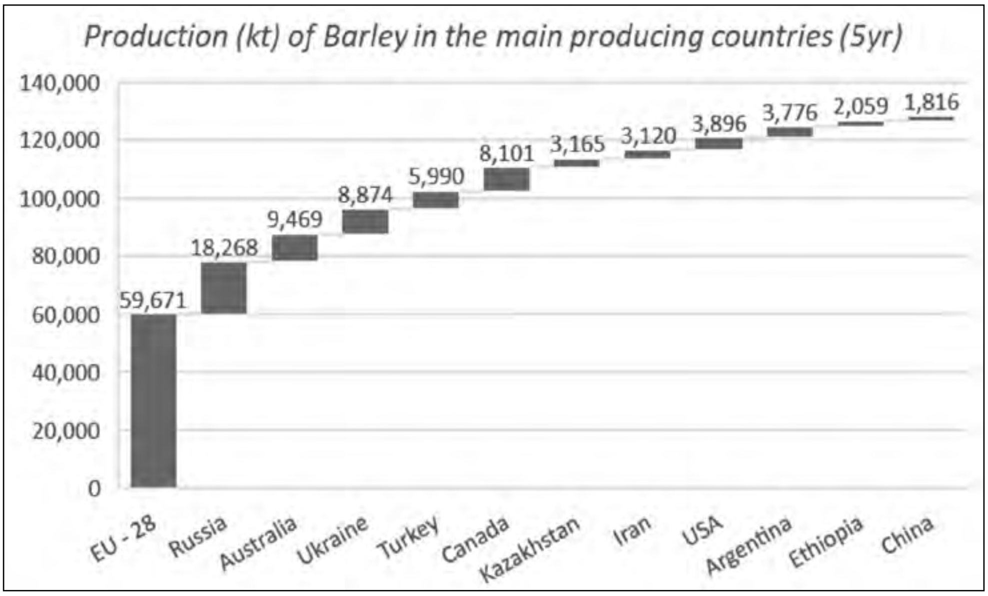

Figure 3. Global production of barley. (Source: USDA).

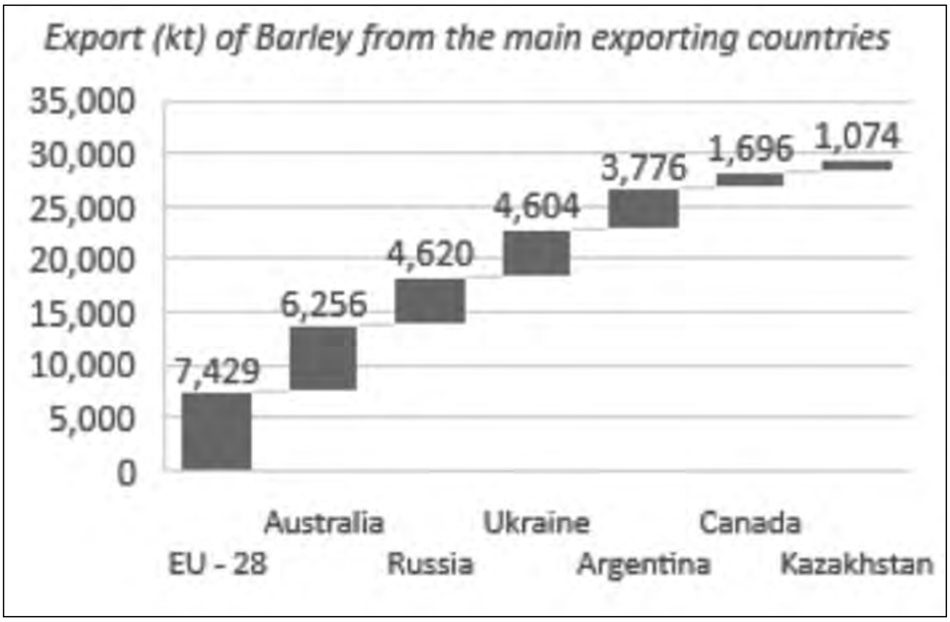

Figure 4. Global exports of barley. (Source: USDA).

Around 70% of Australian barley production is exported, and the remainder is consumed domestically mainly for malting and animal feed purposes. The five-year average of Australia's barley exports to China is around 3.8mmt of which 1.7mmt is of malting quality and around 2.1mmt of feed quality. Other important export markets for Australian barley include Saudi Arabia, Japan and United Arab Emirates (UAE). The product specifications for each of these markets can vary.

Background to the issue and impact

On 19 May 2020, the Chinese government imposed anti-dumping (AD) duties of 73.6% and countervailing duties (CVD) of 6.9% on all barley imports originating in Australia for five years.

Australian grain industry organisations, exporters and Australian Government made substantial submissions to demonstrate the findings of the AD and CVD cases had no basis in fact.

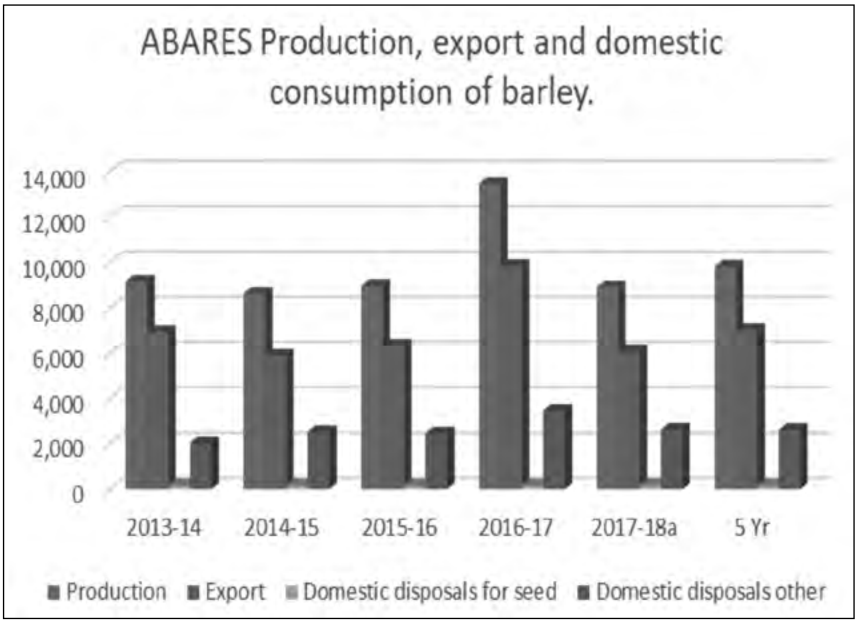

Figure 5. Australian supply and demand for barley. (Source: ABARES).

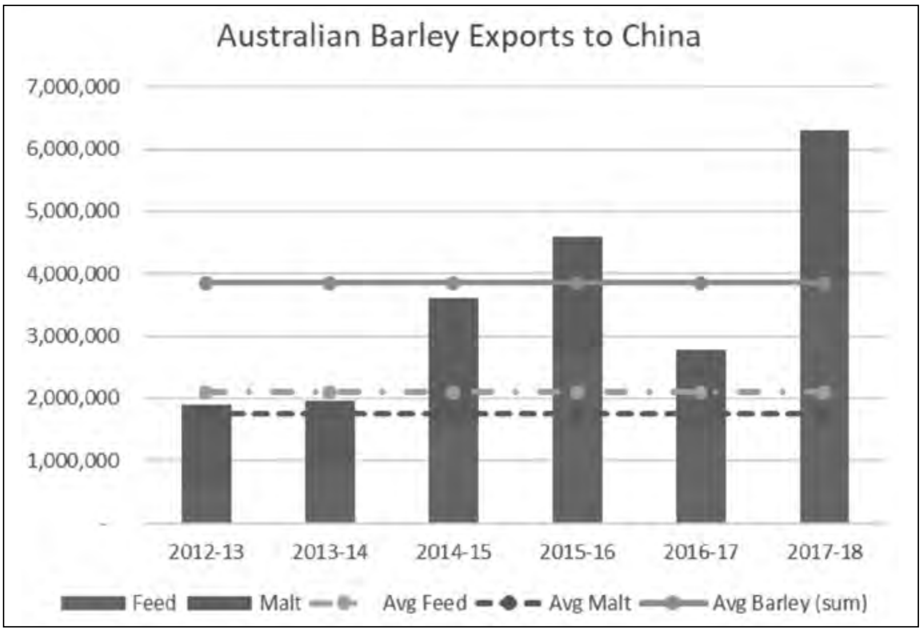

Figure 6. Australian barley exports to China. (Source: ABS).

The cost to Australian barley industry and producers is significant, estimated to be at least $2.5 billion over the initial five-year period of the tariffs (i.e., $500m per annum). This will have an impact on rural and regional communities.

Australian grain exports to China have grown since 2011-12, largely due to growth in barley exports, with a peak of around $A2.5 billion (free on board (FOB) of exports in 2014-15 and a five-year average of $A1.9 billion (FOB). The five-year average for exports is approximately 4.9mmt, of which around 65% is barley, 23% wheat, 7% sorghum and 5% canola. China's portion of Australian grain exports has grown to around 20-25% of all grain exports, however this is expected to decline by around 7% of all Australian exports (a five-year average of around $A1.4 billion per annum), due to the trade inhibiting tariffs on Australian barley exports.

With no barley exports, analysis of historic shipments suggests that wheat will be the dominant commodity exported to China of around 1.4mmt per annum, which will comprise around 67% of the significantly reduced Australian grain exports to China. Australia has a long and established milling wheat trade with China.

In December 2020, the Australian Government advised China it would be seeking to address the dispute through the WTO trade dispute resolution process. While this process can take considerable time, it does require the parties to engage formally in dispute resolution process, which may be constructive in the current political climate and the challenged state of the Australia/China bi-lateral relationship. The objective from an industry perspective is to ‘remove politics from the trade’.

Building demand and market priorities

There is no ‘silver bullet’ solution to replace the lost barley demand from China. The China barley market was based on the development of strong customer relationships, specific varieties marketed for certain products and the premium prices paid by customers. Alternative markets will have their own trade/technical barriers and price challenges to overcome. To restore industry value, the following factors (amongst others) will need to be considered:

- Current barley markets.
- Domestic market.
- New market opportunities.
- Alternative crop opportunities.
- Technical services.
- Improving value chain efficiency.
- Technical market access.
- Tariffs.
- Non-tariff trade measures (NTMs).

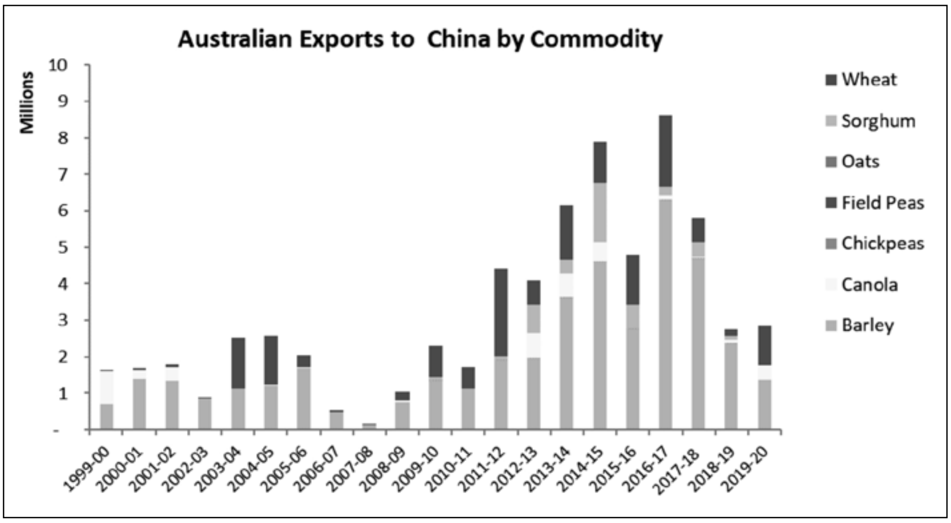

Figure 7. Australian grain exports to China. (Source: ABARES & ABS).

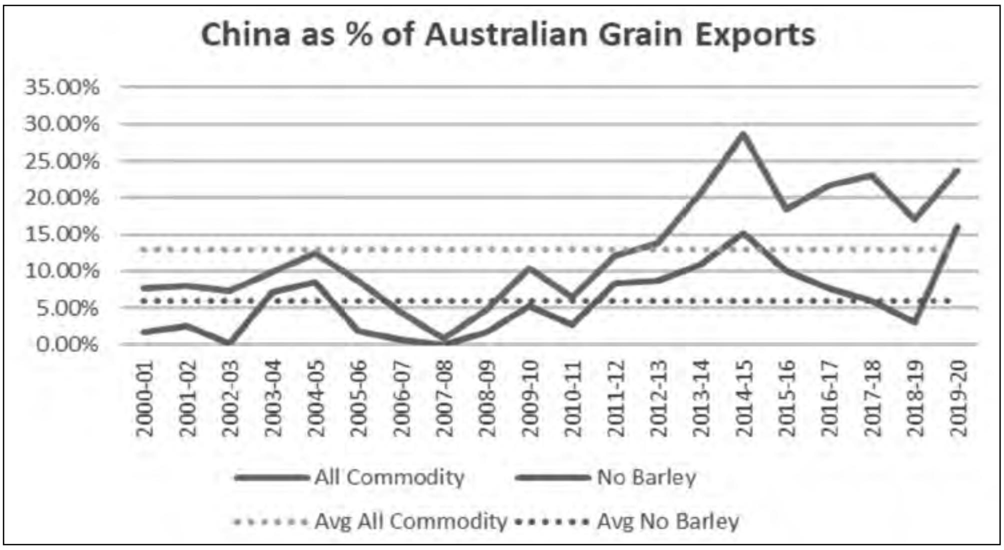

Figure 8. Percent of Australian grain exports to China. (Source: ABARES & ABS).

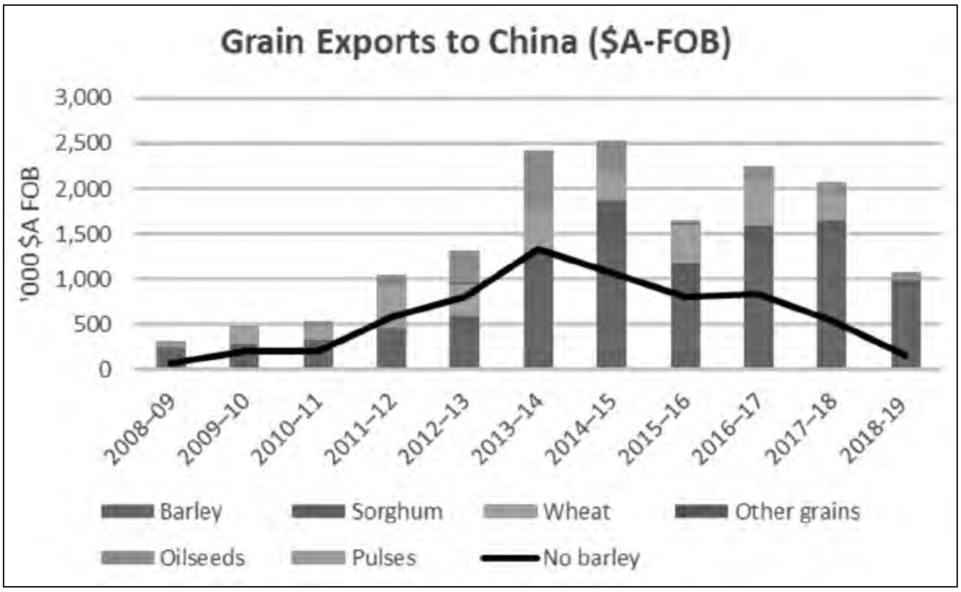

Figure 9. Grain exports to China ($A FOB). (Source: ABARES & ABS).

Demand opportunities

Figures 10 to 13 show major export destination markets, totalling the last five years, for Australian grain, noting the domestic market is the largest consumptive market for Australian grain. The graphs capture the potential markets where an expansion of volume could be a key priority. However, it should also be acknowledged that they do not necessarily present highest value or all potential growth opportunities (for example India is noted as a potential growth opportunity for barley; while Bangladesh and Myanmar are noted growth market opportunities for wheat).

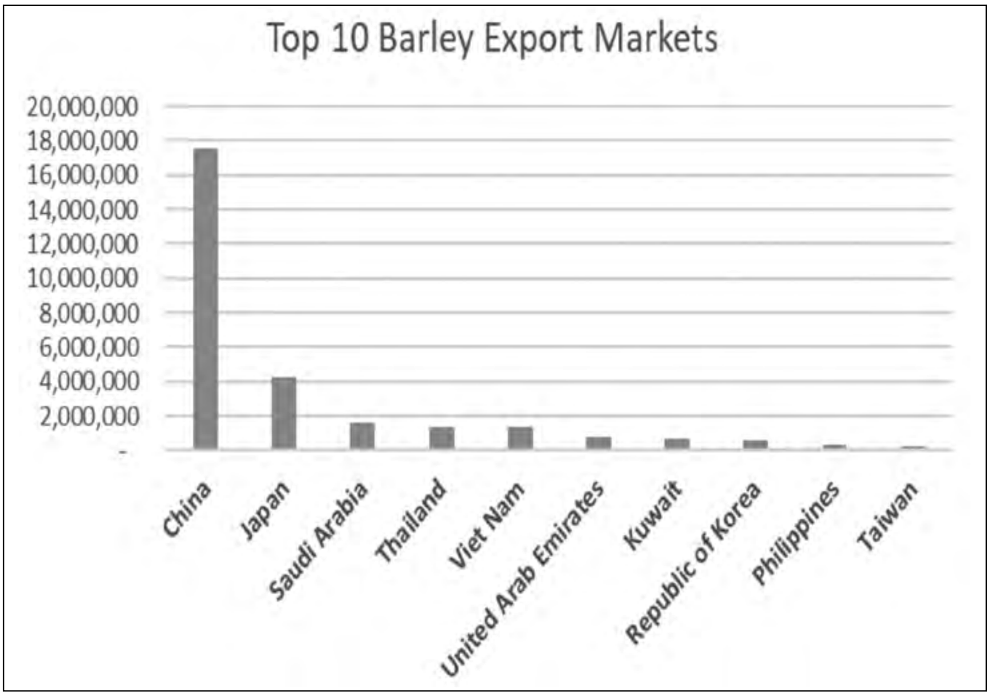

Figure 10. Top 10 barley export markets. (Source: ABS).

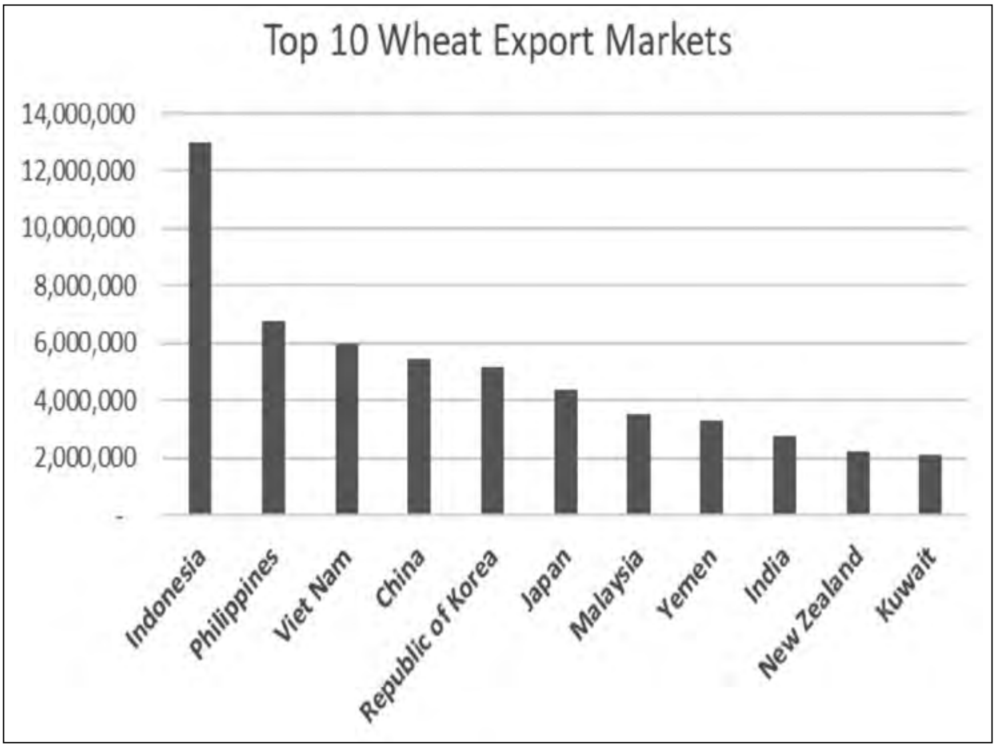

Figure 11. Top 10 wheat export markets (Source: ABS).

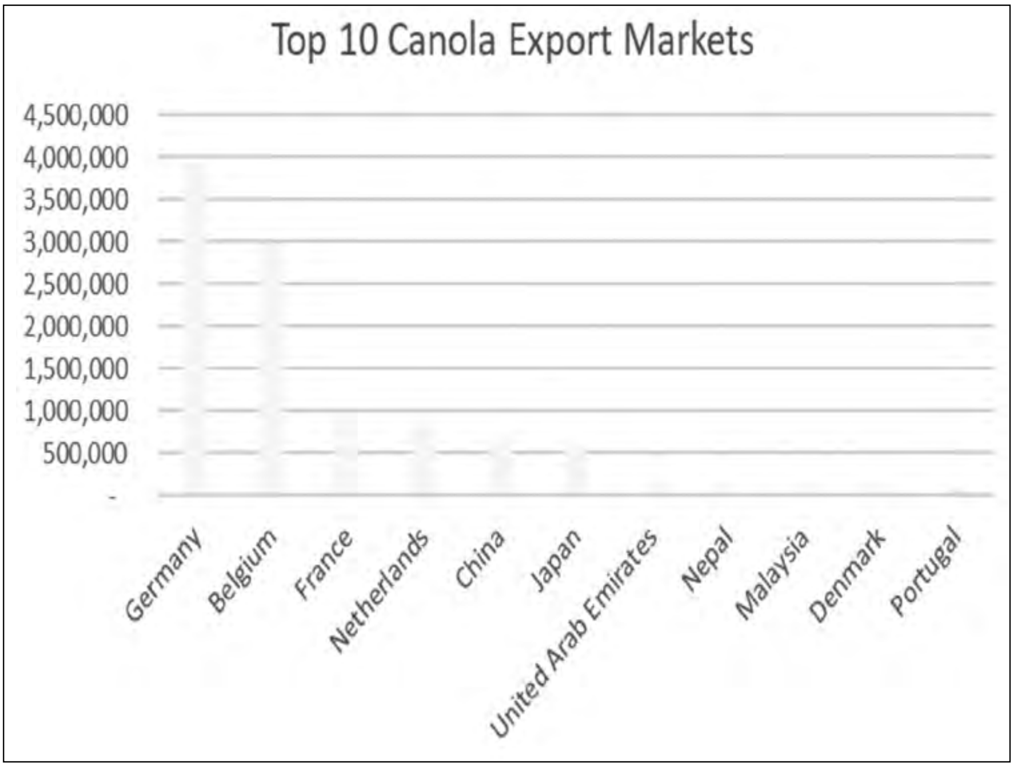

Figure 12. Top 10 canola export markets (Source: ABS).

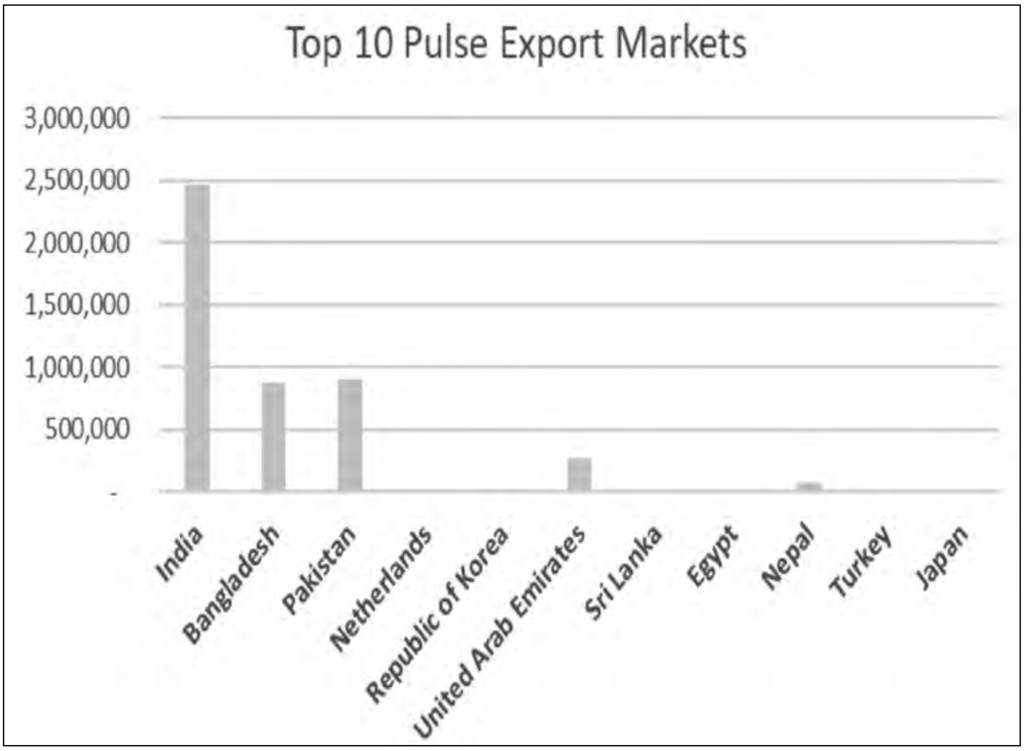

Figure 13. Top 10 pulse export markets (Source: ABS).

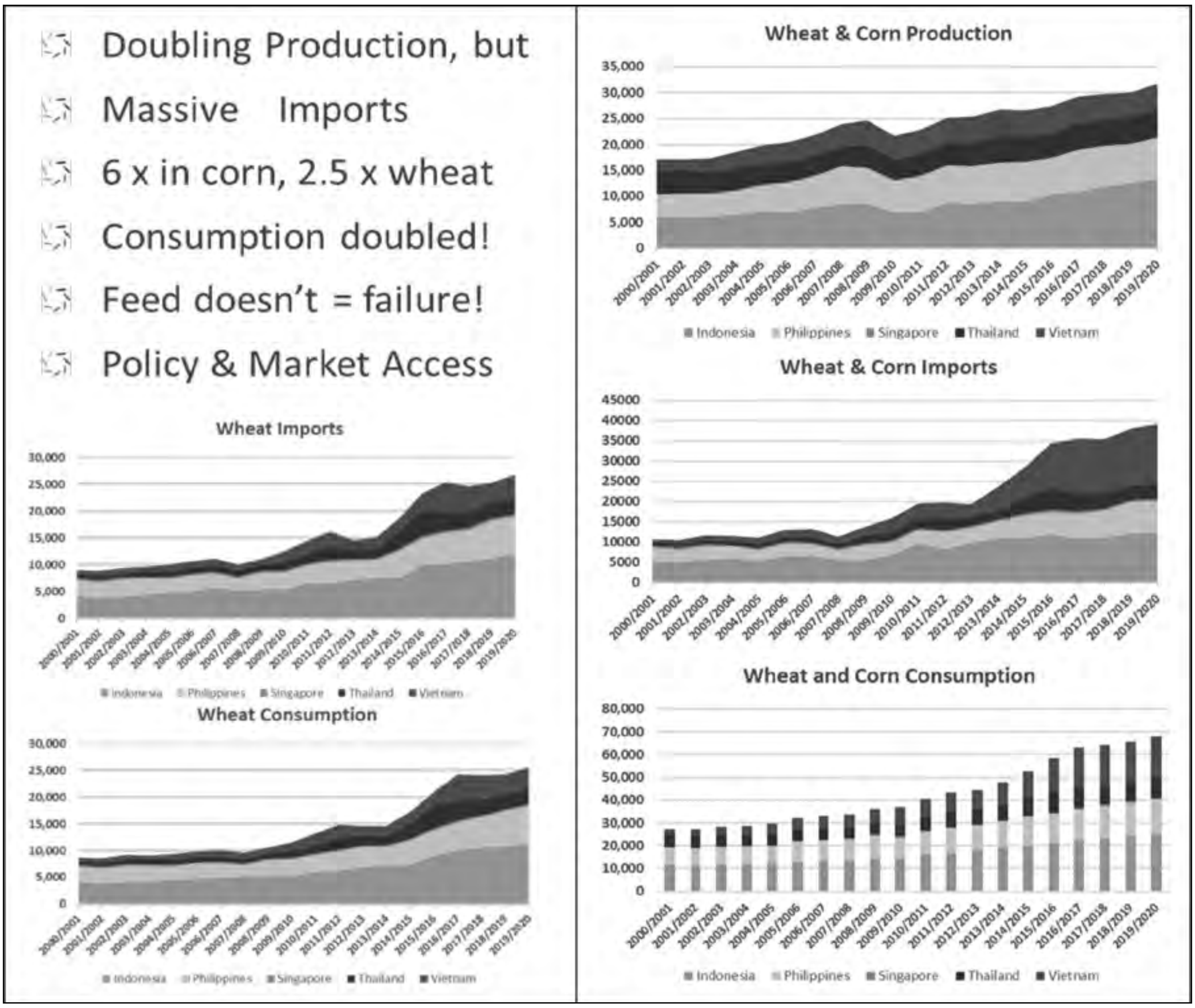

Figure 14. South East Asian demand. (Source: USDA).

Demand growth

There is a substantial growth opportunity for Australian grains in South-East Asia ((SEA) Indonesia, Thailand, Philippines, Vietnam, Singapore), in both human consumption and feed markets, as population and economic growth drive increased demand for animal protein and wheat-based food products. Figure 14 shows the substantial increase in imports and consumption for wheat and corn in SEA.

Market access to many of these countries is restricted through tariff measures, import bans and also NTMs that are designed to protect domestic corn producers in each country. While there may be short term demand challenges related to COVID-19, Australia needs to accelerate the longer-term process of breaking down these trade barriers and develop a story that Australian grain can complement and assist in the development of the local supply of feed grains and animal protein (rather than compete with local producers). A small part of these markets will be a significant market opportunity for the Australian grain industry. Similarly, improved market access and government tariff and NTM intervention in India offers opportunity to participate in India's growing demand and food supply surety policies.

Supply chain investment for competitiveness and growth

In addition to market access and efficient trade, the future success of Australia's grain industry is dependent on a competitive and efficient supply chain.

Around 30-35% of a grower's total cost is associated to supply chain costs. Global competition is intensifying. The quality advantage for Australian grain is reducing as processers and consumers increase their efficiency and utilisation of grain from alternative and cheaper origins and utilise technology to enable flexibility and use of different quality raw materials. This is applying pressure on Australian margins, and costs at both farm and supply chain level. Australia must compete and develop competitive advantage on both the grain quality and the supply chain fronts.

Improving supply chain efficiency, improves value of every tonne of grain and ensures the industry's global competitiveness. The value created will flow to producers and regional communities.

A strategy developed by GTA called 'Modernising the grain supply chain – from drought, through COVID-19 to 2030' has identified four key 'Strategic Growth Pillars' to develop and grow industry, through strategic efficiency gains in the value chain. The Strategic Growth Pillars are:

a) Skills & Capability

b) Quality & Market Access

c) Technology

d) Transport & Logistics

The grain value chain is reacting to global competition. The historical consolidated supply chain maintained by large bulk handling companies is evolving into a competitive mix of on-farm storage and commercial storage operators operating in an increasingly dynamic and entrepreneurial market. The grain supply chain is increasing its storage capacity and the number of operators through multiple container packers, new ports, country storage operators and farm-based storage and logistical enterprises.

This increasingly competitive and spatially distributed storage model provides opportunity for participants including grain producers as they more than ever can extract and capture value from the post farm gate supply chain. While delivering benefit, a broad and competitive multi-operator storage model does require guidance and support and pre-competitive cooperation if Australia is to drive efficiency and maintain its well-deserved reputation in the world market that has been built and earned over many years.

To enhance the competitiveness of the Australian value chain both industry and government need to play a significant role in investing in the long-term future to increase productivity and reduce paddock and supply chain costs to ensure our market position and improve farm gate returns.

However, industry alone cannot make the required supply chain investments or drive the system wide operational efficiencies on their own. There are several reasons including:

a) The overall size or quantum of investment required.

b) The risks around developing new technology.

c) The broad base of beneficiaries across the value chain.

d) Limited 'first mover advantage' for developing new technology.

e) Limited 'first mover advantage' for investing in certain infrastructure relating to pre-competitive activities.

In developing policy settings to improve the position of Australian agricultural industry, trade is just one, albeit important policy consideration. Other factors, such as the supply chain, should be considered in order to improve competitiveness and extract economic value.

The Strategic Growth Pillars identified in the supply chain report are aligned with Government policy objectives in Agriculture, Trade and Market Access, Information Technology and Transport and Supply Chain portfolios. Delivery of projects in these portfolios provides opportunity for industry to work in partnership with Government to improve Australia's global competitiveness and deliver value to regional communities.

Conclusion

Grain Trade Australia provides an industry driven self-regulatory framework across the grains industry to facilitate and promote the trade of grain and provides industry stewardship through specialist industry codes.

The 80% tariffs imposed on Australian barley exports by China, are estimated to reduce grain industry value by $2.5 billion over the five-year period of the tariffs.

Australian industry will work on building demand for Australian barley and other grains, oilseeds and pulses to recapture value lost from the barley tariffs. This work should also include looking to improve efficiency of the grains supply chain to ensure Australia's competitiveness in the global market place.

As 30-35% of growers total cost is in the supply chain, most of the benefits from improvements in the supply chain, will flow back to growers in improved value for <u>every</u> tonne moving through the supply chain, not just against tonnes flowing to individual markets.

Acknowledgements

The author would like to thank the Barley Industry Working Group (with members from GTA members, GIMAF, Grain Growers Limited, Australian Grain Exporters Council, Grain Producers Australia) for their extensive work and commitment on the China barley tariff issues.

Useful Resources:

Australian Bureau of Agricultural and Resource Economics and Sciences, https://www.agriculture.gov.au/abares

Australian Bureau of Statistics, www.abs.gov.au

Grain Trade Australia, www.graintrade.org.au

USDA, www.usda.gov

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Glyphosate resistant annual ryegrass update - 2020 season

Peter Boutsalis[1,2], Sam Kleemann[2] and Christopher Preston[1].

[1]School of Agriculture, Food & Wine, University of Adelaide; [2]Plant Science Consulting P/L.

GRDC project code: UCS00020

Keywords

- glyphosate resistance, annual ryegrass, optimising control, testing, random weed survey, double knock.

Take home messages

- Glyphosate resistance in annual ryegrass continues to increase.
- There are ways to optimise glyphosate efficacy.
- Partner glyphosate with other herbicides to improve weed control.

Incidence of glyphosate resistance

The GRDC continues to support 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. Resistance is defined as a sample where ≥20% plant survival was detected in a pot trial. The incidence of glyphosate resistance identified in paddocks in different cropping regions across South Australia (SA) and Victoria (Vic) from random weed surveys is presented in Figure 1.

Additionally, Bayer CropScience provides access to a significant database (Resistance tracker, https://www.crop.bayer.com.au/tools/mix-it-up/resistance-tracker) which contains data from commercial testing companies. This tool searches herbicide resistance for numerous weed species by postcode and year, with data collated over the past 15 to 20 years.

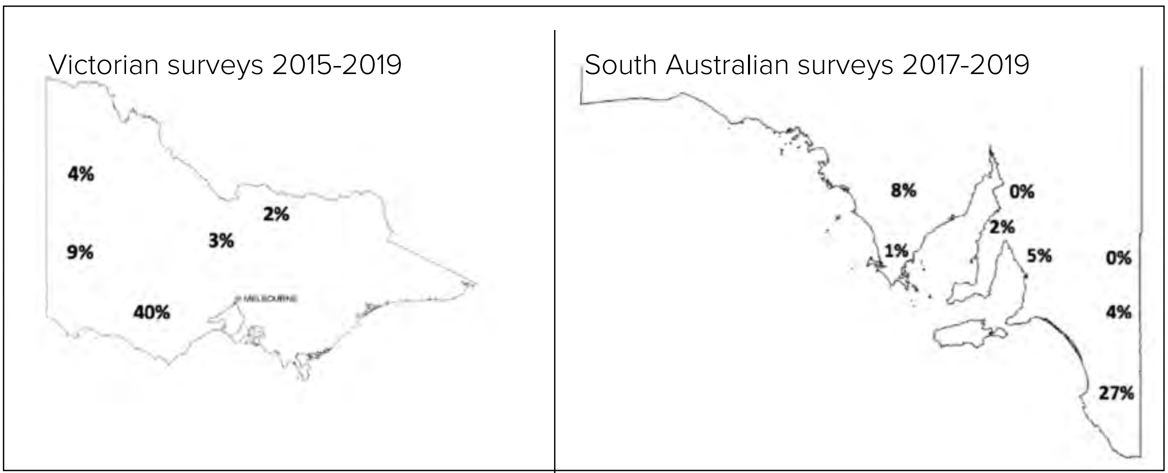

Figure 1. Incidence of paddocks containing glyphosate resistant ryegrass. Resistance is defined as a sample where ≥20% plant survival was detected in a pot trial.

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 possible targeting multiple flushes of weeds, in particular ryegrass from early autumn prior to sowing. Plants surviving following glyphosate application from Western Australia (WA), SA, Vic and New South Wales (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 79% of ryegrass samples sent from SA, Vic and NSW in 2020 respectively, were confirmed resistant to glyphosate. This highlights that in most cases, glyphosate resistance has contributed to reduced control in the paddock.

Discrepancy between resistance testing and paddock failures to glyphosate

In some cases, plants that have survived glyphosate application in the paddock are not resistant. Reasons for the discrepancy between paddock observations and a resistance test result can include poor application, application onto stressed plants, incorrect timing, sampling plants that were not exposed to glyphosate 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 initially very low. At the current time there are over a dozen species that have developed resistance to glyphosate in Australia (https://www.croplife.org.au/resources/programs/resistance-management/herbicide-resistant-weeds-list-draft-3/). The most important species are ryegrass, sowthistle, barnyard grass and feathertop Rhodes grass. Ryegrass and sowthistle will be discussed further within this paper.

There are several contributing factors for the increasing glyphosate resistance in ryegrass with generally more than one factor responsible. Reducing rates can increase the development of resistance particularly in an obligate outcrossing species such as ryegrass resulting in the accumulation of weak resistance mechanisms to create 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.

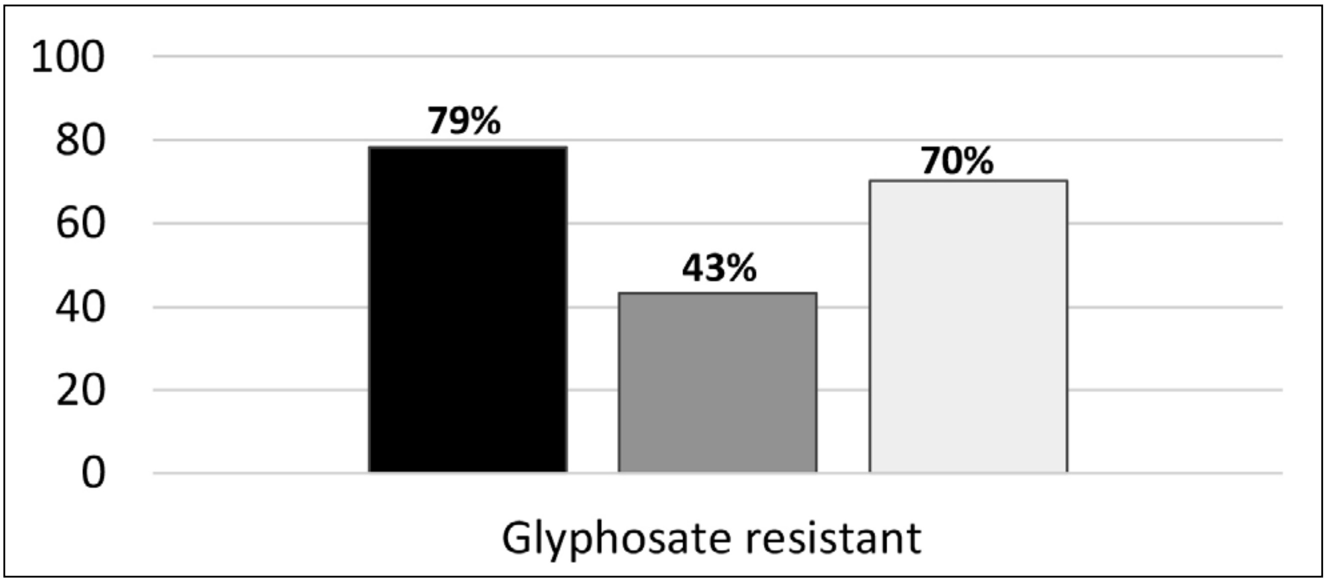

Figure 2. Percent (%) resistance to glyphosate confirmed in farmer ryegrass samples originating from 83 New South Wales, 37 South Australian and 74 Victorian cropping paddocks treated with glyphosate in autumn 2020. Testing conducted by Plant Science Consulting using the Quick-Test.

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

1. Using low quality glyphosate products and surfactants.
2. Mixing glyphosate with too many other active ingredients resulting in antagonism, particularly in low water volumes.
3. Using low quality water, particularly hard water. Glyphosate is a weak acid, and therefore, binds to positive cations (e.g., 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 in solution from leaf surfaces, thereby reducing absorption.
5. Applying glyphosate onto stressed plants can reduce translocation. Maximising glyphosate efficacy relies on translocation to the root and shoot tips. While this occurs readily in small seedlings, in larger plants, glyphosate is required to translocate further to the root and shoot tips to provide high levels of control.
6. Shading effects that reduce leaf coverage resulting in sub-lethal effects.
7. As glyphosate strongly binds to soil particles, application of glyphosate onto dust covered leaves can reduce efficacy.
8. Application factors such as speed, nozzle selection and boom height can reduce the amount of glyphosate coverage.
9. A combination of the above factors can reduce control, thereby increasing the selection for resistance.

Optimising glyphosate performance

The selection of glyphosate resistance can be reduced by considering the points mentioned previously. Additionally, there are a number of important pathways to follow to improve glyphosate performance including:

1. Avoid applying glyphosate under hot conditions. A trial spraying ryegrass during the end of a hot period and following a cool change was conducted in October 2019. Ryegrass growing in pots was 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 achieved when glyphosate was applied at midday (Figure 3). 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, e.g., after rainfall.

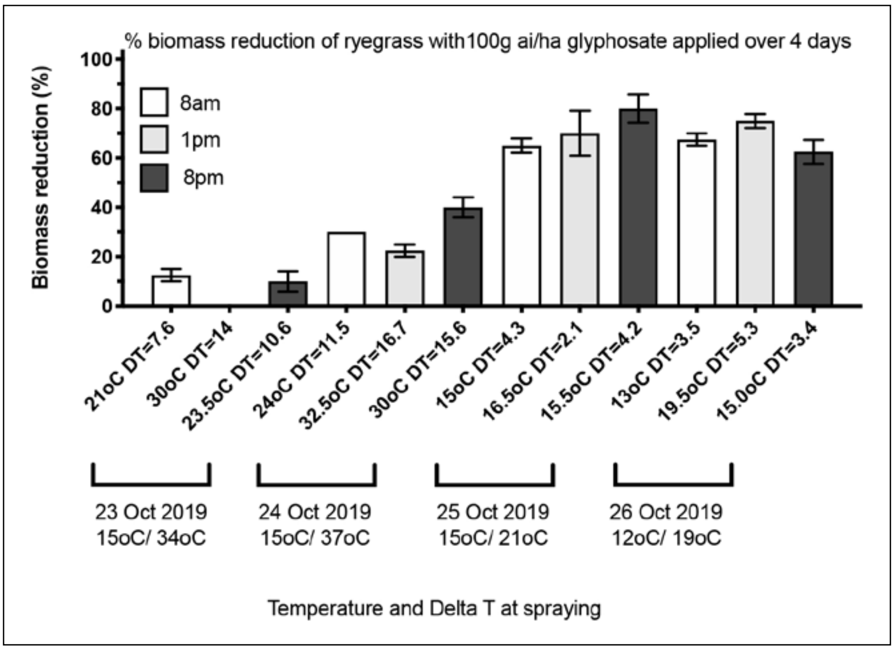

Figure 3. Effect of temperature and Delta T on glyphosate for ryegrass control.

2. 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 sulphate 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 increase leaf uptake. In a pot trial conducted with soft water, AMS was shown to significantly improve control of ryegrass with 222ml/ha (100g ai/ha) of glyphosate 450 (Figure 4). As a general rule, growers using rainwater (soft) should consider 1% AMS, if using hardwater (i.e., bore, dam water), 2% AMS is recommended. The addition of a wetter resulted in a further improvement in control.

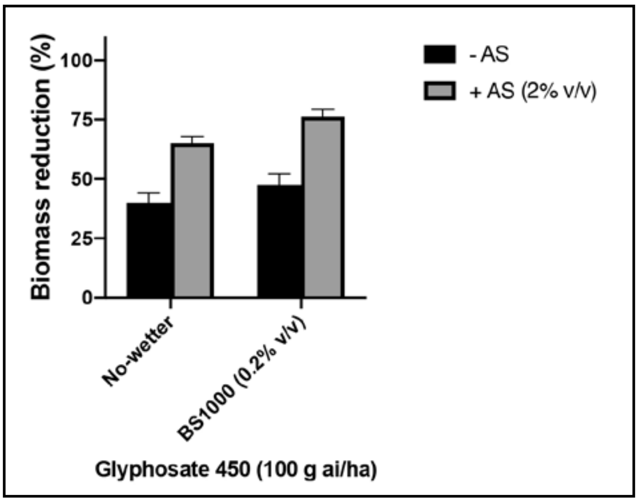

Figure 4. Effect of ammonium sulfate(AS) and wetter (BS1000) on glyphosate performance for ryegrass control.

3. Herbicide activity can vary at different growth stages. In a pot trial investigating the effect of glyphosate at four ryegrass growth stages (1-leaf to 4-tiller), good control was achieved at the three older growth stages but not on 1-leaf ryegrass (Figure 5). Most glyphosate labels do not recommend application of glyphosate on 1-leaf ryegrass seedlings because they are still relying on seed reserves for growth. Consequently, very little glyphosate moves towards the roots.

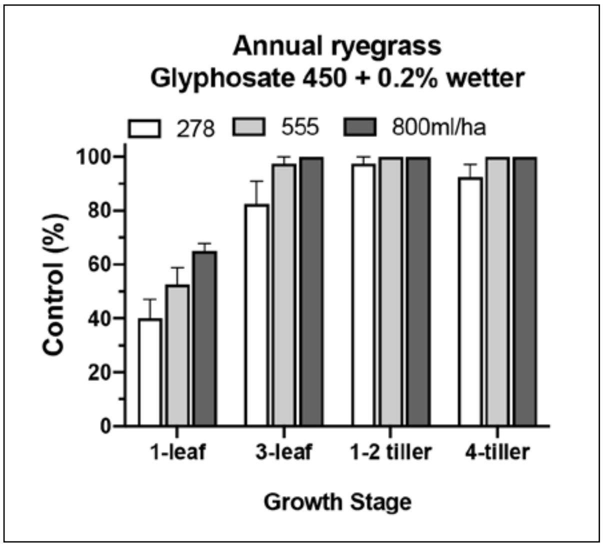

Figure 5. Effect of ryegrass growth stage on glyphosate activity.

A double knock strategy is defined as the sequential application of two weed control tactics to combat the same weed population. The most common double knock strategy is glyphosate followed by paraquat. It has been widely adopted to prevent or combat glyphosate resistance, particularly in ryegrass. The first 'knock' with glyphosate is aimed to control most of the population with the second 'knock' (paraquat) intended to kill any individuals that have survived glyphosate. In the presence of glyphosate resistance, paraquat applied one to five days following glyphosate was shown to provide optimum control in trial work conducted by Dr Christopher Preston (Figure 6). The timing depends on weed size and growing conditions, with three to five days required to maximise glyphosate activity. After a week (depending on environmental conditions) glyphosate resistant plants treated with glyphosate 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.

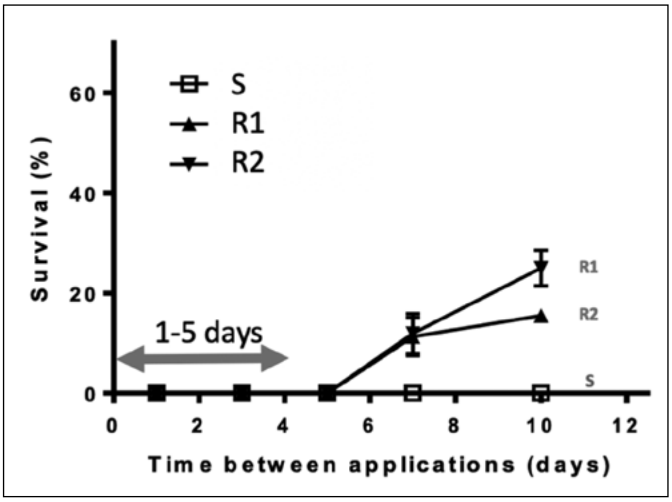

Figure 6. Double knock timing and its effect on ryegrass survival rate. Glyphosate applied onto a susceptible (S) and two glyphosate resistant ryegrass biotypes (R1 and R2) followed by paraquat 1, 3, 5, 7 and 10 days after application (DAA). (Source: Trial work conducted by Dr Christopher Preston (The University of Adelaide)).

Summary

In the southern cropping zone, glyphosate resistance in ryegrass continues to increase as indicated by random weed surveys across the region and the Bayer Resistance Tracker database. The early break in autumn 2020 resulted in the targeted testing of about 200 ryegrass populations prior to sowing with over half confirmed resistant to glyphosate. Although it took about 20 years after the registration of glyphosate for the first case of resistance to be confirmed, in the past 10 years there has been an exponential rise in the number of confirmed cases. Decades of strong selection pressure resulting from repeated use, coupled with application under suboptimum conditions has played a major role in the exponential rise. More efficient use of glyphosate combined with effective integrated weed management (IWM) strategies is required to reduce further increases in resistance.

Acknowledgements

The information for the random weed surveys was undertaken as part of GRDC project UCS00020, and therefore, is made possible by the significant contributions of growers through the support of the GRDC, the author would like to thank them for their continued support.

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Keeping the glyphosate option – the state of play

Katie Asplin.

CropLife Australia.

Keywords

- glyphosate, regulation.

Take home messages

- Everyone has a role to play in agricultural debates in Australia.
- The gap between science and the public discourse must be filled with credible evidence to ensure access to key agricultural production tools.
- Every independent, science and risk-based regulatory agency has comprehensively evaluated glyphosate and found it safe, when used according to label directions.
- It is paramount that all effective and safe pest management options are available for growers and environmental land managers to avoid environmental damage, loss of biodiversity and agricultural productivity.

Background

It is becoming increasingly apparent that too often there is a gap between science/evidence and the public discourse. We see this in the glyphosate debate, which threatens farmer access to key agricultural production tools. In such cases, we need to fill this gap with credible information so that Australian farmers maintain their ability to grow and produce food in an environmentally sustainable, efficient and profitable manner.

With the global population set to top nine billion people by 2050, the world will need to produce more food than ever before. That is a staggering challenge which will require a huge effort from everyone in the agricultural supply chain and every tool in the tool-box that enables growers and producers to do what they do best.

Discussion

Since 2018, there has been an increase in glyphosate media reporting. This is largely the result of court proceedings.

Agricultural chemicals, including glyphosate, continue to be some of the most regulated products in the world. The world's most advanced, independent and scientifically competent regulators have comprehensively evaluated glyphosate and declared it to be safe when used according to label directions. This includes Germany, European Union, New Zealand, Canada, the United States and Japan.

Agricultural chemicals are only registered for use in Australia when they present no unacceptable risks to users, the public and the environment. The Australian Pesticides and Veterinary Medicines Authority (APVMA) is responsible for regulating these chemicals in Australia and is globally renowned for its comprehensive, rigorous, science and evidence-based assessments.

In 2015 the International Agency for Research on Cancer (IARC) released a monograph naming glyphosate a probable carcinogen. Following that, the APVMA undertook a comprehensive reconsideration nomination assessment. They found no grounds for glyphosate to be reconsidered.

The misleading and exaggerated commentary surrounding the IARC monograph on glyphosate is unfounded and must stop. IARC only plays the limited role of advising regulatory bodies on potential hazards, allowing the relevant regulatory agencies to assess if there are any associated risks and manage them appropriately.

A risk assessment, as conducted by the APVMA, involves considering both the hazard associated with a chemical as well as the likelihood and extent of exposure to that chemical. By determining the hazard, the regulator identifies the potential for that chemical or product to cause harm. If the combination of hazard and exposure are not likely to cause harm, or any potential impacts can be mitigated through personal protective equipment or other risk management processes, the product is considered safe to use and will be registered. This is why label directions for use must be followed.

Conclusion

It is paramount that all effective and safe pest management options are available for growers and environmental land managers to avoid environmental damage, loss of biodiversity and agricultural productivity. Any restriction to the use of glyphosate, one of the most commonly used and safest herbicides, would limit the Australian farmers' and land managers' available options to the detriment of sustainable food production, as well as the natural and managed environment.

CropLife will continue to contribute to the discussion on glyphosate to ensure the voice of science and evidence is part of the narrative. It is equally important that everyone within the agricultural community continue to share fact based information with their networks. Adequately equipping the broader agriculture sector with information is critical to ensuring farmers maintain access to these crucial products.

CropLife has produced a range of materials which include answers to commonly asked questions about glyphosate. Contact publicaffairs@croplife.org.au for access.

Useful resources

Glyphosate – the facts (https://croplife.org.au/glyphosate)

Glyphosate fact sheet (https://www.croplife.org.au/wp-content/uploads/2020/07/GlyphosateFacts_2020.pdf)

APVMA glyphosate information (https://apvma.gov.au/node/13891)

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Herbicide mode of action global alignment

Katie Asplin.

CropLife Australia.

Keywords

- herbicide, mode of action, resistance, herbicide resistance.

Take home messages

- Herbicide Mode of Action (MoA) classifications will be updated to align with the new globally aligned system.
- The science hasn't changed – just the classification codes on product labels and literature will change from a letter to a number.
- Continue to follow current integrated weed management strategies and rotation plans.
- More information will be provided to growers and advisers throughout 2021.
- Growers can expect to start seeing herbicide labels with the new mode of action classification system from early 2022.

Background

Farming is becoming increasingly global. Farmers, agronomists and academics around the world are now, more than ever, sharing and accessing information to assist them to grow crops, while managing sustainability issues such as herbicide resistant weeds.

It's important then that the herbicide MoA classification system used in Australia be aligned with the global classification system to ensure Australian farmers and advisers can access the most up-to-date information relating to managing herbicide resistance.

Discussion

Herbicide Mode of Action (MoA) classifications have been updated internationally to capture new active constituents and ensure the MoA classification system is globally relevant.

The global MoA classification system is based on numerical codes which provides infinite capacity to accommodate new herbicide MoA coming to market, unlike the alphabetical codes currently used in Australia.

CropLife is working with key herbicide resistance management experts, advisers, GRDC and the Australian Pesticides and Veterinary Medicines Authority (APVMA) to ensure farmers and agronomists are aware of the planned changes.

Farmers can expect to start seeing herbicide labels with the new mode of action classification system from early 2022. There will be a transition period during which herbicide labels will exist in the supply chain, some bearing the legacy alphabetical MoA classifications, and others transitioned to the global numerical system.

The numerical classification system should be fully implemented by the end of 2024.

A mobile app compatible with Android and Apple systems is available via the HRAC website (https://hracglobal.com/index.php?q=app) at no cost to users. It will cross reference the herbicide active ingredient with its former MoA letter and new MoA number. Printed materials will also be made available to enable cross referencing of the changes.

Conclusion

CropLife is working with industry experts to identify the consequences of these changes regarding how products fit into an integrated weed management (IWM) program and will provide more specific guidance on the changes in mid-2021.

The way growers use herbicides in the field will not change. The science hasn't changed and the mix and rotate messages remain correct. It is just the classification codes used on product labels and literature that will change from a letter to a number. Growers are advised to continue to follow their current IWM strategy and rotation plans.

Acknowledgements

This project is made possible by the significant contributions of CropLife members and the herbicide mode of action alignment advisory group.

Useful resources

CropLife Australia resistance management https://www.croplife.org.au/resources/programs/resistance-management/

Global classification lookup app available for download https://hracglobal.com/tools/classification-lookup

Glyphosate fact sheet (https://www.croplife.org.au/wp-content/uploads/2020/07/GlyphosateFacts_2020.pdf)

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Herbicide MoA alignment: Stage 1

Herbicide Mode of Action (MoA) classifications have been updated internationally to capture new active constituents and ensure the MoA classification system is globally relevant.

The global MoA classification system is based on numerical codes which provides infinite capacity to accommodate new herbicide MoA coming to market, unlike the alphabetical codes currently used in Australia.

Farming is becoming increasingly global. Farmers, agronomists and academics around the world are now, more than ever, sharing and accessing information to assist them to grow crops, while managing sustainability issues such as herbicide resistant weeds.

It's important then that the herbicide MoA classification system utilised in Australia be aligned with the global classification system. This will ensure more efficient farming systems into the future and allow Australian farmers and advisors to access the most up-to-date information relating to managing herbicide resistance.

CropLife Australia is working with key herbicide resistance management experts, advisors and the APVMA to ensure farmers and agronomists are aware of the planned changes.

Growers can expect to start seeing herbicide labels with the new mode of action classification system from early 2022. There will be a transition period during which herbicide labels will exist in the supply chain, some bearing the legacy alphabetical MoA classifications, and others transitioned to the global numerical system.

The numerical classification system should be fully implemented by the end of 2024.

A mobile app compatible with Android and Apple systems is available via the **HRAC website** (hracglobal.com) at no cost to users. It will cross reference the herbicide active ingredient with its former MoA letter and new MoA number. Printed materials will also be made available to enable cross referencing of the changes.

CropLife Australia

Frequently asked questions

Q. Why change from letters to numbers?

A. A numerical code system is more globally relevant and sustainable, compared to the current alphabetic code used in Australia. Today there are 25 recognised MoAs. Over the next 10 years we anticipate up to four new modes of action to be commercialised, which will exceed the 26-letter maximum in the English alphabet.

Q. What is going to change?

A. The current alphabetical codes for herbicide active ingredients will change to numerical codes, in alignment with the global MoA classification system. For example, Group A herbicides will be labelled as Group 1 herbicides and Group M (glyphosate) will become Group 9.

Some new MoA will be introduced to accommodate some of the new chemistry being introduced world-wide. Some active ingredients will also be reclassified into different groups to better reflect their actual mode of action, not chemical structure.

A complete summary of the changes is available via the mobile app. More detailed information regarding the changes will be available in mid-2021.

Q. What are the main changes?

A. The main changes are outlined in the free mobile app, which you can download from the **HRAC website**. We are still working with industry experts to identify the consequences of these changes regarding how products fit into an integrated weed management program and will provide more specific guidance on the changes in mid-2021.

Q. How will the changes affect what we do?

A. The way growers use herbicides in the field will not change. The science hasn't changed and the mix and rotate messages remain correct. It is just the classification codes used on product labels and literature that will change from a letter to a number. Continue to follow your current IWM strategy and rotation plans.

Q. When will the changes take place?

A. There will be a transition period starting from July 2021, with growers likely to begin to see labels bearing the new MoA numbering system in the marketplace in early 2022.

Q. Does this mean the current MoA are wrong?

A. The science has not changed. Stick with your current IWM strategy and plans to rotate herbicides. In this era of multiple cross resistance, there is no magic bullet amongst the new modes of action.

Q. How will I know which products to rotate?

A. The science hasn't changed – stick with your current IWM strategy and plans to rotate herbicides. If in doubt, particularly with newer herbicides recently introduced, consult the manufacturer or your local agronomic advisor.

A summary of the changes is available via the mobile app. More detailed information regarding the changes will be available in mid-2021.

Q. Can I still use product on hand which has the old MoA printed on the label?

A. Yes. Legacy labels will be phased out over the next few years and will continue to be legally valid, although growers are encouraged to familiarise themselves with the new MoA classification system and corresponding resistance management strategies from 1 July 2021.

Q. Where can I find out more information?

A. You can find more information at the **CropLife website** and the free mobile app is available on the **HRAC website**.

Download the Global HRAC Herbicide MOA Classification app via Google Play or the App Store.

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To find out more visit:
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Group G herbicides – how to fit them into the farming system

Christopher Preston.

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Keywords

- contact herbicide, herbicide soil activity, herbicide water solubility.

Take home messages

- New registrations for Group G herbicides are expanding the ways these herbicides can be used.
- The choice of a spike with knockdowns should be based on activity against the most problematic weeds.
- Care needs to be taken with pre-emergent applications in light soils and where crop tolerance is not high to keep the herbicide out of the crop row.

Group G herbicides – how they work

Group G herbicides inhibit the enzyme protoporphyrinogen IX oxidase (PPO or Protox) in the chlorophyll biosynthesis pathway. The mode of action of these herbicides is quite complex. Inhibition of Protox results in an accumulation of the substrate for the enzyme, protoporphyrinogen IX, which leaks out of the chloroplast into the cytoplasm. Within the cytoplasm, protoporphyrinogen IX undergoes non-enzymatic oxidation to protoporphyrin IX. In the light, protoporphryin IX is converted to a radical, which then reacts with lipids in the cell membrane, destroying the integrity of the cell. This leads to the bleaching symptoms seen with Group G herbicides.

These herbicides are mostly absorbed by the shoots, even when applied to soil. They are typically contact herbicides with typically no translocation out of the treated leaf. This means that good coverage is important for activity. Group G herbicides control broadleaf weeds and usually have little or limited activity against grasses.

Group G herbicide use patterns

The most common use pattern for Group G herbicides in grain production in Australia has been as a spike application with knockdown herbicides to control weeds prior to sowing the crop. The registration of additional Group G herbicides and expansion of registrations in recent years has increased the potential use patterns for these herbicides. Most products are registered for spike applications with glyphosate or paraquat; however, many now have other applications as well. One of the newer use patterns is as a pre-emergent herbicide. Table 1 lists the Group G herbicides registered for use in grain production in Australia and their registered uses.

Chemical characteristics and behaviour of Group G herbicides

Much of our thinking about the behaviour of Group G herbicides has been influenced by the products that have been in use for a long time. There is a tendency to think of Group G herbicides having low solubility, resulting in contact herbicide behaviour and limited movement in the soil. Table 2 describes the solubility and binding to organic matter characteristics for various Group G herbicides. There is a wide range in solubility of Group G herbicides, with some more recently registered herbicides having much higher water solubility than has been traditionally associated with Group G herbicides.

Table 1. Registered use patterns of Group G herbicides in grain production in Australia.					
Herbicide (Trade name)	Spike	Pre-sowing residual	In crop	Late/Crop top	Fenceline
Oxyfluorfen (Goal®, Striker®)	✓				
Butafenacil (B Power®)	✓				
Tiafenacil (Terrad'or®)	✓				
Carfentrazone (Hammer®, Affinity® Force)	✓		✓		
Pyraflufen-ethyl (Ecopar®)	✓		✓		
Flumioxazin (Terrain®)	✓	✓			v
Saflufenacil (Sharpen®)	✓			✓	
Fomesafen[a] (Reflex®)		✓			
Saflufenacil + Trifludimoxazin (Voraxor®)	✓	✓			✓

[a]*Registration of Reflex is expected in 2021*

Table 2. Water solubility and binding to organic matter characteristics of Group G herbicides.		
Herbicide	Solubility (mg/L)	Binding to organic matter (K_{OC}) (mL/g)
Pyraflufen-ethyl	0.082	1949
Oxyfluorfen	0.116	7566
Flumioxazin	0.786	889
Trifludimoxazin	1.78	~570
Butafenacil	10	365
Carfentrazone-ethyl	29.3	486
Fomesafen	50	228
Tiafenacil	110	~18
Saflufenacil	2100	~30

As can be seen from Table 2, the compounds with low water solubility have high binding to soil organic carbon and those with high water solubility have low binding to soil organic carbon. This means the products with low water solubility will be particularly immobile in soil. For instance, saflufenacil, with high water solubility and low binding to soil organic matter, is highly mobile in soil. Saflufenacil will be particularly mobile in sandy soils with low organic matter.

These properties influence the behaviour of Group G herbicides, both in plants and in soil. For an herbicide to enter a leaf, it needs to cross the waxy cuticle. This is not a problem for a lipophilic herbicide like oxyflurofen. It readily moves into the cuticle following the concentration gradient (Figure 1). However, once it reaches the inside of the cuticle, its low water solubility means it will only slowly permeate the cell wall space. Due to the low water solubility, there is little movement from the site of application. This results in the classic spotting of leaves that is seen from application of these herbicides.

As the water solubility of the Group G herbicides increases, there will be more movement within the leaf, resulting in larger areas of damage from each surface droplet. For instance, saflufenacil, being highly water soluble, passes through the cuticle in a different manner and is much more mobile in the leaf. Saflufenacil also has some movement out of the treated leaves, but it is very limited.

The solubility of the herbicides also influences how they will behave on the soil surface. Oxyfluorfen with its low water solubility is used in horticulture to create a surface seal of herbicide to control emerging broadleaf weeds (Figure 2). Due to the low solubility of oxyfluorfen, any breaks in the surface seal, such as what happens with traffic, can allow weeds to emerge without contacting the herbicide. Flumioxazin, with low water solubility, has similar behaviour. However, saflufenacil is much more mobile and creates a wider band of herbicide, making it harder for the weeds to avoid contact.

The other factor in the activity of Group G herbicides is the ability of plants to detoxify them. There are variations between the herbicides and between species in the rate at which the herbicides can be detoxified. The combination of exposure, movement and detoxification capability of the herbicides influences the weed spectrum. Because

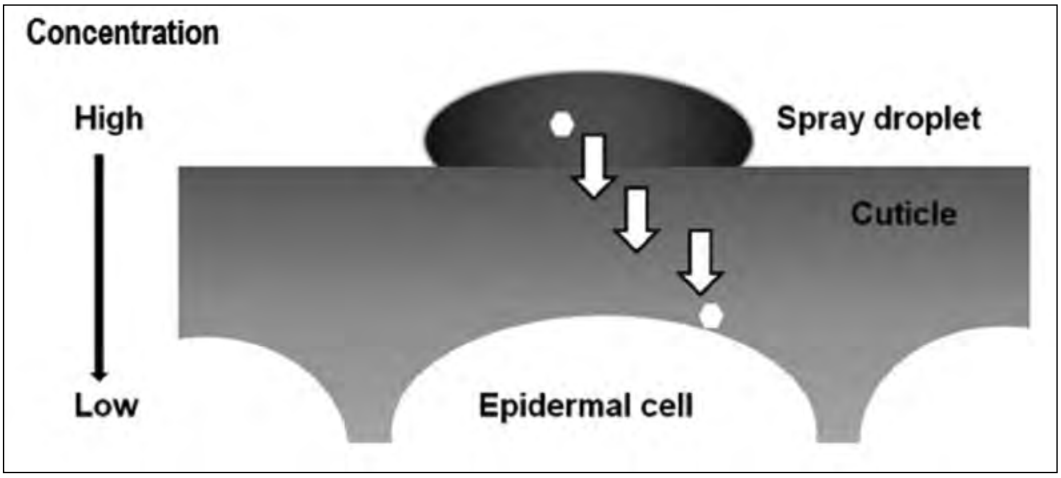

Figure 1. Movement of a lipophilic herbicide across the cuticle driven by the concentration gradient from high in the spray droplet to low in the cell wall space.

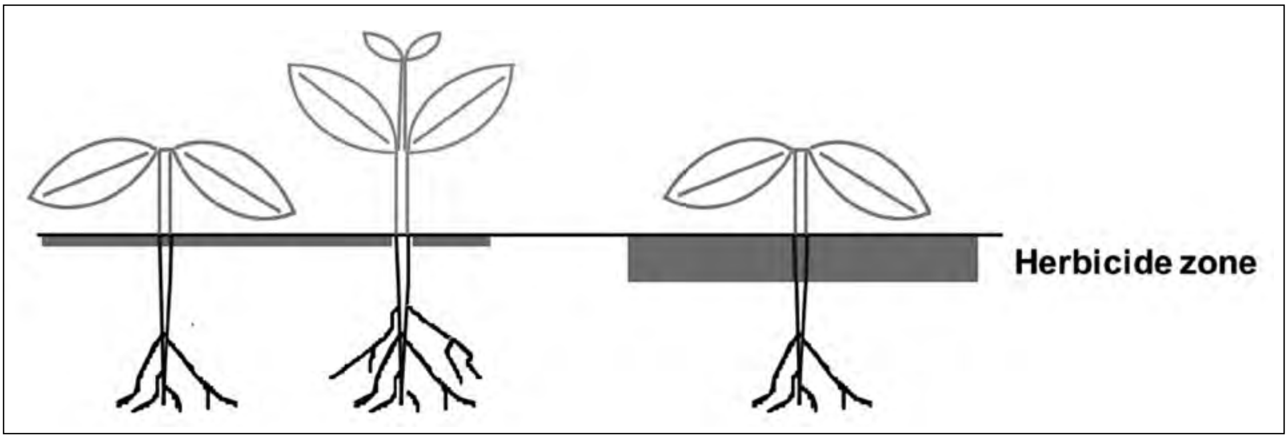

Figure 2. Some Group G herbicides with low water solubility create a surface seal on the soil surface. The herbicide is absorbed by the weed shoot as it emerges through the herbicide zone. Any break in the herbicide zone could allow the weed to avoid picking up the herbicide (left) and survive. More soluble herbicides have a wider herbicide band (right) making any breaks in the surface seal less important.

of their limited water solubility and the growth pattern of grasses, Group G herbicide are more effective against broadleaf weeds than grasses. The more water-soluble compounds will tend to have higher grass activity; however, this can be reduced by high rates of detoxification.

Fitting Group G herbicides into Australian grain production systems

With the introduction of new herbicides and new uses of existing Group G herbicides, there will be increased choice in their use. There are now many herbicides that can be used as spikes with knockdown herbicides. The choice of product for this use should be dictated by the main weeds of concern. Where mallows are the main concern, carfentrazone-ethyl remains a good choice. For fleabane, saflufenacil would be a better choice. In situations where glyphosate-resistant ryegrass is an issue, tiafenacil will provide the highest level of efficacy.

Plant back restrictions need to be considered with some of the newer Group G herbicides. Most have no plant back restrictions when spike rates are used. However, plant backs to canola for tiafenacil and saflufenacil range from 1 to 6 weeks, depending on the rate used.

Starting with flumioxazin, registrations for Group G herbicides for pre-emergent weed control have been developed. Terrain (flumioxazin) is registered for use prior to wheat and some pulses, Reflex (fomesafen) is registered for use prior to pulse crops and Voraxor (saflufenacil + trifludimoxazin) is registered for use prior to wheat, barley and durum, primarily for the control of broadleaf weeds. It is important to keep the herbicide away from the crop row where there is insufficient crop safety. This means knife-points and press-wheel seeding equipment should be used with pre-emergent uses of these herbicides. Pulse crops have some tolerance to fomesafen, and this herbicide can also be used post-sow, pre-emergent (PSPE) on all winter pulse crops, except lentils.

The more water-soluble products (Reflex and Voraxor) will tend to provide better weed control due to their greater movement within the soil. However, that also increases their risk of producing crop damage, particularly in lighter soils. Factors that allow movement of the herbicide into the crop row will exacerbate crop damage.

Carfentrazone and pyraflufen-ethyl can be used mixed with MCPA (2-methyl-4-chlorophenoxyacetic acid) to control broadleaf weeds post-emergent in cereal crops. Saflufenacil is registered for control of green material late in pulse crops and flumioxazin and Voraxor are registered for fence line weed control.

Should we worry about resistance to Group G herbicides?

Currently there is no known resistance to Group G herbicides in Australia. However, there are 13 weed species across the world with resistance to Group G herbicides. Most of these are broadleaf weeds; however, resistance has occurred in three grass weeds: annual ryegrass, wild oats and crowsfoot grass.

Where resistance to Group G herbicides has occurred, it has been typically in situations where Group G herbicides have been used intensively, including horticulture, turf and soybeans. As yet in Australia, Group G herbicides have not been used intensively in grain production. Mostly their use has been as spikes with knockdown herbicides, which targets a smaller percentage of the weed population. The expanded use patterns for Group G herbicides in grain production is likely to increase the selection pressure for resistance. Choices will need to be made about where Group G herbicides fit best in rotations.

Resistance to Group G herbicides is often the result of target site mutations, but non-target site resistance mechanisms are also known. There are a number of known mutations in PPX2, the gene for the target enzyme, which result in variations in the amount of resistance to different Group G herbicides. Resistance when it does occur in Australia is likely to be unpredictable and herbicide testing will be a useful tool in managing resistance.

Useful resources

GRDC Fact Sheet – Mixing knockdown partners with Group G herbicides

https://grdc.com.au/__data/assets/pdf_file/0028/381736/10408-GRDC-Fact-sheet-Group-G-herbicides.pdf

Specific guidelines for Group G herbicides

https://www.croplife.org.au/resources/programs/resistance-management/specific-guidelines-for-group-g-herbicides/

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Harvest Weed Seed Control – getting the best results

***Chris Davey*[1,2].**

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Keywords

- chaff lining, chaff decking, weed seed impact mill, positive straw discharge, stripper front.

Take home messages

- Regardless of your choice of tool for harvest weed seed control (HWSC), it will only deal with the weed seeds that enter the front of the harvester.
- The amount of weed seeds that enter the header front depends on the season, the weed phenology and crop growth, and weed competition.
- Chaff lining is an entry point into HWSC.
- Chaff decking is best suited for a controlled traffic farming (CTF) system.
- The choice of seed impact mill will be based around many considerations, including header model and make, and local supply and service of the mill.
- Stripper fronts have the ability to capture as much weed seed in their chaff component as draper fronts.

Background

Harvest weed seed control (HWSC) is a key component of the WeedSmart Big 6 (https://www.weedsmart.org.au/big-6/). It is our final chance to non-chemically reduce the amount of problematic weed seeds that are returned to our weed seed bank.

HWSC options include chaff carts, narrow windrow burning, direct baling, and the more recent options of chaff lining, chaff decking and the use of a seed impact mill.

The decision of which HWSC tool to implement on your farm is a difficult one, as no one tool suits all farms. Weed type, crops grown, rainfall, yield potential, local machinery dealers – all of these things and more, influence the decision of what HWSC tool to utilise.

Options

Chaff carts rely on weed seeds being collected through the harvester before being transported off the back of the sieves via a conveyor belt to the cart. Chaff dumps are then either lined up for ease of burning before the next seeding or grazed if in a mixed farming system. Some growers have also experimented with baling the chaff and have reported great success.

Originally known as 'windrow rotting', chaff lining has been championed by Western Australian (WA) growers, including Mic Fels. The concept involves funnelling the chaff fraction of crop residue (containing weed seeds) into a confined row directly behind the harvester using a narrow chute. The chaff and weed seeds are then left to rot down over time. To promote rotting, the chaff lines need to be placed in the same location year after year.

Chaff decking is a form of chaff lining, which combines dual chute placement of the chaff onto the wheel marks with the hostile environment that compaction and the constant traffic of a controlled traffic farming (CTF) system creates on the line.

Seed impact mills have been around for a couple of decades now, initiated by the work of Ray Harrington in the late 1990s. It is only in the last five years, that they have been available as integrated units. Seed impact mills work by crushing, grinding and impacting the weed seeds contained in the chaff fraction of the harvest residue.

Discussion

Analysis of chaff carts as a HWSC tool

Strengths

- Capture of problematic weed seeds that can be dealt with.
- Dual purpose chaff – salinity management, livestock grazing.
- Can be baled.

Weaknesses

- Percentage of weed seeds entering the header – weed type, difference within a species, harvest timing (same for all HWSC strategies!).
- Relies on burning to completely remove/reduce weed seeds.
- Grazing chaff heaps can result in weed seed spread through the paddock, via chaff spread or animal faeces.
- Extra fuel consumption.
- More time consuming.
- Nutrient loss.

Analysis of chaff lining as a HWSC tool

Strengths

- Capture of problematic weed seeds that can be dealt with.
- Cheaper than other HWSC options – can make your own or buy a retro fit model.
- Concentration of weed seeds into a localised, known area.
- Non-chemical.
- No burning involved.

Weaknesses

- Percentage of weed seeds entering the header – weed type, difference within a species, harvest timing (same for all HWSC strategies!).
- Ideally, the header is required to follow the same marks each year.
- Lack of decomposition.
- Volunteer grain germinating in the line (e.g., wheat in barley).
- Nutrient concentration.
- Potential nutrient loss.
- Crop establishment through the chaff line in subsequent years.

Analysis of chaff decks as a HWSC tool

Strengths

- Same as those listed for chaff lining.
- More hostile environment for weeds on the tram lines/tracks – soil compaction, competition, physical damage from wheels.
- Better summer weed control through reduced dust which impedes herbicide uptake.

Weaknesses

- Same as those listed for chaff lining.
- Reliant on having CTF set up.

Analysis of seed impact mills as a HWSC tool

Strengths

- Percentage kill/control rate.
- No burning.
- Organic matter back into the ground.
- Fast-paced development of impact mill technology.

Weaknesses

- Capital outlay.
- Fuel consumption/efficiency.
- One make and model doesn’t currently suit all situations.
- Crop moisture/greenness.
- Blockages.
- Wear and tear (maintenance).
- Snails, rocks/dirt.

The choice of seed impact mill will be determined by the header type and make, local dealer, back-up service available and what the best fit is in the farming enterprise.

Summary of the Yorke Peninsula seed impact mill experience

- Don't rush the harvest, particularly after frosts and/or a wet spring that has resulted in re-growth.
- Ensure crop is as dry as possible to prevent blockages.
- Mills do not efficiently process lentils that have stems that remain green at harvest.
- Seed impact mills are increasing in their longevity.
- Great results can be achieved with a stripper front and a seed impact mill.
- 'Drive to the mill' – I like this phrase!

Further considerations regarding HWSC options

- Cash flow – what you can afford and the return on investment (ROI)?
- Continuous cropping versus mixed farming – can chaff be used elsewhere on the farm?
- Phenology of the problematic weed/s – dormancy, maturity, growth habit, etc.
- Burning permits in your local council – tighter restrictions regarding burning.
- Rainfall and yield potential – how much chaff will you be dealing with?
- Ongoing expenses – repairs and maintenance.
- What is my soil nutritional health like? For example, what are the nutritional costs to me to replace the nutrients lost? Potassium (K) makes up a big part of the nutritional cost in places like WA.
- Can I adopt other components of the WeedSmart Big 6, other than HWSC?

Conclusion

- All HWSC strategies only deal with the weed seeds that enter the harvester front.
- Not all strategies will suit everyone.
- Labour will also play an integral part of your decision making.
- Peter Newman's HWSC calculator is a great starting point to compare the cost of the different strategies (https://www.weedsmart.org.au/big-6/harvest-weed-seed-control/).
- Chaff lining/decking is an economic/low-cost entry into HWSC. It relies heavily on the decay of weed seeds within the line as a means of weed control and reduction of weed seed into the soil bank. However, during the past few seasons, particularly in South Australia (SA), dry summers with minimal rain have occurred, which has led to little or no decomposition of the weed seeds in the chaff line. Evidence of this has been measured in trials by Gurjeet Gill (SA) and John Broster and Annie Ruttledge (NSW) through their trial work on weed seed decay in chaff lines.

Acknowledgements

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Useful resources

AHRI, 2019, What's the cost of harvest weed seed control for YOU? https://ahri.uwa.edu.au/whats-the-cost-of-hwsc-for-you/

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Addressing the rundown of nitrogen and soil organic carbon

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GRDC project code: CSP00207

Keywords

- soil organic matter, SOM, nutrient balance, carbon sequestration, soil constraints, cover crops, nitrogen bank, nitrogen loss.

Take home messages

- It is well known that stocks of soil organic carbon have declined in many Australian agricultural systems, including dryland grains production.
- This loss of carbon (C) has also resulted in a significant reduction in soil nutrient stocks, particularly nitrogen (N), that supply a significant proportion of a crop's nutrition.
- Rebuilding soil C and N stocks is slow, and depends upon increased crop production to drive C inputs, supported by fertiliser requirements being met.
- Overcoming soil constraints, inclusion of cover crops and legume rotations, and a recognition of N budgeting requirements over multiple seasons should turn a system towards rebuilding C and N stocks.

Introduction

Soil organic matter (SOM) contains the largest stocks of both C and N in all terrestrial ecosystems, including those under agricultural management. Globally, 1200-1550 gigatonne (Gt) C is stored in soils, with estimates of 22.6 – 39.7 Gt in the top 30cm of Australian soils (Viscarra Rossel *et al.* 2014). Assuming a C:N ratio of 11.8 (Kirkby *et al.* 2011), this equates to 1.92 – 3.36 Gt N stored in the SOM of the top 30cm of all of Australia's soils, an average of just over 4t N/ha. Soil organic matter is responsible for the provision of multiple ecosystem services important for agricultural production, including the provision of nutrients (particularly N), maintaining a diverse and heathy microbial community, infiltration and water retention, amongst others. Though often thought of as a single entity, it can be functionally broken down into discrete fractions that behave differently in terms of the agroecosystem services they provide, their vulnerability to loss, and their potential rates of accumulation.

The distinction between SOM and soil organic C (SOC) is that the latter refers solely to the C component of SOM. In modern analytical laboratories, SOC is commonly reported back to advisers and growers via a direct analysis by Leco® or equivalent instrument, rather than older outmoded techniques of ashing. Drawing this distinction allows clarity by separating the C from N and other nutrients contained within SOM. It is also important to differentiate between values reported as C or N content (usually as a percentage, or grams per kilogram) and those reported in a stock e.g., tons of C per hectare. Stock measurements implicitly factor in soil bulk density and gravel content, and are usually expressed to a defined soil depth.

In addition to the SOC itself and its fractions, two smaller but important pools of C exist in soil: microbial biomass C (MBC), which typically contains approximately 1% of the total C in a soil and represents the C stored in live microorganisms, and dissolved organic C (DOC) which is the soluble fraction (Gupta *et al.* 2019). This latter pool contains most of the C directly accessible by microorganisms for energy, but also more recalcitrant compounds that while soluble do not directly reflect availability of C. Though representing only a small percentage of the standing pool of C in the soil, the flux through these pools is high i.e., they turn over quickly, and thus, the flow of C through them belies their importance when measured as a stock. In many ways, this could be thought of in terms of a bath: If you were to run the tap with the plug out and measure the amount of water in the bath, you would find very little there at any point in time. However, you would be wrong to conclude that water is not important for the function of a bath. This same concept of 'flux' versus the 'pool' needs to be considered for N also.

Conversion of native ecosystems to managed agricultural production often coincides with a decline in SOC content and stock. Data from 20 different studies in Australian agricultural soils show that cultivation of the 0-10 cm layer had reduced C stocks to roughly 50% of those in their native condition, with similar but more varied results found when depths down to 30cm were considered (Luo *et al.* 2010). In Australian broadacre agriculture, no-till (NT) and stubble retention have been almost universally adopted over the past 20-30 years, with the general presumption that amongst other agronomic benefits, SOC stocks also increase. Contrasting findings in the literature, even between global meta-analyses (Kopittke *et al.* 2017; Powlson *et al.* 2014) suggest this outcome to be variable, and likely climate- and soil- specific (Ogle *et al.* 2019). Sanderman *et al.* (2010) reported improved cropping practices in Australia has the potential to increase SOC stocks by 0-2-0.3 t/ha/yr, though many of the improvements within that definition (e.g., NT, enhanced rotations, stubble retention) are now well established as best practice.

Recognising the intrinsic links between SOC and N, their loss in agricultural soils, and the opportunity to potentially replenish stocks, the aim of this paper is to build an understanding of how SOC and N availability are tied together, and the importance of seeking approaches that may address their decline. It provides a summary of the current state-of-the-art of knowledge on the mechanistic underpinnings of organic matter dynamics in soils, and uses this to construct actionable management possibilities to achieve these outcomes.

Linkages between the soil carbon and nitrogen cycles

Organic matter – form and function

To better understand how C accumulates, is lost and behaves in soil, a fractionation procedure has been developed to separate measurable fractions of discrete chemistry and functionality. This separates SOC into three fractions (Figure 1 and to follow):

- Particulate organic C (POC): The least decomposed fraction that is accumulated rapidly but also most vulnerable to loss, with an estimated turnover time of approximately 10 years. When considered beyond just its C component as SOM, this typically has a C:N ratio in the range of 20-40:1, still mostly resembles the crop biomass inputs from which it is derived, and is more responsible for the supply of energy to soil microorganisms than nutrients to crops.
- Humus-like organic C (HOC): Stabilised organic carbon that has undergone degradation and is often protected from loss due to binding to the soil mineral phase and protection within microaggregates. It has a decadal turnover time (up to approximately 100 years). This typically has a C:N ratio in the range of 8-14:1 as SOM, and is the likely source of most plant nutrients.
- Resistant organic C (ROC): This is a charcoal-like substance, typically with a very high C:N ratio >100:1 as SOM and a residence time of millennia. It occurs primarily because of the deposition of charcoal either from fires on the land (including from initial clearing) or deposition of soot. The soil amendment biochar also falls into this category. While not directly responsible for the delivery of nutrients, it influences the retention and exchange of cations including potassium and ammonium.

Inputs and retention of C in dryland soils

In Australian broadacre cropping systems, there are typically only two sources of C input to soil: the C fixed by plants in the paddock through photosynthesis, and the C contained in organic amendments such as composts and manures that may be applied. Though encouraged, if available at a reasonable price close to a source, the import of organic matter is not a viable option in many locations. Thus, the focus of this section is primarily

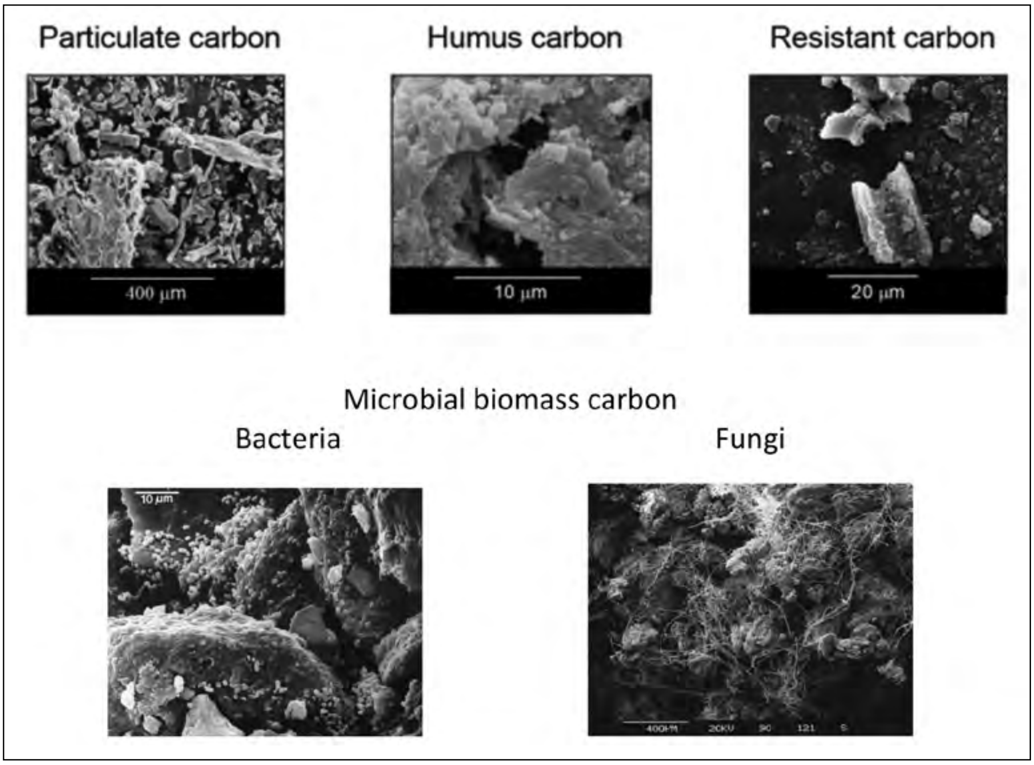

Figure 1. Electron micrographs of the three SOC fractions (courtesy of Jeff Baldock, CSIRO), and microbial biomass (courtesy of V. Gupta, CSIRO). Particulate carbon (POC) shows recognisable fragments of undecomposed plant material, humus carbon (HOC) is a waxy substance bound to mineral particles, and resistant carbon (ROC) shows a clear crystalline structure. The bacterial cells and fungal hyphae are clearly visible against the soil aggregates in the two lower pictures.

on inputs from the crop or pasture plants grown in situ.

Carbon is fixed by plants through the uptake of carbon dioxide from the atmosphere and its subsequent conversion via glucose to compounds useful to the plant. As discussed in more detail in Macdonald *et al.* (2020), it is possible to estimate the inputs of plant C to the soil on the basis of observed crop yield. Further, using this estimation based upon data derived from the scientific literature, it is also possible to contextualise expectations for SOC increase in the context of likely required yield increase. This can be done on the basis of several literature-derived figures for the key aspects of C allocation within a crop, and retention factors for C additions to soil (Table 1).

It is important to note that these values are averages or in some cases estimates. The drive towards greater yielding varieties with increased harvest index (HI) often means that the proportion of photosynthetically fixed C in a plant which remains after harvest decreases as more resources are allocated by the plant to grain. Root:shoot ratios are less frequently measured, and the amount of

Table 1. Calculation factors and their literature values used to estimate theoretical SOC stock change potential on the basis of crop inputs. Values are based upon literature (references in Macdonald *et al.* 2020) and can be updated with local expert knowledge for a given management scenario.

Calculation Factor	Value
Harvest index for cereal (HI)	0.37
Root:shoot ratio for cereal (RS)	0.50
Carbon content of cereal biomass (CC)	0.44
Retention factor of biomass (RF^b)	0.30
Rhizodeposition ratio (proportion of root biomass, RR)	0.50
Retention factor of rhizodeposition (RF^r)	0.57

C exuded via rhizodeposits (and thus not directly measured in studies quantifying root biomass) is even more poorly understood in Australian grain growing systems. The impacts of soil type, management and environmental factors on the retention of C either from above- and below-ground biomass, or rhizodeposits is also not well parameterised. Finally, any increased losses through priming processes whereby loss of SOC is accelerated by increased microbial activity is not considered (Chowdhury *et al.* 2014; Fang *et al.* 2020). Nonetheless, these numbers can be used to calculate possible increased in C inputs as a result of increased grain yield, assuming factors such as HI are unchanged.

First calculated is the likely change in above-ground biomass C (Δ_{ABC}; Eqn 1), below-ground biomass C (Δ_{BBC}; Eqn 2) and rhizodeposited C (Δ_{RC}; Eqn 3) which would accompany the change in yield.

$$\Delta_{ABC}=(\Delta_{yield}/_{HI})\times CC \quad \text{[Equation 1]}$$

$$\Delta_{BBC}=\Delta_{ABC}\times RS \quad \text{[Equation 2]}$$

$$\Delta_{RC}= \Delta_{BBC}\times RR \quad \text{[Equation 3]}$$

Having calculated the changes in the plant three C components as a result of a change in yield, the retention factors RF^b and RF^r are applied to obtain an estimate in the change in SOC (Δ_{SOC}):

$$\Delta_{SOC}=((\Delta_{ABC}+\Delta_{BBC})\ RF^b)+(\Delta_{RC}\times RF^r) \quad \text{[Equation 4]}$$

The estimates calculated from Eqn 4 suggest for a 0.5t/ha increase in grain yield, an increase of 0.45t/ha SOC may be observed in the soil profile. This would be a 20% yield increase based on this year's forecast average grain yield of 2.5t/ha across the Southern Region, according to ABARES' current estimates. Assuming a bulk density of 1.3g/cm^3 and a C content of 1.5% in the 0-30 cm layer to give a standing SOC stock estimate of 60t C/ha, this would be a change of less than 1% of that already in

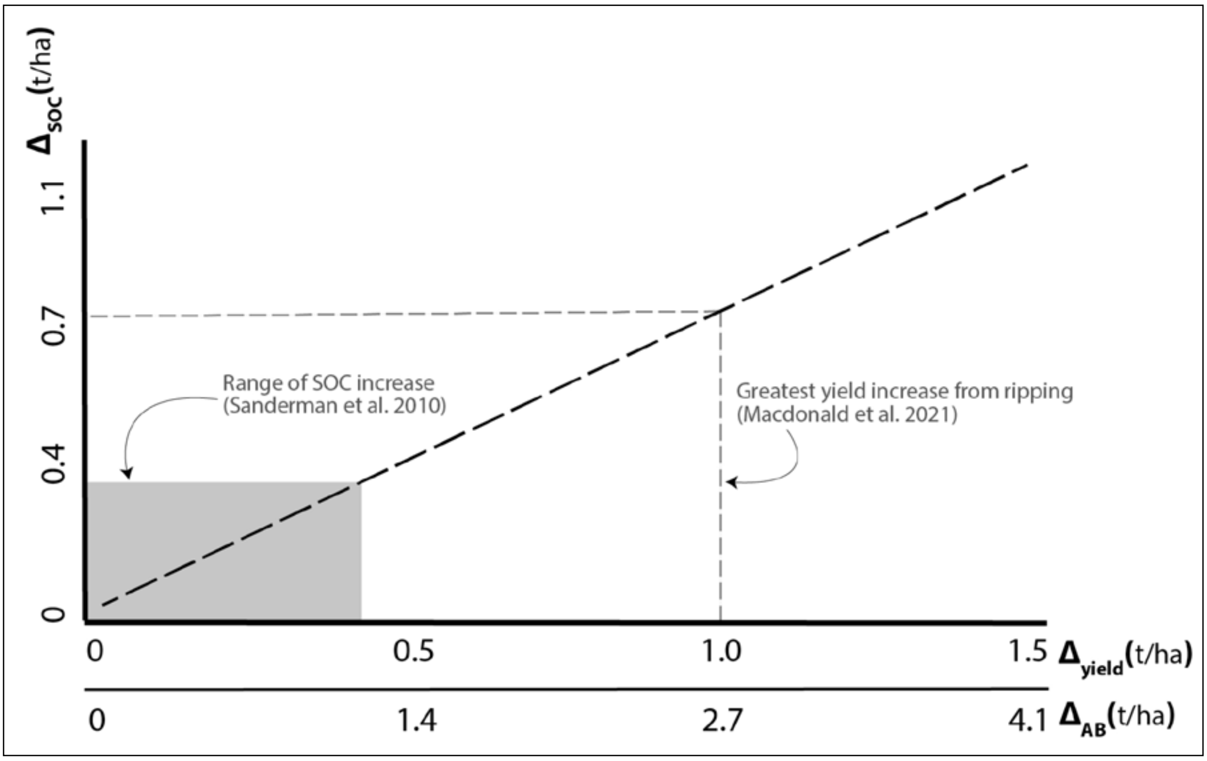

Figure 2. Relationship between changes in grain yield (Δ_{yield}; 1st x-axis) or aboveground biomass (Δ_{AB}; 2nd x-axis) and changes in SOC (Δ_{SOC}; y-axis) calculated using Eqns 1-4 and the literature derived estimates from Table 1. Values are estimates and per year. The greyed area shows the range for the published studies summarised by Sanderman *et al.* (2010) where 'improved management practices' resulted in an increase of up to 0.3t SOC/yr, a probable yield increase of approximately 0.4t/ha grain would be required. The grey dashed lines show the estimated change in SOC as a result of the average greatest yield increase realised as a result of deep ripping and associated activities in the current GRDC 'Sandy Soils' project (Macdonald *et al.*, 2021).

the soil i.e. a change of ~0.01% from 1.50% to 1.51% in the measured value. Such a change would be very difficult to quantify with any certainty, and thus measurements of SOC would need to be taken at intervals over a 5-10 year period to be certain that such an increase in inputs was indeed resulting in an increase in SOC stocks.

It is important to note that many of the factors listed (e.g., R:S, HI and RR) would be expected to vary in a non-linear manner with yield, and thus increases in yield in the higher ranges may not result in the same proportion of photosynthetically-fixed C being translocated to the non-grain pools as per the factors in Table 1. Further, retention factors are likely to be very soil-type dependent, and it is unlikely that such figures would apply equally across different soil classes and textures. Lastly, these figures do not consider losses of existing C, either through priming (Chowdhury *et al.* 2014) or as a result of disturbance in more energy-intensive amelioration activities such as the deep ripping reported in Macdonald *et al.* (2021) and shown in Figure 2.

Soil nitrogen cycling – processes, inputs and losses

In soil, most N is not immediately available, and is bound within SOM as organic N. As plants can only take up mineral N and a small proportion of dissolved organic N (DON), SOM must be decomposed to release these compounds. A snapshot study found on average only 0.59-4.80% of total N was present in plant available forms in Australian agricultural systems (Farrell *et al.* 2016).

The main input of N in broadacre cropping comes either from fertiliser or the inclusion of legumes in a rotation sequence, although a small proportion may also arrive through atmospheric deposition and fixation by free-living microbes in the soil. It is generally perceived that the efficiency of fertiliser N in Australian grains systems is low, with 40-50% of the N applied to a crop being recovered in that crop within the same season (Angus and Grace 2017). That does not however mean that the remaining N is lost from the system. In Australian dryland cropping systems losses of fertiliser N through leaching are low, especially in low rainfall zones. Further, while gaseous emissions of N2 and NH3 are less well quantified and may contribute significant losses of N in some situations (Harris *et al.* 2016), N2O emissions are amongst the lowest of any managed agricultural system.

Even in more heavily fertilised irrigated cotton systems of New South Wales and Queensland, the majority of N taken up by a crop is accessed via soil processes; primarily SOM mineralisation (Macdonald *et al.* 2017), and thus, the acknowledgement that efficiency of fertiliser N use sits at approximately 50% in a given season obscures the use of N supplied in previous systems.

The 'elephant in the room' when it comes to N export or loss from farming systems is actually the amount that is removed in the produce itself, or by livestock during grazing in mixed systems. As reported at previous GRDC Updates events, a comprehensive study by Norton (2016) found that the majority of properties studied were net exporters of N from the crop alone. If other losses (particularly N2 from denirtifcation, which is the least quantified) are also present in the system, this could contribute to significant N mining in the medium to longer term, with concomitant impacts on SOC stocks (Baldock *et al.* 2018).

Management to build carbon and nitrogen stocks

For both C and N, the same principle applies; the stock in the soil is a function of inputs and outputs. While the inputs of N are perhaps somewhat simpler to conceptualise and manage, it is primarily plant growth that results in C inputs to soil, and there are several means of manipulating this to improve the likelihood of increasing C stocks. And, as C stocks increase over the longer term, it is likely that the ability of the soil to supply N through the mineralisation of SOM will also increase, provided that the N balance remains positive.

Addressing soil constraints to increase soil organic matter inputs

The principles of conservation agriculture typically align with the goals of retaining and building SOM. These include minimising disturbance, maximising crop diversity/rotation, minimising fallow/bare ground, and integrating livestock where possible. However, these practices will only favour accrual of SOM where they increase inputs and/or decrease loss pathways.

Despite gains in productivity from broad adoption of NT and early sowing, there remains a yield gap between paddock production and the water limited yield potential. In many Australian cropping systems crop water use is limited by a range of surface and subsurface constraints which limit root growth and exploration. Common constraints include compaction, soil acidity and associated toxicities (aluminium, magnesium), alkalinity, sodicity and associated toxicity (boron, chloride, salt), and water repellence. While conservation practices and crop selection are useful tools in mitigating the impact of these constraints, they will not correct the physico-chemical condition of the soil.

Amelioration practices aim to overcome soil constraints for long-term improvement to crop growth and productivity. Under these scenarios, crop productivity and biomass production can be significantly increased, and will have subsequent impact on C and N flows through the soil profile. Examples include current research targeting subsoil acidity (Fleming *et al.* 2020), and deep ripping combined with the addition of organic amendments resulting in yield gains in some situations between 0.4 – 2 t/ha (Macdonald *et al.* 2021; Trengrove and Sherriff 2018). Research is ongoing to assess the longer-term benefits of these approaches to manage soil constraints, including developing a clearer understanding of scenarios in which they can be relied upon to deliver clear cumulative yield increases.

Nitrogen balance, excess and the 'Nitrogen-bank'

Typical N fertiliser decisions focus either on rules of thumb for a district, or predictions of yield, and thus, likely N demand on the basis of model predictions e.g., Yield Prophet®. By and large, such predictions target maximum profit over yield. Importantly, they typically focus on returns within a single season. As Norton (2016) has shown, the net N balance of such practice is usually negative, meaning that N is being 'mined' from the SOM at a greater rate than it is returned, resulting in a concomitant loss of C. Thus, yields are effectively being 'subsidised' by SOM loss resulting in medium-long term reduction in the ability of soil to supply N through in-season mineralisation. This reduces the soil's fertility in the longer term, and as mineralisation tends to release N at a rate closely matching the crop's pattern of N demand, it is unlikely that extra fertiliser can simply offset lost N mineralisation potential in the longer term. Further, the main factor driving the yield gap in Australian grains systems is N limitation (Hochman and Horan 2018), and in wet and favourable seasons this conservative approach to N management may impact profit in the short-term.

Instead, growers and advisers could consider the N requirement of the system as a whole by 1) considering nutrient balance in the medium-long term i.e., N balance over a 5-10 year period, not just the season ahead; and 2) considering the need to 'feed the soil' via immobilisation of nutrients, as much as the crop itself. This second point explicitly accounts for the fertiliser N required to build SOM which is sometimes seen as a negative cost of building C stocks (Richardson *et al.* 2014), but allows for the replenishment of the store of N that is released slowly through mineralisation.

An emerging approach to slow and potentially reverse declines in SOC and N stocks is known as the 'Nitrogen Bank' strategy (Meier *et al.* 2021). Recognising that losses of N from dryland grains systems are often low, and thus, economic and environmental risks are minimal (Smith *et al.* 2019), we suggest that applying greater rates of N will increase profitability through addressing the main constraint to yield and reducing SOC run-down. A major limitation in calculating a crop's N requirement is the ability to forecast rainfall and water-limited yield potential early in the season. A simple solution to this uncertainty is proposed whereby fertiliser application is calculated as the balance of crop N demand required to achieve the economic yield after subtraction of the available N stock at sowing, ignoring in-season mineralisation. If it is a dry season, excess N will mostly remain in situ and be captured in the next season's pre-sowing N testing, and fertiliser application rates adjusted accordingly. This approach effectively removes much reliance on SOM to deliver N through in-season mineralisation, and SOM that is mineralised is likely replaced through greater plant C inputs and the higher N availability resulting from the increased fertilisation rates. It should be noted that whilst showing early promise with minimal fertiliser N losses in the drier systems that dominate the Southern Region (Smith *et al.* 2019), substantial losses through denitrification of larger up-front N additions have been documented in ex-pasture systems in the high rainfall zone (e.g., up to ~90% applied N, Harris *et al.* 2016). Further research is required to better understand the climatic and soil boundaries at which higher up-front N applications can be applied with minimal loss.

Legumes and nitrogen fixation

One of the key benefits of grain and pasture legumes in crop rotation is the N contribution through legume-rhizobia symbiosis that provides the legume N requirements and as an important contributor of N supply to subsequent crops. The effect of recent intensification of Australian cropping systems and the consideration of grain legumes as rotational crops has the potential to reduce N inputs and increase N use efficiency in following crops and improve overall soil quality. It is generally accepted that for many legume species, on average 20kg of shoot-N per tonne of dry matter is fixed by grain legumes, although the actual amount of N fixed can vary 15 to 25 kg N fixed per tonne depending on the legume type, field conditions including management practices applied and seasonal conditions (Peoples *et al.* 2009).

However, it should be remembered that N fixation provides the majority of the N demand of the grain legume crop itself, and a large part of the fixed N is exported in the grain. Hence, its contribution to the overall soil N supply may be limited. Despite this, grain legume crop residues generally have higher concentrations of N and lower C:N ratios than those of cereals. For example, with a harvest index of 34%, grain legume crops (pulses) add above-ground residues ranging from 1.4 to 10 t per ha which provides 1 to 3.9 t of C/ha for use by soil biota. As the quality and N content of pulse crop residues defines the amount of N added to the system, it influences the N mineralisation and tie-up (immobilisation) processes.

Despite the increased preference for cropping in recent years, pastures remain a dominant part of southern farming systems which can play a key role in sustaining and improving SOM and fertility. Nitrogen fixation from pastures provide an important component of the N supply to subsequent cereal crops, which are further complemented by the C inputs from above and below ground plant components (Peoples *et al.* 2012; Sanderman *et al.* 2014).

The amount of N fixed by various annual and perennial legumes in Australia can vary from <10 to >250 kg N/ha/year. Additionally, the below-ground pool of N in roots and nodules provides a significant source of N inputs e.g., 40-55% of total plant N estimated to be present below ground in pasture systems (Peoples *et al.* 2017). It is suggested that various factors including poor effectiveness of native rhizobial strains, little or no fresh rhizobial inoculation even with in sown pastures, nutrient disorders and soilborne diseases can reduce nodulation and contribute to the less-than-ideal contribution from N fixation by pasture legumes reported in recent decades (Peoples *et al.* 2012).

There is an opportunity to improve our understanding of the constraints to N fixation. Implementation of management strategies that can improve legume productivity and N fixation can not only arrest the decline in the N supply capacity of soils but also contribute to the improvement of overall SOM quantity and quality (Angus and Peoples, 2012; Sanderman *et al.* 2017). Given that the formation of new SOM is not only contingent on there being sufficient C and nutrients, but also the need for them to be co-located near clay minerals and in conditions suitable for microbial growth, conversion of legume root biomass to more stabilised SOM is likely to be more efficient than other plant inputs supplemented with nutrients supplied by fertiliser.

Break and cover crops

A final potential strategy to build C stocks, improve soil resilience and address N decline is the implementation of break or cover-cropping, either as green manure or to provide supplemental stock feed. Winter cover crops may be grown in lieu of a cash crop as part of a rotation sequence, or they may be established opportunistically during the summer fallow. With regards to managing the soil, their aim is to reduce erosion by maintaining a ground cover, increase C inputs and microbial activity, and potentially address nutrient stratification or subsoil constraints through deep roots.

A recent study in Europe found that length of vegetation cover was more important for grain yields and soil function than diversity within a rotation (Garland *et al.* 2021). If sown as a species mixture, the combination of species can be tailored to occupy multiple niches so that biomass production 'overyields' i.e., produces more biomass than that from an equivalent monoculture.

Cover cropping is an increasingly adopted strategy overseas, particularly in the USA. However, in Australia's much drier climate, substantial questions remain as to whether any benefits derived offset potential loss of water through evapotranspiration of the cover crop, particularly in summer applications where the prevailing guidance is to manage weeds to maximise soil water retention. Current research led by Agex, SANTFA and CSIRO (Farrell and Stanley, 2021) is exploring these issues across 20 sites in the southern region, and is due to report in 2022.

Looking to the future

A growing body of evidence that suggests fertiliser strategies designed to maximise profit or offset financial risk in the short term do not meet the N demand of the system, and thus, invoke N-mining and resultant SOC loss. To arrest and reverse the loss of C and concomitant draw-down of N reserves in soils, the simple equation is that inputs need to be greater than exports and losses. There are several 'levers that can be pulled' on both sides of this equation, but it is important to understand that for the most part, the soil C and N cycles are intrinsically linked, as most N is bound in SOM, and the effectiveness of management efforts will be strongly influenced by climate and soil type (Hunt *et al.* 2020). Approaches that increase N inputs will both reduce N-mining and increase C inputs through greater plant productivity.

Recognising the monetary value of the N tied up in SOM (and indeed exploited through N-mining) suggests that a longer-term approach to N fertilisation strategies and legume rotations which result in a net import of N are required. Coupled with strategies that increase plant C inputs either through the alleviation of soil constraints or where appropriate, increased plant growth and time of soil cover through cover cropping, it is likely that over time SOM and thus N and C stocks will increase.

Many growers and advisers will ask **'Why should we do this? Can we offset the rundown of soil N over the longer term by just increasing fertiliser rates once yields drop?'** The pragmatic answer is perhaps **'maybe…'.** However, mineralisation of SOM mimics N demand of crops and this is difficult to match with fertilisers, even advanced slow-release formulations. It seems highly unlikely that increased reliance on fertiliser N will improve the efficiency of N use by crops at the system level, with increased losses and lower efficiency of use in the longer term. Of course, the delivery of N is but one of the many ecosystem services we rely upon SOM to deliver.

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Notes

Nitrogen fertiliser use efficiency ‘rules of thumb’ - how reliable are they?

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Keywords

- mineralisation, denitrification, crop utilisation, ^{15}N mass balances.

Take home messages

- An assessment of current ‘rules of thumb’ (RoT) for predicting nitrogen (N) fertiliser requirements in the southern region cropping systems has identified the need to update current assumptions.
- Deep soil N testing prior to (or just after) sowing is critical for good fertiliser N management.
- Current RoTs and other decision support systems for in-crop N mineralisation do not provide predictions at an adequate time step or scale.
- Crop utilisation of fertiliser and soil N varied markedly in response to seasonal rainfall distribution. Across all major cropping zones in Victoria, the average crop recovery of fertiliser N in the year of application is about 35% and this is recommended to replace the RoT of 50%.
- ^{15}N fertiliser mass balance studies revealed significant losses of fertiliser N, with an average of 25%, 32% and 41% of applied N in the low-medium rainfall, high rainfall and irrigated cropping systems, respectively.
- The important N loss pathways remain unknown, but identification is critical if appropriate N management strategies to minimise losses and maximise crop uptake are to be developed.

Background

Nitrogen (N) fertiliser is a key determinant of grain yield and the ability of cereal crops to achieve water limited yield potential in western Victoria (Armstrong *et al.* 2018). Because N fertilisers are one of the largest variable cost inputs (in both the southern region and nationally), accurate predictions of N fertiliser requirements are critical for grower profitability.

A national survey of more than 300 growers and advisers conducted in 2015 across a broad range of rainfall/productivity zones, including South Australia (SA) and Victoria (Vic) assessed how they made decisions and the underlying assumptions used to arrive at N management recommendations (UQ00179). The survey found that most of these busy advisers and growers utilised nutrient budgeting and general ‘rules of thumb’ (RoT) adjusted with localised information (experience) and specific data such as results from pre-sowing soil N testing. Many did not use elaborate decision support systems (DSS) or tools including simulation models such as Yield Prophet®, and where they did, it tended to act as a backup (validation) of the RoT. Another report (Unkovich *et al.* 2016) of adviser and grower practices in the southern region suggest a greater use of more elaborate DSS. However, these growers and advisers indicated concern about the accuracy of both simple N decision methods and the more elaborate DSS given the major changes in soil fertility and cropping systems since these tools were developed. Some expressed concern about using a DSS ‘black box’ especially without evidence of the embedded assumptions and caveats underpinning these procedures.

The basic components (assumptions) of most of the RoT approaches are from several assessments made each season of the estimated yield (demand) and the efficiency of N uptake by the crop from the soil and fertiliser inputs. Soil N supply depends on (i) available mineral N at sowing, (ii) within season N mineralisation from organic matter (iii) the efficiency of recovery of soil and applied N by the crop and (iv) net off-site losses of N or immobilisation by microbes. Differences between soil N supply and anticipated crop demand are then met by fertiliser application. In general, there is a supply shortfall to account for seasonal risk e.g. growers rarely fertilise to achieve yield potential because of the uncertainty of spring conditions and the risks of frost, drought or heat shock. Variability in any of these N supply and demand components can significantly influence fertiliser decision-making, and therefore alter the return on investment.

Nitrogen management is influenced by a range of factors, many which are logistical in nature. It is argued, however, that the current lack of confidence by many growers and advisers in existing N management approaches at a biophysical level stems from uncertainty surrounding the magnitude and seasonal variability of these key processes at a local scale and across soil types, and the inability to readily access relevant data used in these determinations. This paper reviews the assumptions underpinning the key components used to predict soil and fertiliser N supply in current RoTs used to guide fertiliser N management decisions for the current season. Biophysical data from recent studies focused on western Victoria is used, but this data is likely to be applicable to the whole southern region. Recent publications are referenced such as Unkovich *et al.* (2020) that have reviewed both published and grey literature relating to previous research into the processes underlying these assumptions.

Methods

Data used for assessments of assumptions (available N at sowing, within season net N mineralisation, the efficiency of recovery of soil and applied N by the crop and net off-site losses of N or immobilisation) were obtained primarily from two PhD studies (A. Wallace and K. Dunsford). The first study was based on data collected in two Australian Government funded Projects (*Action on Ground* (AonG), *'Reducing on-farm nitrous oxide (N_2O) emissions through improved nitrogen use efficiency in grains'*) and the 'Filling the Research Gap' NANORP program. Both assessed crop response to and utilisation of N fertiliser applied to cereal crops (mainly wheat) in growers' paddocks across a broad range of environments and soil types encompassing the key grain production areas of western Victoria: high rainfall > 550mm annual (HRZ), medium rainfall 400-550mm (MRZ), low rainfall < 400mm (LRZ) and irrigated cropping systems of northern Victoria. The AonG data comprised nine sites undertaken between 2014 and 2016 equating to a total of 29 site by year comparisons (Figure 1). The trials were located in grower paddocks (i.e., using grower management of the crop). At each site, a simple N rate response trial was established using a randomised complete block design with plot sizes of approximately 18m^2. Three N treatments were applied at each of the nine sites based on industry standard practice relevant to each region and the seasonal conditions. Sites received a small rate of N in the starter fertiliser across all plots at sowing (0-20kg N/ha), typically in the form of Mono-Ammonium Phosphate (MAP) or Di-Ammonium Phosphate (DAP) depending on grower management. Treatments included two rates of N fertiliser applied during the growing season plus a control which received no additional N during the season. The NANORP data comprised a total of six site by years experiments conducted between 2012 to 2014 in the Wimmera (Wallace *et al.* 2020). These experiments tested a range of different N management strategies. The utilisation and recovery in the soil: plant system of N fertiliser applied to wheat crops in both data sets was assessed using a ^{15}N mass balance approach to develop crop utilisation coefficients. Differences in the amount of labelled N applied and that recovered in the soil were assumed to represent losses. In the AonG trials, ^{15}N labelled urea was top-dressed during the vegetative or stem elongation growth stages when a rainfall event was anticipated in the following two to three days, although in higher yielding situations (especially the HRZ and irrigated sites) a second application later in the year was made in favourable seasons.

Nitrogen mineralisation data was collected from 73 grower paddocks (including those used in the AonG project) in the LRZ, MRZ and HRZ, between 2013 and 2016. Data was also collected from the SCRIME long-term rotation/tillage experiment at Longerenong (Armstrong *et al.* 2019). The contribution of net in-crop N mineralisation (net ICM – the balance of N mineralised from soil organic matter and crop residues minus N immobilised by soil microbes) to crop N supply was assessed in all studies. Net ICM of N was estimated as the difference between measurable N supply (mineral N measured at sowing plus fertiliser inputs minus the sum of mineral N measured and crop N uptake at maturity) based on the procedure used by Armstrong *et al.* (1997):

Net ICM (kg N/ha) = Crop N x 1.1 + SN_M – (SN_S + N_{fert})............Equation 1

Where Crop N is the total amount of N contained in the shoots of the crop at maturity multiplied by 1.1 to estimate the fraction of N allocated to roots (Angus 2001; Gan *et al.* 2011). SN_M and SN_S are soil nitrate (0 – 1.2m) at maturity and at sowing, respectively, and N_{fert} is applied fertiliser N. Only nitrate data was used for this calculation and not ammonium, since most mineral N in dryland cropping soils is rapidly converted to nitrate.

Results and discussion

Available N at sowing

The amount of mineral N in the profile prior to or just after sowing is a crucial indicator of soil N supply for the coming season. In some circumstances, sufficient N can mineralise over the preceding summer/autumn fallow, to meet crop requirements, without the need to add additional N (Dunsford 2019; Harris *et al.* 2016). At present, only a minority of paddocks are tested for mineral N in deeper profile layers ('deep N'), due principally to logistical challenges (Sean Mason 2020 pers. comm; project 9176604) such as access to a suitable soil sampler. As an alternative to direct measurement, estimates of likely mineral N can potentially be made by considering the previous rotation and rainfall. As data from SCRIME shows (Table 1), pre-sowing mineral N can be influenced equally by fallow summer/autumn rainfall (Figure 1) as by previous rotation (Armstrong *et al.* 2019). As such, delaying direct assessment of mineral soil N supply until after sowing may provide growers with increased confidence in both the starting point of N supply to a crop and potential grain yields.

Within season net N mineralisation

Studies of in-crop N mineralisation in southern region cropping systems indicate that this source of N potentially represents a significant proportion of a crop's requirement (Dunsford 2019). A comprehensive review of DSS tools including simple RoTs for estimating in-crop N mineralisation has recently been published (Unkovich *et al.* 2020). Many of these tools were developed in an era when pasture legume-leys dominated cropping systems or on acid soils in southern NSW rather than current continuous cropping, reduced tillage/stubble retention practices and alkaline soils that dominate cropping in the southern region (Dunsford 2019). Dunsford (2019) found that the 'Ridge Approach', provided a fair estimate (R = 0.46) of net in-crop N mineralisation across a large section of cropping systems in western Victoria, based on soil organic carbon (SOC) of the topsoil and actual growing season rainfall (GSR, Table 2). The Ridge method is calculated as:

N mineralisation (k/ha) = 0.15 × SOC (%) × GSR (mm)............Equation 2

If long-term average rainfall is used in the calculation, however, the reliability of the prediction is reduced considerably (data not presented). The recent extensive review of soil mineralisation by Unkovich *et al.* (2020) concluded that 'none of the currently available tools appear to provide field and season-specific information (prediction) of N mineralisation on a useful time step', or where more

Table 1. Profile (0-120cm) soil nitrate-N (kg/ha) prior to sowing of the wheat phase in response to different rotation/tillage treatments in SCRIME (2001 to 2017). n.d. = not determined. n.s. = not significant (P < 0.05).

Year Treat.[1]	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	mean
WWW	29	19	45	16	19	13	45	89	52	59	27	45	15	21	19	23	26	32.3
PWB	56	42	37	96	38	15	68	74	58	88	48	59	23	31	40	49	67	50.5
GmWB	126	85	53	91	81	62	77	119	68	206	127	91	34	80	85	57	147	89.0
CWP ZT	n.d.	n.d.	n.d.	n.d.	45	52	82	53	63	124	85	55	31	31	39	56	38	59.5
CWPRT	33	21	76	56	93	31	86	76	54	105	68	54	18	77	51	49	76	58.6
CWPCT	n.d.	n.d.	n.d.	n.d.	84	22	108	46	50	n.d.	n.d.	n.d.	35	43	44	61	83	54.9
FWP	91	74	74	n.d.	83	63	52	140	129	274	64	129	84	161	88	66	182	104.7
LLLCWP	42	35	94	23	96	71	106	115	68	167	48	73	90	78	101	87	52	81.0
Mean	*62.7*	*46*	*63*	*56.4*	*67*	*41*	*78*	*89*	*67*	*146*	*67*	*72*	*41*	*65*	*58*	*56*	*84*	*66.3*
lsd (5%)	*27.3*	*11.5*	*27.0*	*n.s.*	*34.6*	*42*	*22.2*	*56.5*	*32.4*	*88*	*45.7*	*26*	*29.7*	*86.0*	*24.0*	*29.6*	*64.7*	*11.9*

[1] W=wheat; P=pulse; =barley; Gm=vetch green manure; ZT=zero tillage; RT=reduced tillage; CT=conventional tillage; C=canola; F=fallow; L=lucerne (Source: Armstrong et al. (2019)).

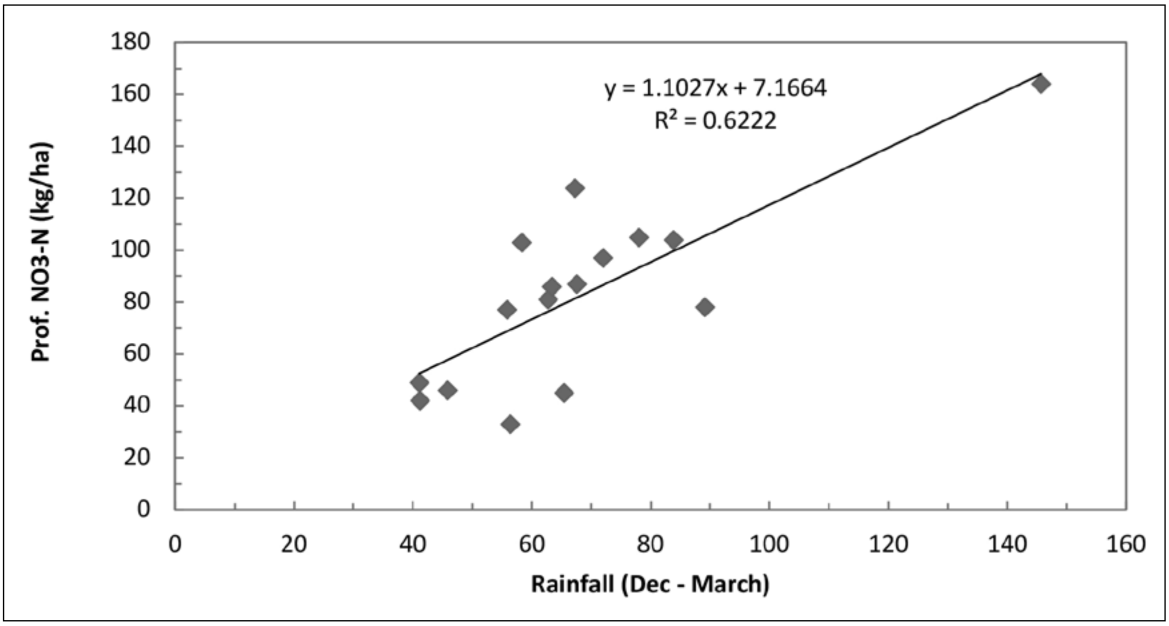

Figure 1. Relationship between rainfall (December of preceding year to March, inclusive in mm) and the amount of nitrate-N (kg/ha) in the profile (0-120cm) prior to sowing at SCRIME for 2001 to 2017. Analysis omits the value for 2011 when 375mm was received during this period.

complex models existed (e.g., Yield Prophet), 'they required detailed parameterisation unlikely to be conducted at an appropriate spatial scale'.

The efficiency of recovery of soil and applied N by the crop

A range of methods have been used to estimate fertiliser efficiency, and in particular, the quantity of fertiliser recovered by the crop. Traditionally, especially in the southern region, this was determined by measuring the difference between the quantity of N in the fertilised crop and a paired unfertilised treatment, expressed as a percentage, and referred to as the 'difference measure' (Strong 1995). Fertilised crops, however, frequently take up more soil N than unfertilised crops in a phenomenon referred to as the 'added N interaction' or a 'priming effect'. As a result, difference measure generally overestimates the efficiency of use of fertiliser N. In contrast to difference methods, the efficiency of recovery of soil and fertiliser N can be assessed using ^{15}N tracers. ^{15}N is a stable (i.e., non-ionising) form of N that occurs 'naturally' at low levels in the environment (0.00367% of all N) and effectively behaves similarly at a chemical and physiological level to ^{14}N. Although the applied ^{15}N is subject to isotopic discrimination during mineralisation-immobilisation (MIT) (Strong 1995), it is considered a better method to assess fertiliser N utilisation (and losses), especially when measurements are made of

Table 2. Correlation coefficients (r) of the relationships between net in-crop nitrogen mineralisation (net ICM) against growing season rainfall (GSR: April to October) and methods of predicting ICM, including soil tests and a simple calculator. Values are presented as *r* with significance indicated by *** *P*<0.001, ** *P*<0.01, and * *P*<0.05.

Method	Soil depth (cm)	Net positive ICM data		
		n	*R*	Significance
GSR (mm)	n.a.	108	0.47	***
Soil organic carbon (SOC) (%)	0-10	108	0.41	***
Total N (mg/g)	0-10	108	0.32	***
Pre-sowing profile nitrate (kg N/ha)	0-120	108	0.28	**
Ridge Method (kg N/ha)	0-10	108	0.46	***
Anaerobic NH_4^+ (kg/ha)	0-10	78	0.37	***
	0-20	78	0.38	***
Hot KCl Gross NH_4^+ (kg/ha)	0-10	78	0.40	***
	0-20	78	0.41	***

Table 3. Mean (and range) of crop recovery of fertiliser N using both 15N labelling and difference methods, errors between these methods and losses of fertiliser N from the crop:soil system within the season of application using pooled data from nine sites (2014 to 2016). N was applied as top-dressed urea during vegetative/early tillering stage.

Zone/ cropping system	Crop recovery using 15N approach	Crop recovery using difference approach*#	Crop recovery error when using the difference approach*	Loss of top-dressed N using 15N approach*
Low-medium rainfall dryland	34% (2 to 75%)	41% (-29 to 226%)	±52% (-52 to +172%)	25% (2 to 47%)
High rainfall dryland	34% (22 to 50%)	33% (-13 to 102%)	±22% (-40 to +64%)	32% (4 to 53%)
Irrigated	5% (12 to 60%)	49% (-13 to 64%)	±27 (-39 to +48%)	41% (26 to 57%)

residual ^{15}N remaining in the soil after harvest. This is due to its ability to accurately detect crop uptake of a relatively small amount of fertiliser N (e.g., 25-100kg N/ha) against a much larger background quantity of soil N (e.g. 2,200kg N/ha assuming soil total N = 0.2% and bulk density of 1.1g/cm^3).

A generalised value of 50% recovery of the fertiliser and available soil N within the season of application by the crop is widely assumed (Unkovich *et al.* 2020). This value is based on experimental data from field trials undertaken in the 1980s cited in Chen *et al.* (2008) in southern Australia and Strong (1995) in southern Queensland, which indicate that wheat crops recover 25 to 60% of the applied N. More recent publications cite fertiliser N recoveries by wheat of 49 and 57% in an acid chromosol in southern NSW (Smith *et al.* 2019).

Data on crop utilisation of ^{15}N labelled urea collected from western Victoria using current grower management practices and rates across a range of environments and seasons indicate a wide range of fertiliser N recoveries (2 to 75%) depending on the zone/cropping system (Table 3). The average crop recovery of fertiliser N (34 to 35%) was surprisingly similar between environments and cropping systems. The key determinant of crop recovery was rainfall (or irrigation) following application. Very low recovery of fertiliser N was measured where GSR post application was <66mm, a common occurrence in low and medium rainfall situations during the seasons tested. Crop recovery was also sensitive to the rate of application (as expected), with higher crop recovery at lower application rates. However, there was no statistical evidence ($P > 0.05$) that

Table 4. Crop total N uptake at maturity, N uptake from fertiliser, total N uptake, recovery of fertiliser N in crop (grain + straw) and estimated loss of fertiliser N from crop:soil system (0-40 cm) using different N management strategies in the Wimmera from 2012 to 2014. (Source: Wallace *et al.* 2020).

Treatment	Total N uptake from soil (kg/ha)	N uptake from fertiliser (kg/ha)	Total N uptake (kg/ha)	Grain yield (kg/ha)	Crop recovery of ^{15}N fertiliser (%)	Fertiliser loss using ^{15}N approach (%)
2012						
0 N	47^{b}	-	47^{c}	2456^{c}	-	-
50 N	45^{b}	24^{a}	69^{b}	3501^{b}	48.5^{a}	23.7^{b}
50 N DMPP	63^{a}	26^{a}	89^{a}	4589^{a}	52.2^{a}	24.3^{b}
0:50 N	59^{a}	28^{a}	87^{a}	3940^{b}	55.3^{a}	15.3^{a}
0:50 N NBPT	47^{b}	26^{a}	73^{b}	3672^{b}	51.7^{a}	12.9^{a}
2013						
0 N	65^{c}	-	65^{b}	3281^{c}	-	
50 N	68^{bc}	16^{c}	84^{b}	4480^{ab}	32.4^{c}	42.4^{c}
50 N DMPP	73^{abc}	18^{c}	91^{b}	4625^{ab}	36.6^{c}	24.8^{b}
0:50 N	77^{ab}	24^{b}	101^{a}	4177^{b}	47.3^{b}	20.6^{b}
0:50 N NBPT	82^{a}	28^{a}	109^{a}	4651^{a}	55.8^{a}	12.6^{a}
2014						
0 N	25^{c}	-	25^{c}	1467^{c}	-	-
50 N	41^{ab}	21^{a}	62^{a}	2046^{ab}	42.0^{a}	34.0^{b}
50 N DMPP	45^{a}	22^{a}	67^{a}	2194^{a}	43.7^{a}	29.4^{ab}
0:50 N	32^{bc}	6^{b}	38^{b}	1687^{bc}	12.1^{b}	34.8^{b}
0:50 N NBPT	31^{bc}	8^{b}	38^{b}	1825^{abc}	15.1^{b}	22.6^{a}

*0N = no N applied. 50N = urea incorporated at sowing; 50 N DMPP = urea + nitrification inhibitor incorporated at sowing; 0:50 N: urea top dressed at early-mid tillering; 0:50 N NBPT = urea + urease inhibitor top-dressed at early-mid tillering. Fertiliser N applied at equivalent of 50 kg N/ha. *Superscripts indicate significant differences (P <0.05) compared with other treatments within a given year.*

applying fertiliser produced an added N interaction (i.e., inducing an increased utilisation of soil N; data not presented), a finding that contrasts with the NANORP study where the interaction was relatively large (Wallace *et al.* 2020).

Data from a smaller spatial scale study (three experiments, all in the Wimmera) indicated a narrower range of crop fertiliser N recoveries, ranging from 12 to 56% (Table 4). This study highlighted the strong effect of seasonal conditions on the effectiveness of different N management strategies. For example, in 2012, N management had no significant effect on crop recovery of fertiliser N (range 49 to 55%), although it did affect grain yield response. In contrast, in 2014, maximum fertiliser recovery by the crop occurred when N was applied early whereas later applications (topdressing) resulted in very low crop recoveries and a trend to poorer grain yield responses due to very low rainfall received from August onwards. A positive finding, however, was that the low crop recovery under these dry conditions generally corresponded to high rates of recovery in the soil at harvest, rather than being lost. In contrast to the AonG survey data, significant interactions were recorded, indicating that utilisation of soil N was stimulated by fertiliser treatment (Wallace *et al.* 2020).

Net off-site losses of N or immobilisation

Significant losses of N can occur from the soil by a range of pathways, including gaseous losses of ammonia (via volatilisation), denitrification (predominantly as dinitrogen- N_2) and leaching (of nitrate) below the root zone.

The use of a ^{15}N labelled fertiliser mass balance approach allowed a quantitative assessment of the potential irretrievable loss of N derived from fertiliser. In our field studies, losses of fertiliser N ranged from 2 to 47% in low and medium rainfall zones (mean = 25%), 4 to 53% (mean = 32%) in the HRZ and 26 to 57% (mean = 41%) in irrigated cropping sites in northern Victoria (Table 3). Similar to crop recoveries, N management strategy significantly affected losses of fertiliser N depending on seasonal conditions, with nitrification inhibitors (DMPP) reducing losses in above average rainfall conditions and urease inhibitors (NBPT) producing significant benefits in reducing losses of top-dressed urea under dry seasonal conditions (Table 4). While the data directly estimated the loss of N derived from the labelled fertiliser applied to the crop:soil system, it could not unfortunately identify the primary N loss processes responsible. Measurements following harvest indicated little movement of ^{15}N below the topsoil (0-10cm and occasionally 10-20cm), suggesting that gaseous loss (denitrification or volatilisation) was most likely responsible rather than leaching. Furthermore, total losses of N from the system are likely to be greater than our data indicate, as our procedure only accounted for fertiliser N and not for losses of 'background' soil mineral N which was not labelled with ^{15}N.

General discussion

Despite its importance to on-farm profitability, N management remains problematic for most growers and advisers. The guiding '4R' principles of the right source, rate, time and place of fertiliser requires knowledge of both crop demand and soil N supply. Seasonal conditions remain the primary driver of crop demand for N in dryland cropping systems and to a significant extent also fertiliser use efficiency. Similarly, seasonal conditions also strongly influence the underlying assumptions of soil N supply, via its effect on both the rate of N mineralisation during the summer/autumn fallow and the rate of N mineralisation in-crop, as well as crop utilisation and losses/immobilisation of fertiliser N.

Although no one can control seasonal conditions, seasonal forecasting is steadily improving and it is thought that growers/advisers can significantly reduce uncertainty of potential N supply through measuring both soil profile N prior to or just after sowing and in-crop N mineralisation using currently available procedures. The previous widely held assumption of 50% recovery of fertiliser and soil N was reputedly based on higher recovery of soil mineral N (70%) and 30% of fertiliser N (Mike Bell, quoting Wayne Strong and Chris Dowling). This value was formulated, however, in a period when soil N supplied most of the crop's N. In current cropping systems, however, where there is less legume/pasture leys and tillage, and organic matter levels have declined, fertiliser N is the dominant source of crop N supply, a more appropriate figure for crop utilisation of fertiliser and soil of 35% is suggested for the southern region. This revised figure appears to be consistent across diverse cropping systems, although this may reflect differing influences. For example, better soil moisture in higher rainfall environments allowing for greater crop access to fertiliser being balanced by lower losses of N in drier environments.

Similarly, losses of fertiliser and presumably soil N appear to be an inherent feature of current cropping systems and based on the data appear to have been underestimated. Although many advisers in the 2015 survey were aware of the mechanisms by which N could be lost from the cropping system, most had difficulty in identifying rates of losses occurring in their environments. Furthermore, because the emphasis of many previous field-based experiments has been on greenhouse gas emissions (N_2O), where total quantities of N in terms of kg/ha are relatively low (Wallace *et al.* 2018), there was a lack of awareness that N_2 losses from denitrification could be of much greater 'agronomic significance', as suggested by the ^{15}N mass balance data. 'Unaccounted for' N which was assumed to be lost averaged 25, 32 and 41% in low-medium, high rainfall and irrigated cropping systems, respectively, but instances of losses of > 50% were recorded across all these systems. These losses occurred at agronomically relevant rates and could be expected to become relatively larger at higher application rates. Previous research (also using ^{15}N mass balances) has found large losses (up to 90% depending on application strategy) of applied fertiliser N from HRZ cropping systems in western Victoria (Harris *et al.* 2016). In the AonG study, fertiliser N was applied via topdressing of urea (mostly during tillering to first node), so an assumption was that volatilisation was the main loss mechanism. However, there were circumstances, especially in the HRZ and irrigated cropping trials and on sodic soils in the MRZ, that background soil conditions may have been conducive to denitrification losses driven by anaerobic waterlogged conditions. Knowing the mechanism of this N loss is important, as the NANORP study clearly showed that use of an appropriate fertiliser management strategy can significantly reduce losses of N and enhance supply to the target crop if applied in the correct situation.

Conclusions

Growers can potentially improve their fertiliser N management by (i) undertaking deep N soil testing, (ii) using current RoT predictions of in-crop N mineralisation and (iii) reducing the assumed crop utilisation of soil + fertiliser N to approximately 35 rather than current 50%.

Large losses of N appear to occur regularly across low and medium rainfall and irrigated cropping systems, not just in the HRZ as previous thought. However, the ability to mitigate these losses is hampered by uncertainty as to the loss pathways. Knowledge of this information would facilitate the identification of appropriate fertiliser management strategies, which have been shown to significantly reduce losses and improve yields.

Acknowledgements

Much of the original data used in this project originated from the Australian Department of Agriculture and Water Resources (AOTGR2- 0073) project *'Reducing on-farm nitrous oxide (N_2O) emissions through improved nitrogen use efficiency in grains'* and Filling the Research Gap' NANORP program. We wish to acknowledge the invaluable discussions and insights provided by our colleagues Murray Unkovich, Mike Bell, Louise Barton and Sean Mason. Katherine Dunsford's PhD was co-funded by Agriculture Victoria, LaTrobe University and GRDC through Project DAN00168. We wish to acknowledge the significant contributions of the many grain growers of western Victoria who assisted us with conducting these experiments on their properties.

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Notes

Hyper Yielding Crops Focus Farms – a great pathway to adoption

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GRDC project code: FAR2004-002SAX

Keywords

- hyper yielding crops, HYC, research centres, innovation groups, Focus trial paddocks, HYC Awards.

Take home messages

- Hyper yielding crops (HYC) research centres provide detailed small plot research on appropriate cultivars for the region/site location and include nutrition, canopy and disease management strategies.
- Small, local 'Innovation groups' have been established in the five states nationally and are being run by project officers from local farming system groups.
- 'Focus paddock' trials will also help road-test the findings of the local HYC research centres by taking research and development learnings from small plot to larger paddock-scale trials.
- Results from the 60 plus 'Award' paddocks are currently being collated and analysed.
- Award growers will receive a detailed report on their paddock, with comparative analysis of all the other Award paddocks in their region and a potential yield target for their crop.

Background

The HYC project is a GRDC investment which runs from 2020 to 2024. The project, led by FAR Australia, follows on from the successful Tasmanian Hyper Yielding Cereals project which established new benchmarks for wheat and barley productivity in the state. The new project based in the high rainfall zone (HRZ) regions of five states Victoria (Vic), South Australia (SA), Tasmania (Tas), New South Wales (NSW) and Western Australia (WA), aims to produce aspirational yields of wheat, barley and canola by examining the key agronomic and farming system levers to achieve higher yielding crops that are both more productive and profitable.

Method

The HYC project is made up of four key components which are fully interlinked with each other. These are shown in Figure 1.

HYC research centres

Five research centres have been established and are located at Gnarwarre (Vic), Millicent (SA), Wallendbeen (NSW), Green Range (WA) and Hagley (Tasmania). The HYC research centres are being led and managed by FAR Australia in collaboration with Brill Ag, CSIRO, the Department of Primary Industries and Regional Development in WA, the SA Research and Development Institute (SARDI) and Southern

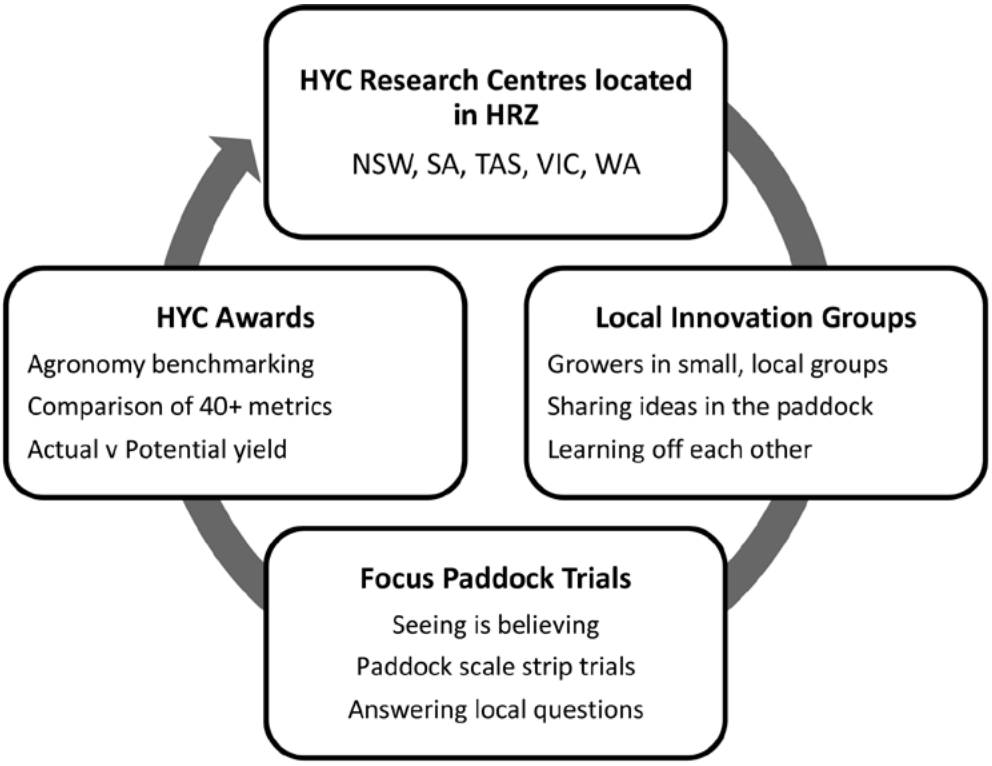

Figure 1. HYC project components.

Farming Systems (SFS). Each of the centres are based on intensively managed small plot trials which are used to identify high yield potential cultivars suited to local environments and determining the most appropriate agronomic management tactics – including nutrition, canopy and disease management strategies.

Local Innovation groups

In order to get the regional research findings out to the local growers the project has engaged four farming system groups (FSG) across the country to set up a number of regional Innovation groups. These are small groups of about 10 -12 growers who will share thoughts and ideas with each other and meet in each others' paddocks a couple of times during the season. The farming system groups are Southern Farming Systems (SFS) in Tas and Vic, MacKillop Farm Management Group (MFMG) in SA, Riverine Plains Inc. in NSW, and Stirling to Coast Farmers in WA.

In 2020 twelve Innovation groups have been established across the five states and there has been a significant amount of interest to increase this number in 2021, as more growers want to take part in the project.

Focus paddock trials

A number of research questions have been raised within the Innovation groups and the relevant FSG project officer helps to facilitate the design, setting up and the taking of key assessments of what are known as Focus paddock strip trials. These Focus paddock trials will also help road-test the findings of the local HYC research centres by taking research and development learnings from small plot to larger paddock-scale trials. It allows the growers to connect between the research science and in the paddock farming.

This component of the project enables a 'seeing is believing' approach, where growers can see the differences they are getting in their paddocks, on their soils, using their own equipment; this is further supported by the local project officers by taking key measurements during the season. By measuring these strip trials and setting them up with a level of replication they can have confidence in the results and then take these learnings and add them into their management, where appropriate.

The project aims to enlist five Focus paddock trials in each state, or on 25 farms across the country, by 2021. There are currently 24 Focus paddock strip trials in 2020.

The agronomic focus of the on-farm strip trials is to optimise yield potential and this is being driven by members of the Innovation groups. For instance, one of the groups has nominated mid-season nitrogen fertiliser management in wheat for Focus paddock trials. Figure 2 shows the range of Focus paddock trials undertaken in 2020.

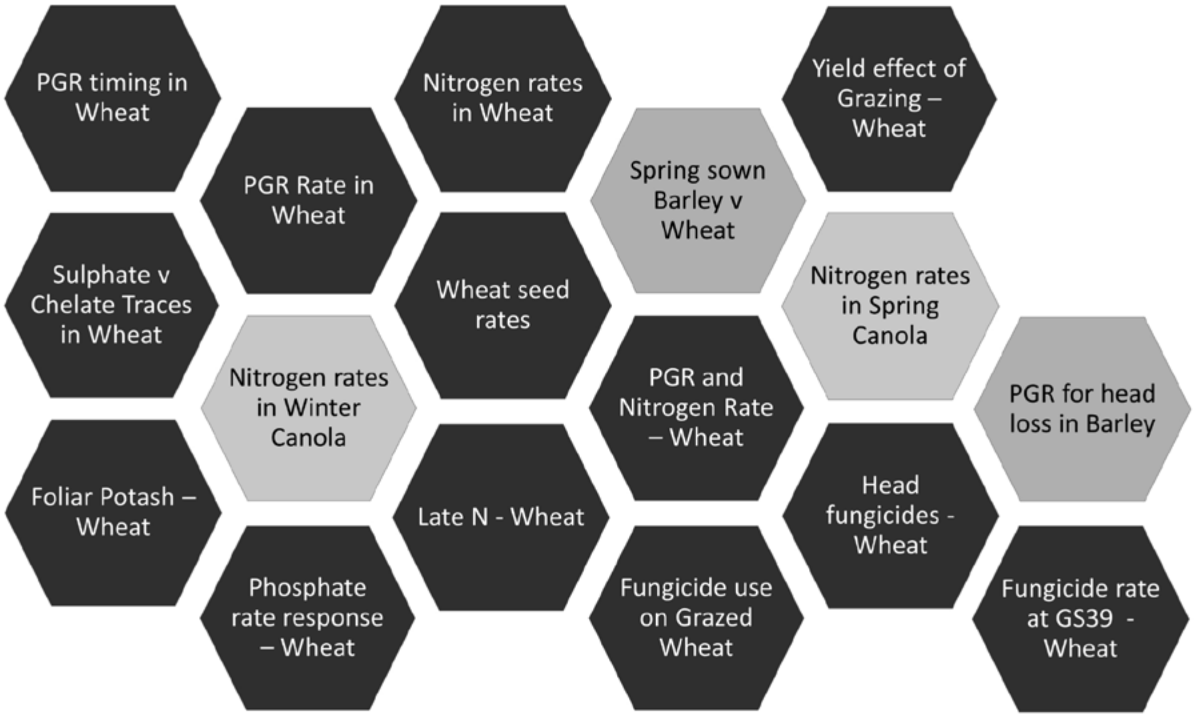

Figure 2. HYC Focus paddock trials 2020.

HYC Awards

The final component of the research project is the HYC Awards program. The HYC Awards program aims to provide agronomic benchmarking for the performance of growers' wheat paddocks and, ultimately, help them to identify the agronomic management practices that contribute to achieving not only higher yields but also what might be limiting their yield potential on-farm. This will be analysed both at a regional level but also nationally, where appropriate.

In order to give growers a theoretical yield target to aim for and also a yield to be judged against in their environment, the project has engaged John Kirkegaard from CSIRO to develop a 'Potential Yield Model'. In broad terms this looks at how good the crop is at capturing water and sunlight and converting these resources into biomass and hence yield.

The water capture is clearly driven from both rainfall and irrigation, and then its availability is affected by the soil depth, texture and structure. The sunlight capture is based on optimising the green area of the canopy, especially during the spring and its duration before the crop senesces. The potential yields obtained through this model will be the basis for two awards per region:

- The highest yield as a percentage of the potential yield by region.
- The highest yield by region.

The HYC Awards aren't about who got the best yield, although that will create some local rivalry, but rather it's about trying to build a whole community of interest, not just in what went right but also what can sometimes go wrong. It's an opportunity for growers to look, compare and discuss those individual factors that help achieve the full yield potential in their environment. The rainfall collection and sunlight capture per paddock has been put together using SILO data and the GPS reference of the paddock. All the relevant data is being entered into the HYC portal which is being developed in collaboration with CeRDI at Federation University, Ballarat. This produces output such as shown in Figure 4 to Figure 8, using details taken from the HYC portal for each paddock.

The HYC project officers were tasked with finding nominations for about 50 wheat paddocks in total (about 10 paddocks per state) as part of the Awards program in 2020 but due to the high level of interest they have ended up with over 60 this season.

Wheat paddocks were nominated for the HYC Awards during July and August, across the five

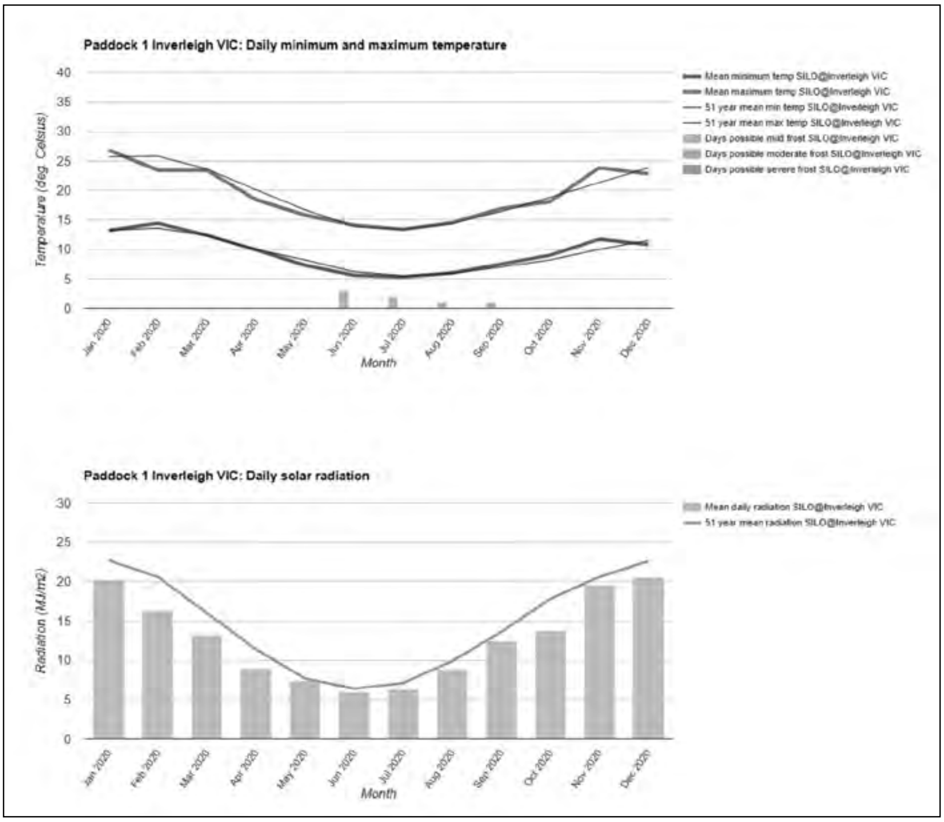

Figure 3. Extract of Silo rainfall data from the paddock data collected on the HYC portal.

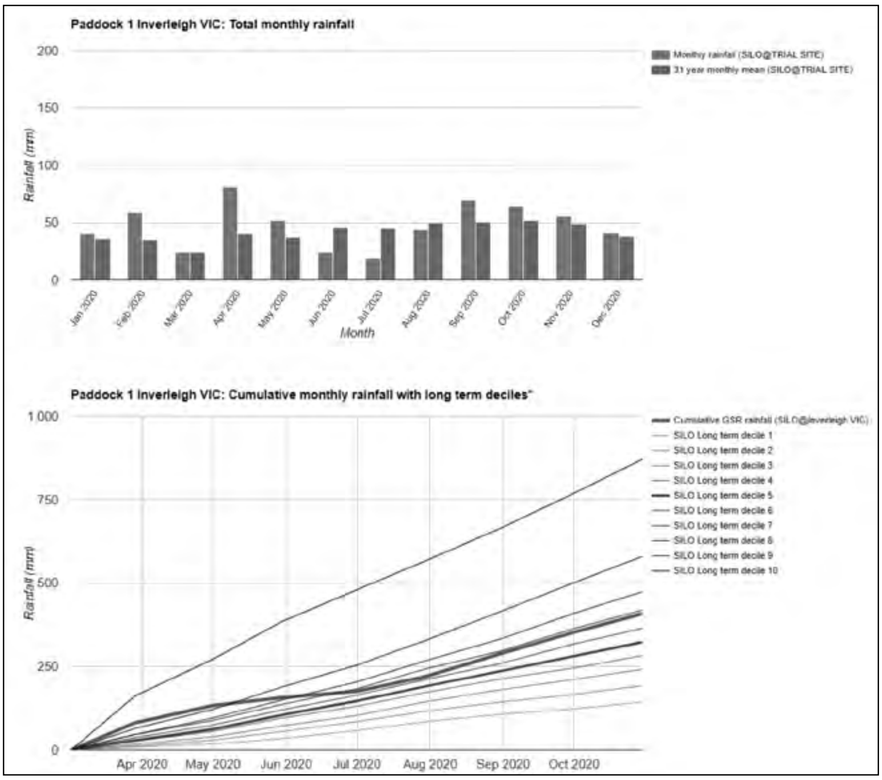

Figure 4. Extract of Silo temperatures and solar radiation data from the paddock data collected on the HYC portal.

Seed

Date	Product	AI	Rate	Units
25-04-20	Trojan		65	kg/ha

Seed Treatment

Date	Product	AI	Rate	Units	Growth Stage
25-04-20	Vibrance	Difenoconazole (66 GAI) Metalaxyl-M (17 GAI) Sedaxane (14 GAI)	230	ml	IBS
25-04-20	Emerge	imidacloprid (500 GAI)	97.5	Ml/ha	IBS

Fertiliser

Date	Product	AI	Rate	Units	N	P	K	S	Ca	Zn	Mg	Mn	Cu	Other
25-04-20	MAP		100	kg/ha	10	22	0	2	0.0	0.0	0.0	0.0	0.0	0.0
25-04-20	UREA		50	kg/ha	23	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
10-06-20	UREA		100	kg/ha	46	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
27-07-20	UREA		100	kg/ha	46	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
				Cumulative total	**125**	**22**	**0**	**2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Deep N Test (0-30cm)

Date		N	P	K	S	Ca	Zn	Mg	Mn	Cu	Other
		21	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
	Cumulative total	**146**	**22**	**0**	**2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Deep N Test (30-60cm)

Date		N	P	K	S	Ca	Zn	Mg	Mn	Cu	Other
		45	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0
	Cumulative total	**191**	**22**	**0**	**2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**

Figure 5. Extract from the paddock data collected on the HYC portal.

states and many have come from the Innovation group members themselves. The project officers have been collecting data from growers and agronomists and entering into the HYC portal. This includes all the standard background paddock input data that a grower would collect, see part of the paddock records in Figure 5.

Project officers have also taken soil tests, peak biomass cuts at GS65 (mid flowering) and harvest biomass cuts including head counts. A sub sample has then been sent to the team at FAR Australia to analyse yield components such as grains/head and harvest index.

A grain sample is also collected from each paddock and this will have both a physical grain test analysis (protein%, test weight and screenings) undertaken, and a full grain nutrient analysis undertaken by APAL, which will be analysed as part of the data set and included in a report.

Having collected all of this data the HYC Awards will produce a report for each grower showing regional comparative data across forty different metrics, but also where their individual paddock value compares against all other HYC Award paddocks. This will be done using histogram bar-charts, comparing the individual grower value with everyone else's in that region and with critical values, if available and appropriate. This means the data used in the report will be completely confidential and only the individual grower will know their values.

Figure 6, Figure 7 and Figure 8 are some examples of the 40-plus metrics that will be put together in the HYC Awards report. As the final data from 2020 wasn't available at the time of writing, these examples use simulated data.

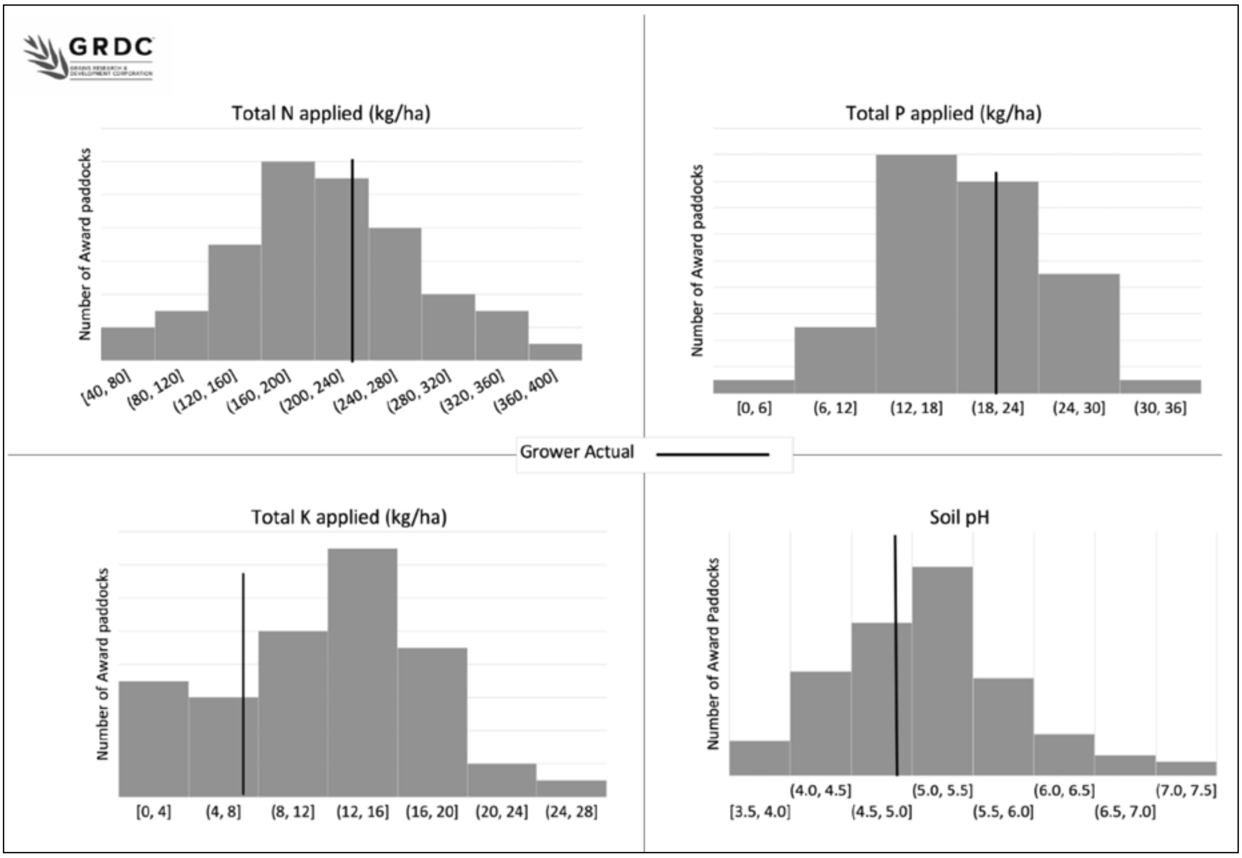

Figure 6. Extract of regional data from HYC Award paddocks compared to grower actual shown as histograms. Data from HYC portal.

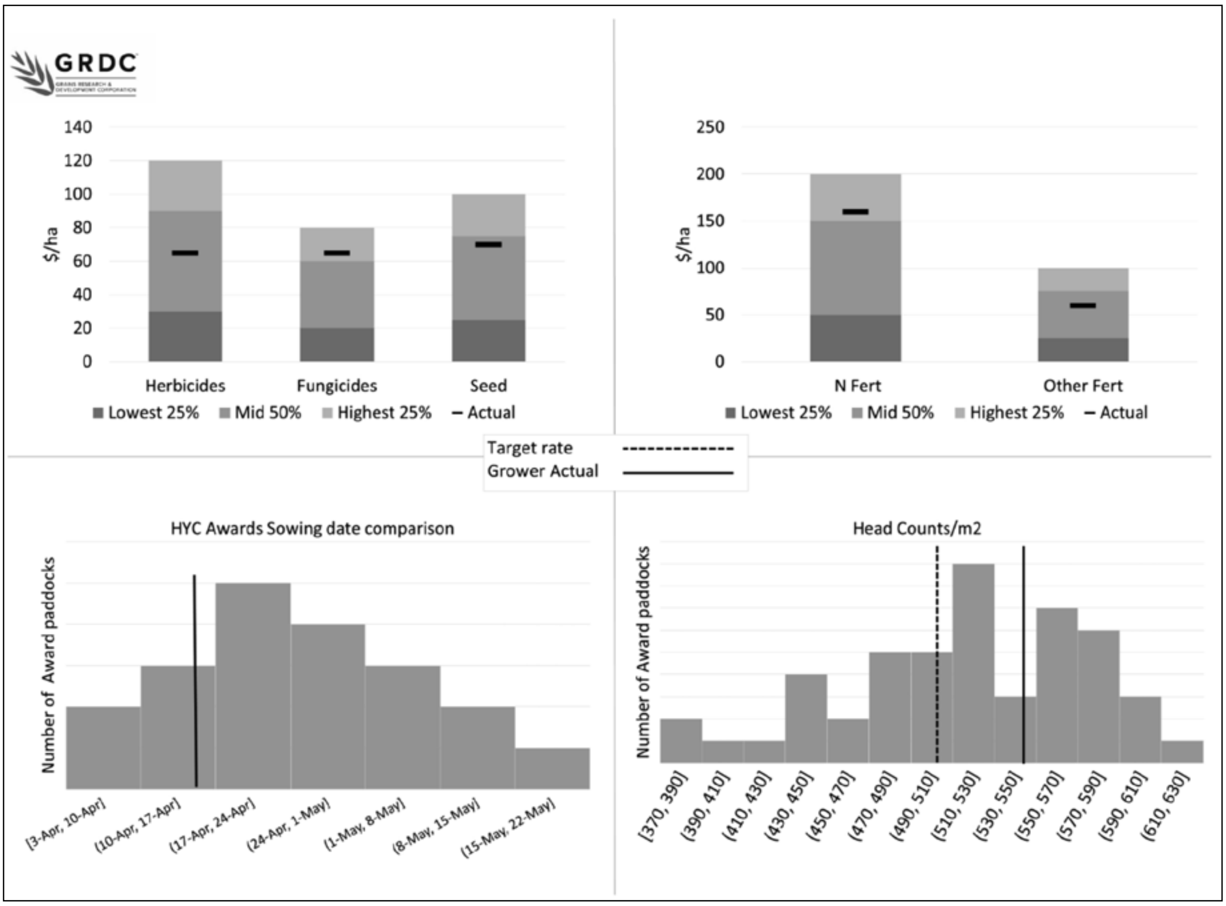

Figure 7. Extract of regional data from HYC Award paddocks compared to grower actual shown as histograms. Data from HYC portal.

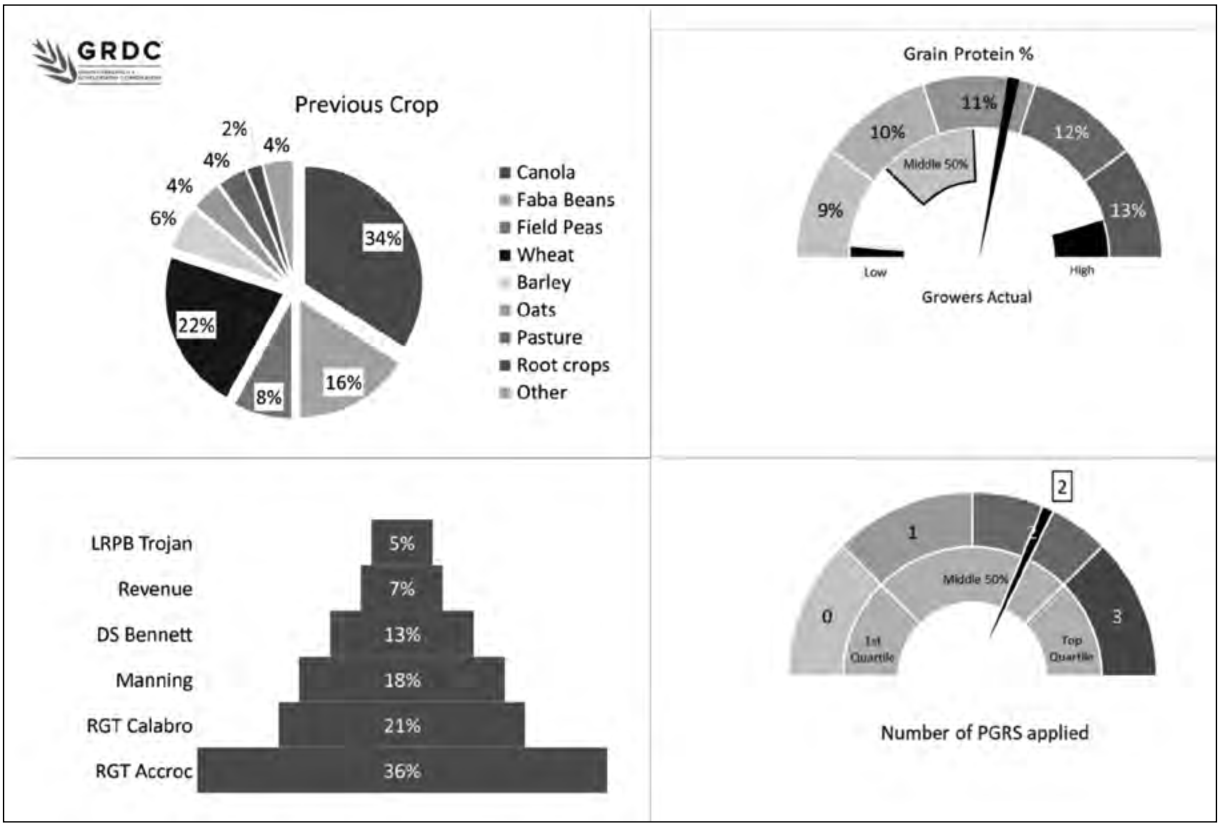

Figure 8. Extract of regional data from HYC Award paddocks compared to grower actual. Data from HYC portal.

Conclusion

The Hyper Yielding Crops project is based in the HRZ regions of five states: Vic, SA, Tas, NSW and WA. It aims to produce aspirational yields of wheat, barley and canola by examining the key agronomic and farming system levers to achieve higher yielding crops that are both more productive and profitable. There is a strong focus on getting the research to the growers and so Innovation groups have been established in the five states and within these groups there are Focus paddock trials for groups to answer a research question on a paddock scale strip trial.

The project is also providing a comprehensive paddock agronomic benchmarking report for HYC Award entrants, which will analyse over forty metrics from regional entrants and compare them with the individual growers levels. They will also be provided with a potential yield target for their crop.

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.

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Notes

2020 - the year of the armyworm

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GRDC project code: CES1904-002RTX

Keywords

- armyworm, management, identification, reporting, surveillance.

Take home messages

- The incidence of some pests varies dramatically from year to year; the reports of large infestations of native species of armyworms were very prominent in 2020.
- Drought breaking rains, mild winter temperatures and even changing cropping practices may have contributed to the outbreak of armyworms. The recent arrival of fall armyworm in Australia will further complicate this.
- PestFacts services in south eastern Australia have a 14 year history of assisting the grains industry with identification services, managing invertebrate pests, and with recording pest incidence across time.
- As with other pests, correct identification of armyworms, is an important first step in sustainable management.

Background

'Identification, surveillance and advisory platform for management of grains pests' (CES1904-002RTX) is delivered by cesar Australia, DPIRD, QDAF, NSW DPI, and SARDI. It aims to provide grain growers and advisers with timely in-season information on invertebrate grain pest occurrence and to equip industry with the knowledge needed to implement integrated pest management practices. One delivery platform for this project is PestFacts south-eastern.

PestFacts south-eastern keeps growers and advisers informed about invertebrate pests and beneficials in broadacre crops and pastures during the winter-cropping season in Victoria (Vic) and southern New South Wales (NSW). It has been running since 2006 and provides regular updates to a subscribership of over 1300 grains advisers and growers throughout southern NSW and Vic. Equivalent platforms are the PestFax service (grains western region), PestFacts South Australia, and the Beatsheet (Grains northern region).

PestFacts south-eastern can demonstrate a long history of tracking and collating field observations. Pest reports, and more recently, reports of beneficial species, have been logged in the PestFacts Map database since 2006. This database includes uploaded reports from both PestFacts South Australia (coordinated by the South Australian Research and Development Institute) and from PestFacts south-eastern (coordinated by cesar Australia). Therefore, the database includes over a decade of field reports from across south eastern Australia.

Not all reports are verified (for instance, some reports are verbal or provided over email and lack a digital image or sample for identification). Therefore, this database provides an indication rather than an absolute picture of pest and beneficial occurrences over a given season. In addition, there are potential influencing factors that may bias reports, which should be taken into account when using information from this database.

For instance, reporting is likely to be influenced by changes in agronomist knowledge over time (e.g., an improved understanding of how to differentiate pest species) and raised awareness about certain pests (e.g., public coverage of exotic pest incursions). Nevertheless, when assessed in context, this dataset remains a powerful tool for retrospectively considering pest occurrences over time.

Armyworm species in south eastern Australia

'Armyworm' is a catch-all common name for the larvae (caterpillars) of several related moth species spanning temperate, sub-tropical and tropical climates. The types of armyworm that most grain growers and advisers are most familiar with in south eastern Australia are those that prefer cereals and grasses. These include three native species: the common armyworm (*Mythimna convecta*), the southern armyworm (*Persectania ewingii*), and the inland armyworm (*Persectania dyscrita*).

These native species as larvae are difficult to tell apart by eye; reliable identification requires adult moth specimens. Nevertheless, identifying each individual species in the field is generally not critical because their broad habits, type of damage and control are similar.

In February 2020, the fall armyworm 'FAW', *Spodoptera frugiperda*, was first reported on the Australian mainland in far north Queensland (Qld). The pest has rapidly spread and has now been detected across parts of Qld, Northern Territory (NT), NSW, and Western Australia (WA).

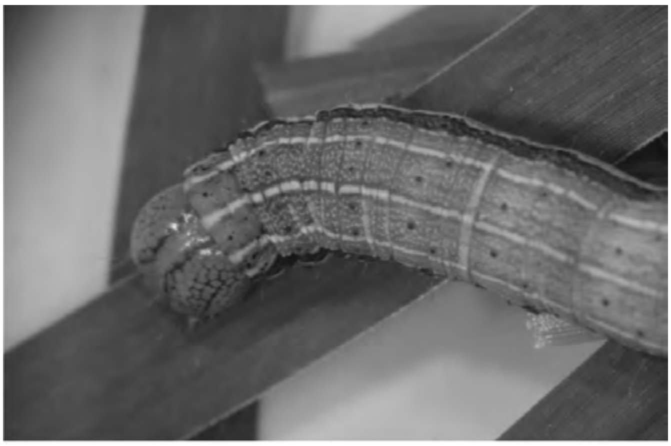

Figure 1. The three parallel light stripes on an apparent 'collar' behind their head (prothoracic shield) is a key feature of the common armyworm, southern armyworm and inland armyworm. The light stripes often, but not always, persist along the abdomen. (Image credit: Julia Severi, cesar Australia).

Models developed by cesar Australia (Plant Health Australia, 2020) and Du Plessis *et al.* (2018) show that FAW will likely be observed in a wide range of growing regions, but the expected seasonal activity will vary depending on climatic conditions. While northern parts of Australia will support permanent, year-round populations, migrations into southern regions, such as central WA, Victoria's high rainfall region or the Mallee region in SA and Vic are predicted to occur from spring as the weather warms.

In this paper, we present an overview of all field reports collected from across south eastern Australia in 2020, with a particular focus on incidences of native species of armyworm throughout this time period.

Results and discussion

Overview of invertebrate reports in 2020

Last year the majority of reports across south eastern Australia to PestFacts services were received from May-August. In 2020, reporting was dominated by detection of lepidoptera, followed by various species of aphid. Overall, reports of armyworm were highest throughout 2020, followed by reports of Russian wheat aphid (Table 1).

During planting and early establishment of winter crops, cabbage centre grub and weed web moth were the most commonly reported species. Cutworm, Russian wheat aphid and armyworm (native spp.) were the most common reports from May-August. As the weather warmed during early spring, native budworm become the most commonly reported species.

Early season Lepidoptera activity

Early 2020 represented an unusual situation for weed web moth, which has long been considered a sporadic and minor pest in South eastern Australia, and cabbage centre grub, which is a warm season pest that generally declines rapidly during autumn.

Based on behaviour and morphological features, reports of weed web moth were suspected to be *Achyra affinitalis*. Reports from the Riverina, South West Slopes, and Central West Slopes and Plains in NSW indicated the presence of high numbers on establishing canola, lucerne and broadleaf weeds. Past records document weed web moth larvae as growing to 15mm. However, during early 2020 several larvae were measured up to 20mm, and even up to 35mm in some instances.

Table 1. Pest reports supplied to PestFacts south-eastern and PestFacts South Australia from January-December 2020 for major pest categories. For brevity, some reports are omitted (e.g., Beneficial reports are not included). Highest reports for each category are bolded.

		TOTAL	JAN-FEB	MAR-APR	MAY-JUN	JUL-AUG	SEP-OCT	NOV DEC
Aphids	Blue green aphid	3			1	2		
	Cabbage aphid	2			1		1	
	Cowpea aphid	25		2	11	6	6	
	Green peach aphid	7			2	4	1	
	Oat aphid	2			2			
	Root aphid	3			3			
	Russian wheat aphid	**55**		2	32	19	2	
	Turnip aphid	4			4			
Mites	Balaustium mite	2		1		1		
	Blue oat mite	9		2	5	1	1	
	Bryobia mite	6		2	3	1		
	Redlegged earth mite	**16**		5	11			
Caterpillars (Lepidoptera)	Beet armyworm	3						3
	Bronzed field beetle	5			3	2		
	Brown pasture looper	19			4	15		
	Cabbage centre grub	12		10	1	1		
	Cutworm	37		8	18	11		
	Corn earworm	5		3		1		1
	Diamondback moth	3				2	1	
	Flea beetle	3			2	1		
	Grass anthelid	1				1		
	Grass blue butterfly	1	1					
	Herringbone caterpillar	13			4	7	2	
	Armyworm – native spp.	**52**		2	9	33	8	
	Native budworm	22		2	3	3	13	1
	Pasture day moth	5			2	3		
	Pasture tunnel moth	4			3	1		
	Pasture webworm	8			3	5		
	Underground grass grub	1				1		
	Weed web moth	20	1	15	4			
Beetles	African black beetle	6		1	5			
	Argentine cockchafer	1		1				
	Black headed cockchafer	1			1			
	False wire worm	2			2			
	Little pasture cockchafer	1			1			
	Vegetable beetle	1			1			
	Yellow headed pasture cockchafer	**8**		1	7			
Weevils	Grey banded leaf weevil	1			1			
	Sitona weevil	1			1			
	Vegetable weevil	**6**			6			
	White-fringed weevil	1		1				
Others	European earwig	5			4	1		
	Leafhopper	9			9			
	Lucerne flea	10		4	5	1		
	Millepede	2			2			
	Rutherglen bug	11		3	4	4		
	Ryegrass mealybug	3			1	2		
	Slaters/Pill bug	3			3			
	Slugs & snails	**14**		2	11	1		

Cabbage centre grub (*Hellula sp.*) was also found in higher than usual numbers in southern and central NSW, with damage being observed on young canola plants and forage brassica.

Atypical reports

Each year PestFacts south-eastern receives reports of atypical invertebrates in crops. During 2020, the service received a number of unusual reports during the winter cropping season. These were primarily located in the Riverina and Central West Slopes and Plains of NSW. Of note were:

- Flea beetle (*Phyllotreta undulata*) in canola;
- Rice root aphid (*Rhopalosiphum rufiabdominale*) in wheat stands; and
- Leafhoppers in canola and other crops.

A high number of armyworm reports

During winter to early summer, reports of armyworm were relatively common in comparison to preceding years. For instance, in 2020 more armyworm reports were received to PestFacts services (PestFacts south-eastern and PestFacts South Australia) than in any year of the preceding 14-year period (Figure 2). In 2020, most armyworm reports were received from the Loddon-Mallee, eastern Wimmera and Eyre Peninsula regions (Figure 3).

According to reporters, significant armyworm damage and large populations were observed in several cases, although there were also many cases where no damage was evident. Reports were also received of armyworm marching behaviour, which happens when populations become stressed and run low on a food source. Examples of reports where feeding damage and high numbers were observed are included below.

Case 1 (Late March):

- Significant damage to an oat crop - quickly moving across one side and leaving no plants behind.
- 2-3 weeks post sowing.
- No real sign of damage one week after sowing.
- Originated from a neighbour's pasture paddock.
- Agronomist monitored the pasture finding 5 - 6 larvae each sweep.

Case 2 (Late July):

- Approximately half a hectare of wheat (GS20-29) observed were plants had no leaf, only stem remaining.

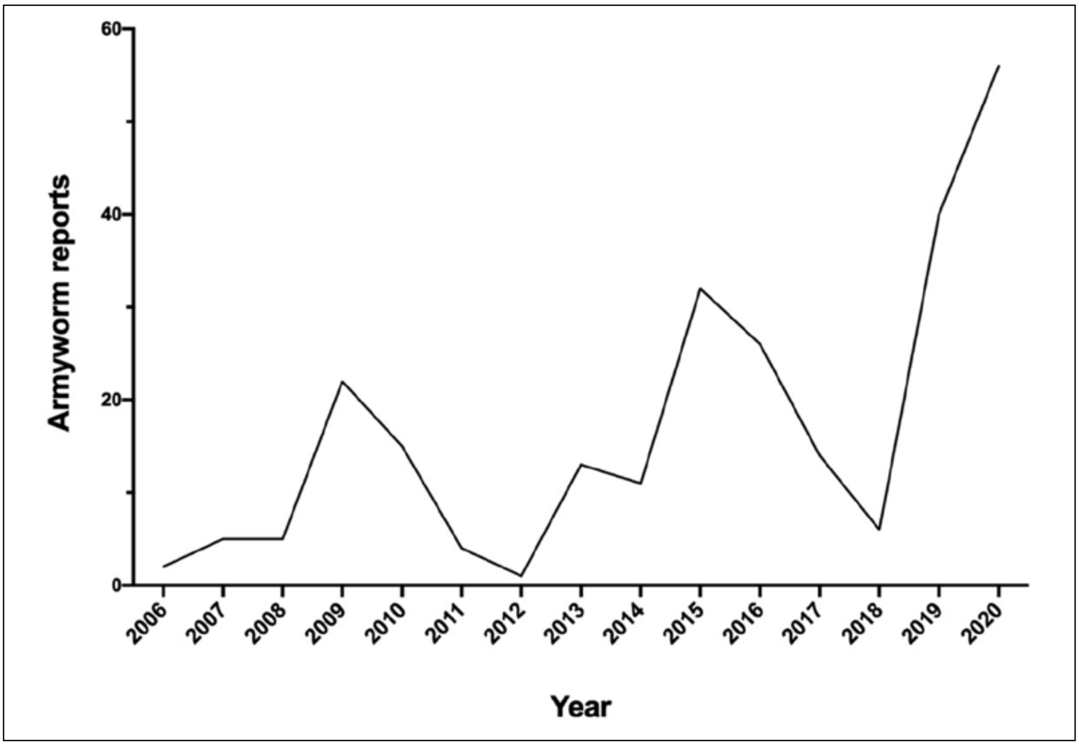

Figure 2. Reports logged as 'armyworm' for South eastern Australia over 2006-2020 (Source: PestFacts Map database).

- Larvae were easy to find, feeding on the plants and sheltering under the surface clods of soil.
- There were an estimated >50 larvae per square metre in the most damaged parts of the paddock.
- There was a high amount of stubble residue on the surface.

Case 3 (late August):

- Armyworm were found crawling across a road.
- The caterpillars were dark in appearance.
- They were moving out of a paddock that was 'eaten out'.

Factors that may influence high armyworm activity and reporting

Many invertebrate pests fall roughly into one of two groups: resident or migrant pests. The latter are inclined to invade crops in seasonal surges. Native species of armyworm are examples of migratory moth species that are well adapted to breed on native and introduced grasses in production and more arid inland regions. When adults of these populations migrate, synoptic conditions that often result in rainfall facilitate their flight, in some instances over hundreds or even a thousand kilometres, to new regions (Farrow and McDonald 1987; Drake and Farrow 1988). Therefore, migrating moths tend to be concentrated in areas where rain is likely. Heavy rains, particularly in autumn, can drive growth of armyworm populations (McDonald 1991). Under the right conditions, armyworm populations can quickly build in numbers as winter grasses and crop host plants enter a vegetative growth phase. Investigation of common armyworm phenology indicates that there are two generations over autumn and winter, with the first generation taking advantage of autumn rainfall, and the second generation being laid in June/July (McDonald *et al.* 1995).

Outbreak events require adequate populations in source areas (i.e., supported by autumn rainfall in arid inland regions), suitable atmospheric conditions to facilitate moth migration to production regions, as well as rainfall and subsequent vegetative growth of plant hosts within a short time after egg lay. Large outbreaks in Queensland and in parts of NSW following heavy rain events in 1988 and 1989 have been described in McDonald *et al.* (1995).

In assessing pest bulletins for southern Australia over a period spanning the early 80s, late 80s, early 90s, and 2006-07, Hoffmann *et al.* (2008) notes a reduced incidence of armyworm outbreaks over this period. The reduction was attributed to

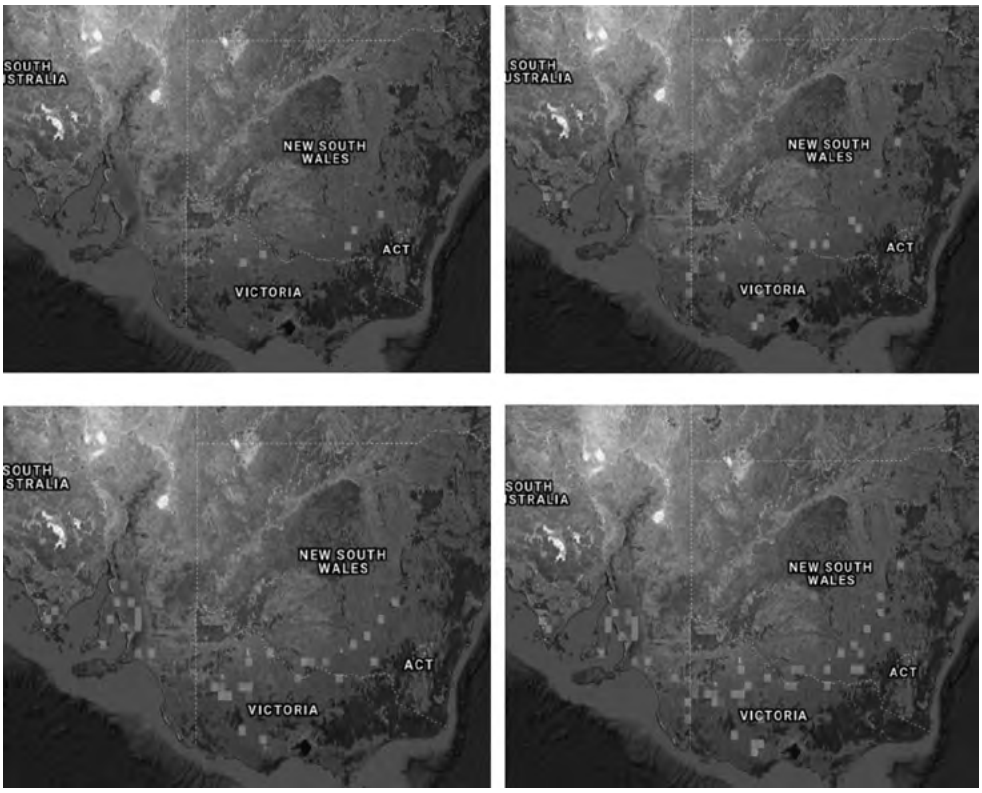

Figure 3. Reports of armyworm to Pest Facts services across three years: 2018 (top left – 6 reports), 2019 (top right – 40 reports), 2020 (bottom left – 55 reports), 2018-2020 (bottom right – 101 reports).

dry conditions preventing a build-up of armyworm species – high winter rainfall was rare across the timeframe assessed by Hoffmann *et al.* (2008). Armyworms are a pest that are well adapted to exploit post-drought conditions. Intense armyworm breeding and slow recovery of natural enemies following the dry weather gives armyworm species a strategic head start.

Such a situation was described in McDonald *et al.* (1990), which assessed a 1983 armyworm outbreak six months after a nation-wide drought had broken. While some population growth of common armyworm at the time was driven by drought-breaking rains, other large populations were supported by localised rainstorms. Multiple instances of moth emergence from April to November, local and long-range migration of emerged moths, and a substantial increase in suitable habitat was likely to have supported armyworm colonisation of inland NSW during this period.

This post-drought effect is observed for armyworm species found overseas. Janssen (1993) describes in detail the phenology of the African armyworm (*Spodoptera exempta*) and factors influencing outbreak situations in Tanzania and Kenya. In this situation, outbreaks occur with the first rains of the wet season. They describe a drought-outbreak effect, whereby large numbers of African armyworm are commonly detected after drought-breaking rains.

In 2020, large native armyworm populations were observed at a number of sites across SA, Vic and southern NSW. In line with high reporting of armyworm, above average rainfall was recorded between 1 January to 30 November across NSW and central Vic (where a high number of armyworm reports were made) (BOM, 2020).

Development times and survival of native armyworm are strongly influenced by temperature. Surveys for the common armyworm from 1988-89 found that survival of common armyworm was low over autumn and winter in Vic and high in Northern NSW and Southern Qld (McDonald *et al.* 1995). The southern armyworm, which has a lower optimum temperature threshold than that of the common armyworm, was found to be more abundant than the common armyworm in more southern latitudes. North of 33° the common armyworm was the dominant species (McDonald *et al.* 1995).

It is possible that a mild winter in south eastern Australia favoured armyworm species. Across Australia, the January – November 2020 mean temperature was the third warmest on record. This combination of higher than average rainfall, and higher than average temperatures from autumn – spring over much of the country (Figure 4) is likely to have supported the breeding of native species of armyworm in arid inland regions, as well as survival in cropping regions over winter.

Another possible contributing factor to the year's outbreak may have been a gradual shift in cropping practices. For example, Hoffman *et al.* (2008) suggest that reduced armyworm reports from the early 80s to mid 2000s may have also been a product of changing farming practices. Specifically, rotation with pasture grasses had become less common during this period. Since 2007, armyworm reports have been increasing. Localised outbreaks may be influenced by other practices, such as stubble retention and no-till, with high loads of

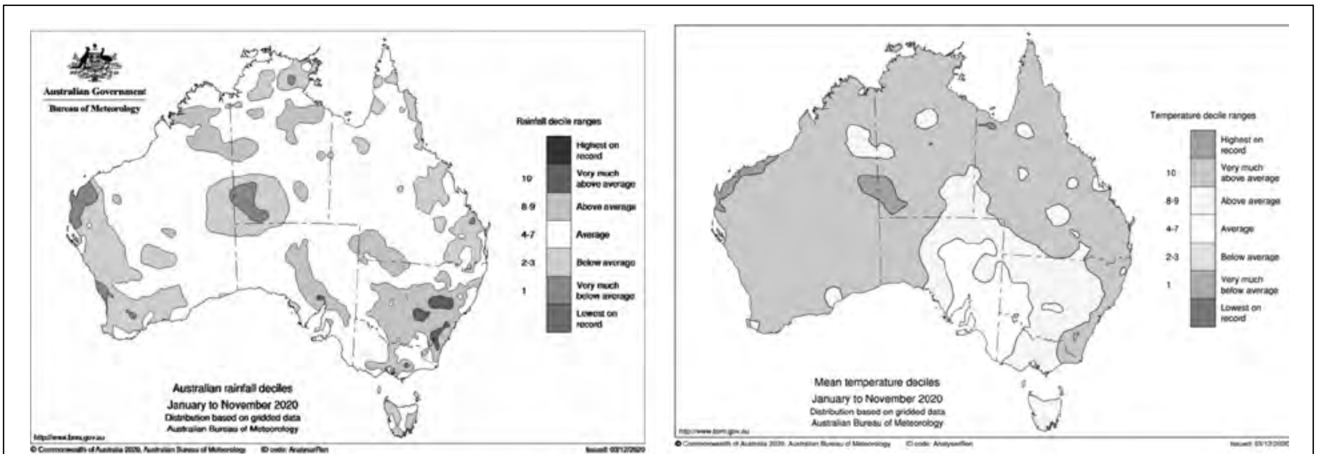

Figure 4. Rainfall deciles for January to November 2020, based on all years 1900 to 2020 (left), and mean temperature deciles for January to November 2020, based on all years 1910 to 2020 (right) (Source: the Bureau of Meteorology)

retained stubble in autumn providing a preferred site for armyworm oviposition.

Several reports in 2020 noted that armyworm had been found in paddocks (often barley paddocks), with a high stubble load. Oviposition behaviour during autumn is central to such a scenario. Armyworm moths lay their egg batches (in their hundreds) in very tight cracks and crevices in gramineae. One known egg-laying site is the remnant crevice between the flag leaf and dead tillers in dried grasses and cereal stubble. Previous observations have demonstrated that green grass pasture (barley grass, *Hordeum glaucum*) with a component of dried grass had higher densities of common armyworm larvae, in comparison to a pasture lacking the dried grass component (McDonald 1991).

In addition, based on laboratory-based experiments undertaken by McDonald (1991), oviposition options offered by dried grass (cocksfoot – *Dactylis glomerata*, oats – *Ayena sativa*, and barley – *Hordeum vulgare*) are a more highly preferred than those offered by green, actively growing grass of the same species. This preference helps to explain why larger larval populations are often found in stubble-retained paddocks and why cereal crops sown into cereal stubble, particularly standing stubble, can be at a higher risk of armyworm invasion and subsequent feeding damage.

Reporting can be positively influenced by increases in knowledge, awareness campaigns, and prior experience that has led to greater diligence in monitoring. For instance, high numbers of lepidoptera early in the 2020 winter cropping season (e.g., weed web moth and cabbage centre grub) may have primed field staff towards observing lepidoptera throughout the season. In addition, during 2020 the industry become particularly aware of the need to investigate armyworm in paddocks following the northern Australia incursion of FAW in February 2020, which had high media coverage from February – May 2020. Rapid spread of this species to more southern regions has led to many in the grains industry adopting an 'early detector' approach.

During the early stages of the FAW incursion, there was notable knowledge accrual behaviour. In early 2020 active learning about armyworm in Australia was evidenced by a large increase in the number of armyworm PestNote page views on the cesar Australia website (2,378 views during 1 February-1 April 2020). The majority of page entrances from February-April 2020 resulted

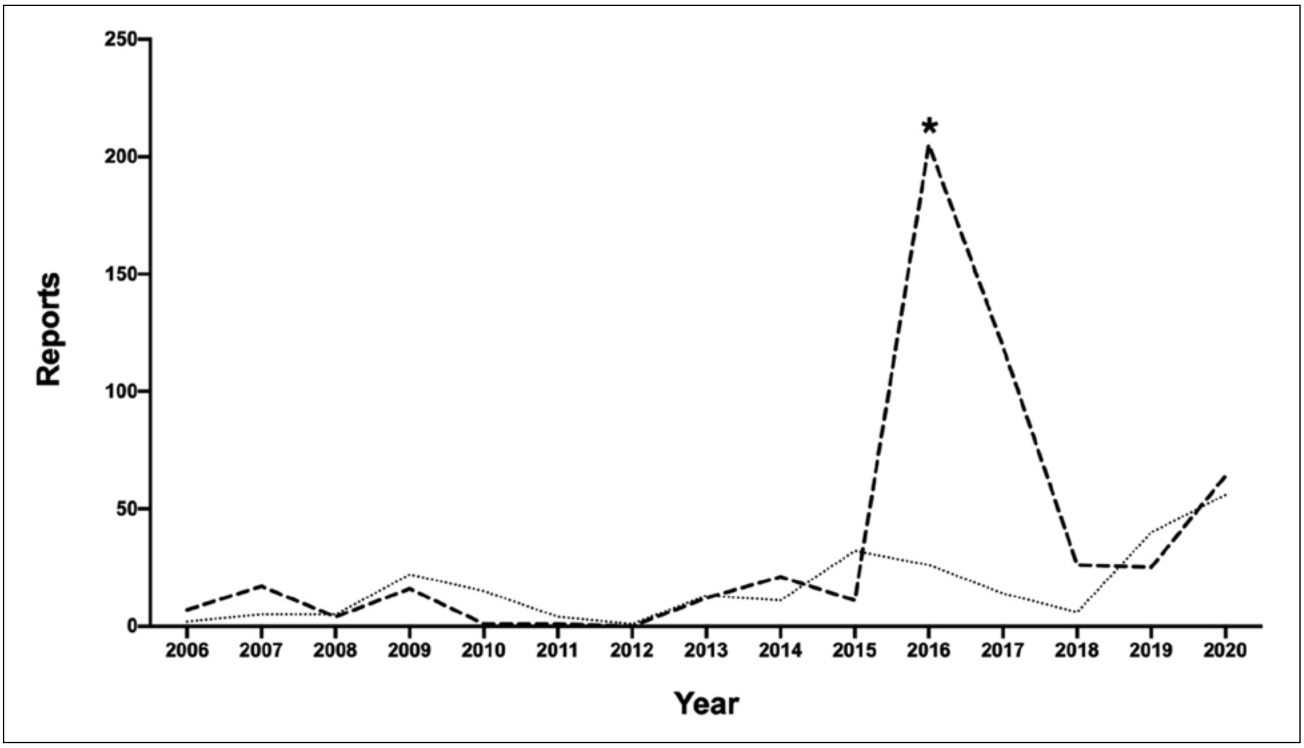

Figure 5. Increase in field pest reports after an exotic species has been detected. Cereal aphid (corn aphid, oat aphid, and Russian wheat aphid) reports from 2006-2020 are shown as the bolded, dashed line. The majority of reports are for Russian wheat aphid. Armyworm reports are included as a dotted line. The asterix indicates when Russian wheat aphid was first detected in Australia.

from direct google key word searching. This is in contrast to 2019, when this PestNote was visited 711 times during the same period. Therefore, a higher awareness of armyworm in the field was likely influenced by such preparatory behaviour at the beginning of the winter cropping season.

Additional reports for a particular pest group following an exotic pest incursion is to be expected. This was observed in 2016, with the detection of Russian wheat aphid (*Diuraphis noxia*) in SA. Figure 5 displays corn aphid (*Rhopalosiphum maidis*), oat aphid (*Rhopalosiphum padi*) and Russian wheat aphid reports from 2006-2020. A notable increase in aphid reports occurred in 2016, when Russian wheat aphid was first detected.

The importance of distinguishing armyworms

Typical feeding behaviour of common armyworm, southern armyworm and inland armyworm is to feed on leaves and young tiller growth. If the crop is young, this occasionally sets back the crop, but generally there is minimal economic impact unless there's heavy defoliation. However, as crops dry down, large populations of armyworm can become more voracious as available green material becomes scarce. It is at this point that the larvae that routinely move up the plant, become attracted to the nodes and stems that stay green for longer. If the larvae are a later stage of maturity, head lopping can occur. In Victoria, the common armyworm is most likely to reach a late larval stage when cereals are drying down. In Tasmania, as reported by Hill (2013) it is the southern armyworm that is likely to reach damaging late instar stages when cereals are most susceptible.

Barley and oats are particularly susceptible to damage if mature caterpillars are present in spring, due to their relatively thin stems and the potential for lopping of maturing heads. Therefore, as host crops approach ripening, detecting an armyworm infestation is important in order to make a decision about whether active control is necessary or not.

With the incursion and establishment of FAW in Australia during early 2020, the need to become proficient in field-based armyworm identification is greater. This involves gaining a sound understanding of species phenology as well as morphology, in order to determine when a species of armyworm is likely to be found in the region, and on what hosts.

Based on work on the predicted seasonality of FAW (Du Plessis *et al.* 2018; Plant Health Australia, 2020), this species is unlikely to be an issue for much of the winter cropping season in southeastern Australia. It requires temperatures to be above a certain threshold for development (approximately 12.5°C for egg to adult development). In addition, it does not have a diapause phase, and therefore, it cannot survive cold winters in an 'inactive' state (Luginbill 1928).

However, FAW is highly migratory and capable of dispersing several thousands of kilometres. It is possible that southeastern Australia could receive seasonal migrations of FAW during summer when susceptible crops like maize and sorghum are grown. Ultimately, how Australia's climatic and vegetation zones will influence the timing and magnitude of migrations is still unknown.

During the warmer months, with much of the industry on alert for the possible spread of FAW into southern cropping regions, it is important to recognise that other species of moth larvae of less importance than fall armyworm can be found in summer field crops.

During the early summer of 2020 one species reported as creating damage in maize and soybeans was the beet armyworm (*Spodoptera exigua*), also known as the lesser armyworm. This species is thought to be native to south-east Asia, and like several other sub-tropical and temperate countries, it has established in much of mainland Australia. With a very wide host range spanning broadleaf plants and grasses, vegetables, flowering ornamentals (Capinera 2020), maize, cotton, lucerne, sunflower, rice, sorghum, millet, linseed and sesame (Common 1990) it demonstrates host range overlap with FAW.

Field reports in 2020 have demonstrated that beet armyworm larvae can be present in FAW host crops during the warmer months in Vic and southern NSW. However, reports have been infrequent and 'windowing' feeding damage is reported as being patchy. Therefore, this species is very unlikely to require chemical intervention. Becoming more familiar with morphological features of the beet armyworm will reduce the chance of a misidentification during monitoring for a FAW incursion.

Like species of native armyworm, which occur in winter cereals, the beet armyworm does not have a hairy appearance and can display some resemblance of the three parallel light stripes on an apparent 'collar' behind their prothoracic shield. These lines continue down the length of their bodies, however they are not always present or as distinctive as may be seen on native armyworm species.

The beet armyworm can vary in colour from light green to dark green-brown and have a mottled appearance. It is not uncommon to observe some pinkish pigmentation. They often have a white stripe down their sides, and white spots close to their spiracles. Beet armyworm larvae can be distinguished from *Helicoverpa* sp. and FAW, by their lack of enlarged spots (pinacula) and lack of coarse hairs.

Aiding entomologists to improve tracking and verification

The level of reporting to PestFacts services has remained relatively stable since 2010, with reporting peaking in 2016-2017 and 2020. A major change in reporting has involved how reports are received, and the format of these reports.

In 2010, reporting was primarily face to face and over the phone, while identification requests were undertaken from live samples. From 2017, with the introduction of the PestFacts Reporter app and increasing usage of Twitter and email, digital images have become the preferred method for requesting an identification (live samples decreased in 2020 in part due to COVID-19 restrictions).

In terms of verifying reports that are uploaded to the PestFacts Map database, the preference towards use of digital samples has been a benefit, with the potential to verify reports having increased from 25% in 2010 to 59% in 2020. Apart from allowing greater opportunity to verify reports, this method reduces cost and time input for the reporter and increases the potential for a faster response from entomologists. However, a greater proportion of digital reports also represents additional challenges. With a greater number of invertebrate identifications to undertake overall, performing identifications efficiently is crucial.

Identification requires the entomologist to clearly view the features of the insect, such as the structures of legs, wings, body hairs, and other appendages, as well as consistency of colour, etc. The ability to verify a report or perform an identification can be hindered by insufficient information and low-quality images. Remembering some basic best practices for taking a high-quality digital image improve the chance of receiving an accurate and timely identification.

Guidelines for supplying a high-quality digital sample

1. Optimise focus: Ensure that it is the invertebrate that is most in focus, and not the plant or your hand or the soil.
2. Take multiple angles: Identifying an invertebrate from just one angle/photo is not ideal, particularly if they are obscured by soil or plants. Take several photos from various angles such as top down, side view and/or front on, where applicable. Taking photos of several individuals to account for variation in the population is also good practice.
3. Use appropriate technology: Carry a 5x or 10x smartphone macro lens that can be clipped over a smartphone camera. They enable a clearer image for smaller invertebrates like aphids and mites, and they can also be used on other types such as caterpillars, moths and beetles. Contact cesar Australia to receive a lens.
4. Consider microscopic features: Small features such as hairs, raised spots, segmentation, head form and mouthparts, antennae and legs, all provide key information about the invertebrate. If the subject is relatively large

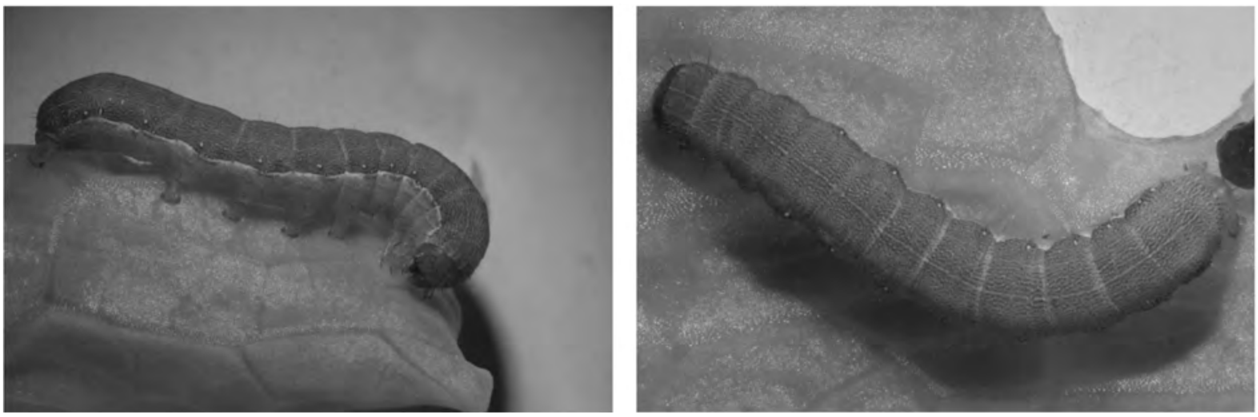

Figure 6. A lateral and dorsal view of a beet armyworm larva (top left and top right) (Image credit: Julia Severi, cesar Australia).

(such as a late instar caterpillar) supply close-up photos of the invertebrate in sections (e.g., thirds).

5. Prepare the subject: Very mobile invertebrates, such as mites, can be placed in the fridge for 10-15 minutes prior to taking a photo. This will slow them down.

Additional information that should be sent with the digital sample, where possible, include:

- The location (to the resolution of the locality, e.g. Rochester);
- Host on which the sample was found;
- Growth stage;
- Damage observed;
- Extent of the infestation (e.g. patchy over 1 hectare); and
- Paddock history (previous crop, tilled/not tilled, seed treatments, spray applications).

There will be some circumstances where digital samples are not sufficient for an identification. Therefore, it is good practice to keep a small container in the car so that a live sample can be collected and mailed.

Conclusion

It is important to note that reporting does not necessarily reflect abundance. For instance, reports of lucerne flea were low in 2020, yet this is generally a highly abundant pest. Rather, these pest reports can be used to gain insight into unusual regional issues during the season and to understand what pest species are viewed as significant to the broader industry. Thus, this reporting system is an indirect mechanism for understanding changes to pest pressure and importance (Hoffmann *et al.* 2008; Mangano *et al.* 2005).

As a method of determining pest importance, Hoffmann *et al.* (2008) notes that outbreak bulletins have caveats. Field staff may not correctly identify species, minor outbreaks may not be reported, and these reports do not necessarily reflect the economic importance of a pest outbreak. Reporting can also be influenced by a variety of factors. Increased reporting will occur when:

- A new species is 'expected';
- When a species is 'unusual' and highly visible;
- When symptoms are very visible and specific (e.g., Russian wheat aphid); and
- When there are issues managing a species in an area (e.g., resistance, no chemical options, an increase due to changes in management).

Reports will decrease in frequency for pests that are 'common' and easy to manage. However, in the absence of a structured system of report collection and validation, these reports have potential to be used as a proxy measure.

Hoffmann *et al.* (2008) had previously assessed southeastern Australian pest reports over a multi-year timeframe in order to identify changes to what pests are deemed as important in the Australian grains industry. It is likely that the importance of pest groups in relation to reporting has once again shifted since that analysis and another assessment of these changes is timely. Through analyses such as the one presented in this paper, and through continued maintenance of databases such as PestFacts Map, the grains industry can more fully understand how pest species cycle in prevalence and importance over many years, and potentially over decades.

Acknowledgment

CES1904-002RTX is delivered by the National Pest Information Network (cesar Australia, DPIRD, QDAF, NSW DPI, and SARDI). This project aims to provide grain growers and advisers with information on invertebrate grain pest occurrence and equip industry with the knowledge needed to implement integrated pest management practices. This initiative is a GRDC investment and includes in-kind contributions from all project partner organisations. The work undertaken is made possible by the significant contributions of growers through the support of the GRDC. PestFacts Map data included in this update was collected and collated by personnel at cesar Australia and the South Australian Research & Development Institute. Acknowledgment goes to all parties who have provided field reports to PestFacts services.

Useful resources

For more information on armyworm, and for threshold advice, visit PestNotes Southern:

http://www.cesaraustralia.com/sustainable-agriculture/pestnotes/insect/armyworm

Watch an example of armyworm marching behaviour on YouTube.

youtube.com/cesaraustralia

PestFacts Map can be found on the Cesar Australia and SARDI websites.

Refer to the I-SPY identification manual for information on identifying armyworm species

https://grdc.com.au/resources-and-publications/all-publications/publications/2018/i-spy

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Notes

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

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GRDC project code: DAS00119

Keywords

- Russian wheat aphid, yield loss, action threshold.

Take home messages

- Natural Russian wheat aphid (RWA) risk 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 the %TwRWA doubles approximately every 35 days.
- The RWA action threshold calculator is now available on-line and allows for an integrated pest management (IPM) approach to controlling RWA.

Background

This project studied the risk of infestation by the Russian wheat aphid (RWA, *Diuraphis noxia* (Kurdjimov 1913)) and its effect on yield in order to develop best management practices for RWA in an Australian context of winter cropping of short cycle cereals. 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 for 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.* 2009), report a wide range of potential damage levels (yield loss and qualitative losses) and derived economic injury levels. Yield losses of around 0.5% 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. Twenty-eight natural RWA infestation field trials in 2018 (15) and 2019 (13) in South Australia (SA), Victoria (Vic), New South Wales (NSW) and Tasmania (Tas) (Table 1).
2. Fifteen RWA inoculated field trials in 2018 (5) and 2019 (10) where 50 RWA/m2 (500,000 RWA/ha) were applied at GS12-14 (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

Results

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. Therefore, the largely adopted use of prophylactic seed treatments against RWA was not justified.

Yield loss in inoculated trials

Regional and varietal differences were large (Figure 2). 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. Of the various aphid pressure metrics, the best predictor of yield loss was the maximum percentage of tillers with RWA present (%TwRWA) with a 0.28% yield loss observed for every %TwRWA. This simple relationship applied to wheat, barley and durum wheat cereal types, years and regions (through the adjustment of potential yield), but oat did not allow RWA development. This yield impact is substantially lower than described for the USA (0.46-0.48%, Archer and Bynum 1992).

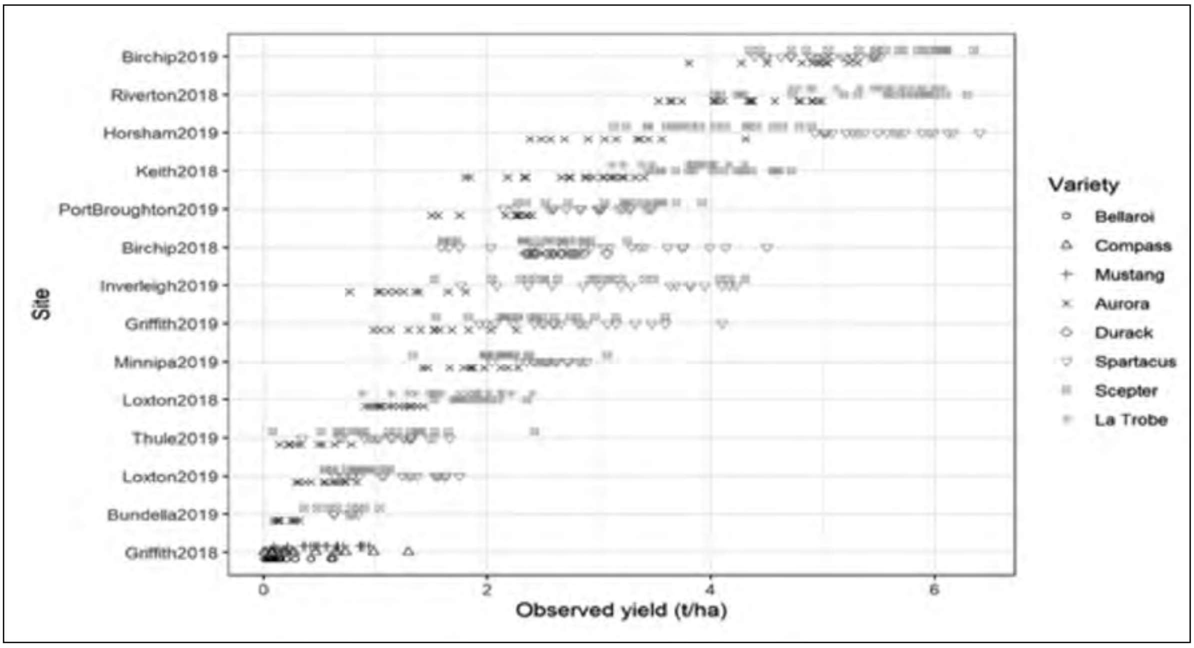

Figure 2. Yield across all trial sites and years with different cereal type/variety denoted by different markers. Barley varieties used were Compass⁽ᵈ⁾, Spartacus CL⁽ᵈ⁾ and La Trobe⁽ᵈ⁾. Durum wheat varieties used were EGA Bellaroi⁽ᵈ⁾ and DBA Aurora⁽ᵈ⁾. Wheat varieties used were Scepter⁽ᵈ⁾ and Mustang⁽ᵈ⁾. Oat variety used was Durack⁽ᵈ⁾.

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

RWA population development

After inoculation, the highest RWA populations that developed were in the drier regions, through a combination of increased RWA establishment during inoculation and an increased population increase. Less tillering in dry areas also contributed to higher

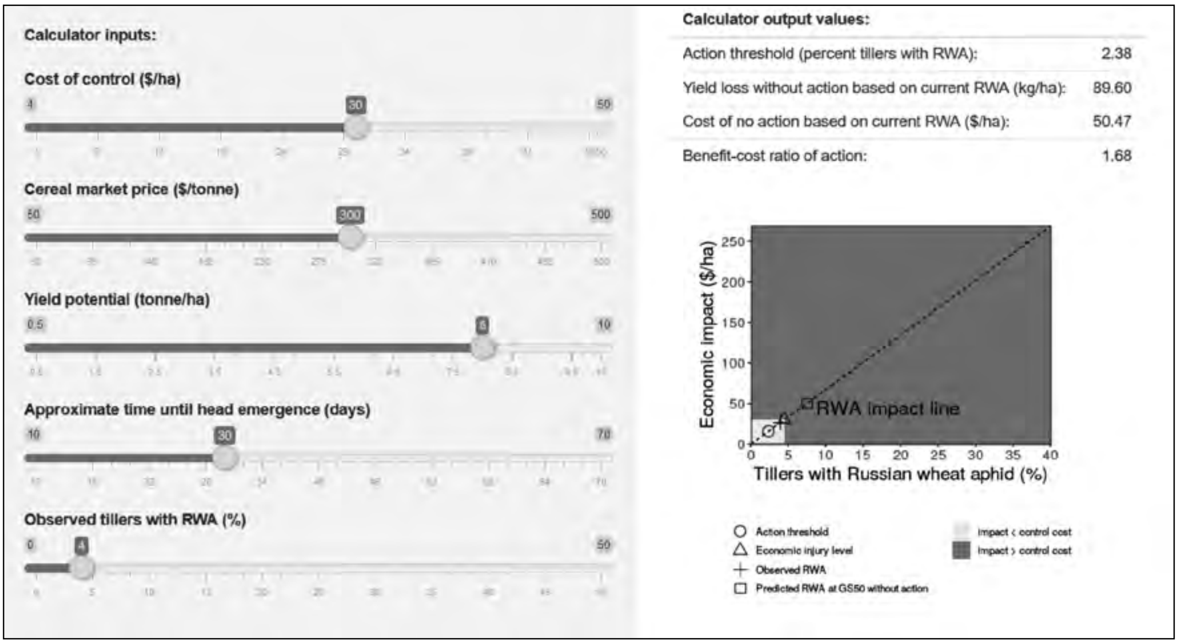

Figure 3. An example of output from the RWA Action Threshold calculator.

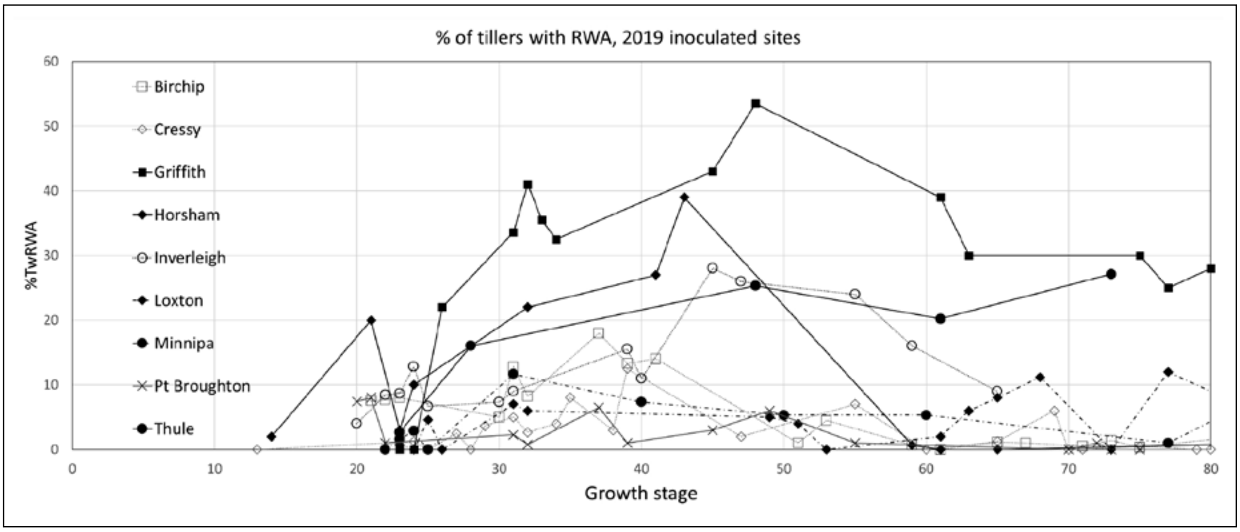

Figure 4. Percentage of tillers with RWA (%TwRWA) against growth stage for the inoculated untreated control plots (AI-UTC) in all inoculated trial sites in 2019.

%TwRWA. The maximum population of RWA and the maximum %TwRWA was reached between GS40 and 50 (Figure 4) 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, a decision rule (action threshold, Figure 3) was proposed 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 GS 32-35, reducing application costs. Growers and advisers are directed to the GRDC calculator (Useful resources) to calculate thresholds for their growing conditions.

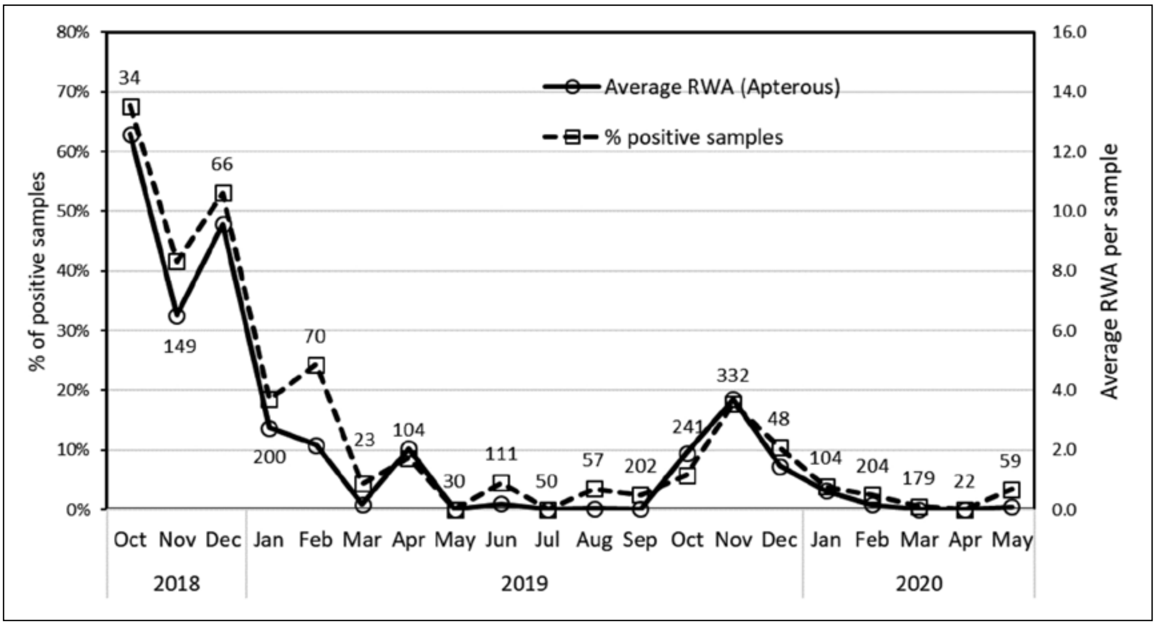

Figure 5. Dynamics of the percentage of positive samples (dotted line, left axis) and average RWA per sample (solid line, right axis) over time in South Australia. Numbers above markers show number of samples taken per month, n=2285.

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.

RWA detections were particularly common in field surveys during the spring to autumn periods (when no crops were present in the field), with high populations during spring in the warm dry grain growing regions of northern Vic, southern NSW and SA. During the summer, green vegetation for most grass species disappeared and RWA populations declined (Figure 5). 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.

Barley grass (*Hordeum leporinum*) and (to a lesser extent) brome grasses (*Bromus* sp.) are 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, where the native bottlebrush (*Enneapogon nigricans*) is the most important summer refuge in low rainfall areas, 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, two to three months before sowing, could cause RWA population to build up on grasses and cereal regrowth, potentially exacerbating early crop invasions. A 250mm 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 an increased RWA risk. Reports in 2020 from the Port Augusta area (SA), where a significant summer rain occurred on 1 February suggested an increase in RWA pressure. This shows that observations, especially in early break years and a 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 times of invasion of crops.

A 'wetter' year with a higher green bridge, or if immigration of aphids occurs at a higher level for some other reason, will not automatically result in a higher impact from RWA. Wetter and colder conditions and rainfall will be less favourable for RWA development in the crop (as can be seen from the Tasmanian trials) compared to the two experimental years (slowing down population development) and will also improve crop development which will better enable the crop to resist RWA.

Crop sensitivity

The project has shown similar yield impact and aphid population **development** for all crops tested except for oat, which is not 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 result in a different risk for reaching population levels above thresholds.

Conclusion

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 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 conducted were very dry with hot summers and growing seasons. These conditions were 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 has been known to be present in Australia (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 to improve the RWA 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

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. Trials were run through multiple contractors requiring long hours of careful observations. Special thanks to Courtney Proctor, Bonnie Wake and Millie Moore for data management and long trips required for aphid inoculation and scoring trials, and Farah Al-Jawahiri for aphid rearings.

Useful resources

GRDC publication. Russian wheat aphid (https://grdc.com.au/resources-and-publications/resources/russian-wheat-aphid)

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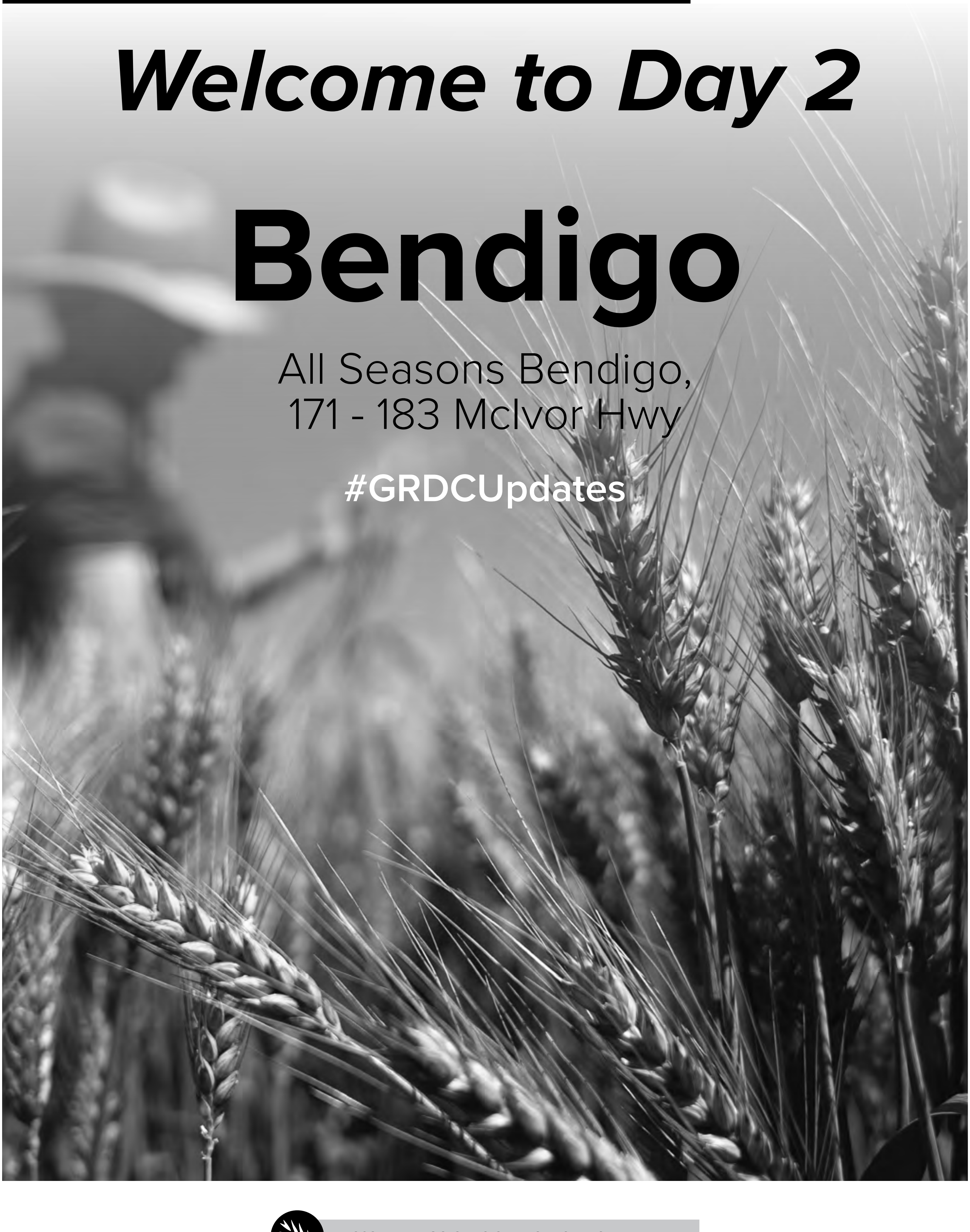
Notes

GRAINS RESEARCH UPDATE

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION



Welcome to Day 2

Bendigo

All Seasons Bendigo,
171 - 183 McIvor Hwy

#GRDCUpdates

GRDC Grains Research Update BENDIGO

PROGRAM DAY 2 - FEBRUARY 25th

Day 2 Agronomist Commentary Panel

Brad Bennett, *Agrivision (LRZ);* ***Greg Toomey,*** *Nutrien Ag Solutions (MRZ) and*
Annieka Paridaen, *Premier Ag Consultancy Group (HRZ)*

Note: Each topic session will include 15 mins dedicated to questions and interaction with the Agronomist Commentary Panel.

8.55 am	**Welcome**	***GRDC representative***
9.10 am	**Cereal disease wrap up**	***Grant Hollaway & Mark McLean,*** *Agriculture Victoria*
9.55 am	**Blackleg infection of canola – latest developments and yield impacts from foliar fungicide**	***Steve Marcroft,*** *Marcroft Grains Pathology*
10.35 am	**MORNING TEA**	
11.05 am	**Soil amelioration practices to alleviate subsoil constraints**	***Roger Armstrong,*** *Agriculture Victoria*
11.50 am	**Faba bean agronomy update**	***Jason Brand,*** *Agriculture Victoria &* ***James Manson,*** *SFS*
12.35 pm	**Pulse disease update**	***Josh Fanning,*** *Agriculture Victoria*
1.15 pm	**LUNCH**	
2.05 pm	**Measuring the impact of inoculation with a new rhizobia testing tool**	***Ross Ballard,*** *SARDI*
2.50 pm	**Maximising the benefits of growing vetch in our farming systems**	***Stuart Nagel,*** *SARDI*
3.35 pm	**Know the 'new lingo' – new classification and scoring of cereal crop development**	***James Hunt,*** *La Trobe University*
4.15 pm	**CLOSE**	

Cereal disease update 2021

Mark McLean[1] Grant Hollaway[1], Hari Dadu[1], Robert Park[2], Art Diggle[3] and Kylie Ireland[4].

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GRDC project codes: DJP1907-001RTX, DAW1810-007RTX, DJP1907-004RTX, DJP1907-002RMX, DJP1905-002SAX, University of Sydney (9175448), CUR1905-001SAX

Keywords

- stripe rust, net form of net blotch, oat diseases, red leather leaf, decision support app, fungicide resistance.

Take home messages

- Proactive disease management that combines options (such as variety selection, paddock selection and appropriate fungicide use) provides proven sustainable and economic control of cereal diseases.
- Stripe rust is likely to be important during 2021 especially where summer rain supports disease carry over. Field experiments found the new StripeRustWM App to be a useful tool to support in-crop fungicide decisions.
- Mixed infection with both spot form of net blotch (SFNB) and net form of net blotch (NFNB) in the Wimmera and Mallee decreased the yield of susceptible barley varieties by 9% and 20%, respectively, demonstrating the benefit of control in disease conducive seasons.
- Red leather leaf was the most common disease of oats in Victoria. During 2020, it reduced hay yield by 10 to 13% and grain yield by 15 to 20% demonstrating the need to implement control strategies.
- Development of fungicide resistance is increasing in cereal pathogens but can be slowed through adoption of integrated control strategies and prudent use of fungicides.

Background

Favourable conditions during autumn and spring provided good conditions for cereal crops in 2020 with below average rainfall during winter slowing development of many foliar diseases. Field trials by Agriculture Victoria measured losses of up to 50% due to foliar diseases, thus demonstrating the ongoing importance of effective strategies to minimise losses due to disease in risk situations.

Wheat - Stripe rust

Stripe rust was common in wheat crops during 2020 and often required fungicide control to protect yield. The management of stripe rust has become more complex with recent exotic incursions and the re-occurrence of an old strain, which impacts resistance in many varieties.

Evaluation of the new stripe rust management App (StripeRustWM) during 2020 proved it to be a useful tool to support in-crop decisions regarding stripe rust control.

Strains of stripe rust and disease ratings

Surveillance of cereal rust strains (pathotypes) by the University of Sydney has detected four exotic strains of wheat stripe rust in Australia since 1979; two of these incursions were detected in the last four years. Three of these incursions may have originated from Europe (1979, 2017 and 2018) while North America (2002) was implicated as the source of the other.

During 2020, the University of Sydney detected approximately seven different strains of wheat stripe rust in eastern Australia, adding to the complexity of assigning resistance ratings to varieties. The usual practice in the assignment of rust ratings is to provide a 'worst case' rating for the strains known to occur in a region. However, during 2020, an old strain (64 E0 A-) of stripe rust was detected in northern New South Wales (NSW) which has increased virulence on many varieties. Because of the ability of rust to spread large distances it was appropriate to provide some warning of the potential impact of this rare strain on varieties. Therefore a '/' has been adopted (e.g., MR/S) to reflect the potential for two reaction types for the affected varieties. This effectively provides a warning of how a variety will perform if this older strain becomes more widespread during 2021. Unfortunately, it is not possible to predict which strains will dominate in any season, and rapid testing to determine strains is not possible. Therefore, monitoring of crops is still an important component of disease management.

The University of Sydney's rust surveillance team now map cereal rust strains during the season on the web (see link within Useful resources section of this paper). This service is useful to gain an idea of strain distribution nationally. It takes about three weeks from when a sample is collected to when these results are available.

Evaluation of StripeRustWM App

A new tablet-based app, 'StripeRustWM' developed by DPIRD and GRDC, was released in 2020 to support in-crop decision making for the management of stripe rust of wheat. StripeRustWM uses information, including variety resistance rating, plant growth stage, presence of rust either within the crop or the district and expected yield to estimate potential losses. It's available free for iPads and Android tablets from the Apple App Store and Google Play.

A field trial conducted during 2020 compared disease development and grain yield with the App's predictions. Three varieties, Mace⏀ (susceptible to very susceptible (SVS)), Wyalkatchem⏀ (susceptible (S)) and Scepter⏀ (moderately susceptible to susceptible (MSS)) were grown and fungicides applied based on five treatment scenarios (Table 1) and an untreated control.

Stripe rust development was consistent with varietal resistance ratings with greater severity in Mace⏀ (SVS) than Wyalkatchem⏀ (S) and Scepter⏀ (MSS) (Table 2). For each variety, fungicide sprays applied early in the epidemic (rust identification in the district (T1) or traces in the crop (T2)) provided best protection. Delaying application until the occurrence of hot spots (T3) or before 10% of leaves were found with stripe rust infection (T4) were significantly less effective. A second spray (T5) on plots with recurring infection following the first spray (T1) provided some suppression of the late infection. A natural infection of Septoria was found in all the three varieties (Table 2) and its impact was considered within the App by using the 'other diseases' parameter.

Grain yield differences corresponded with stripe rust severity due to the applied treatments (Table 3). Yield predictions made by the StripeRustWM App for the three varieties showed a moderate to good correlation with actual yields (R^2 = 0.65 to 0.72) (Figure 1). For susceptible varieties, there was a better agreement between the experiment and the App's predictions of loss. For the partially resistant variety, Scepter⏀ (MSS), the App overestimated the yield loss compared with what actually occurred, indicating the need for further refinement of the App.

Close association (>65%) between the experiment grain yield and predicted yield for all varieties with different resistance ratings demonstrated that the StripeRustWM App is a useful tool to assist with disease management. These findings will be used to further improve the App's predictions.

Table 1. Fungicide treatments applied to evaluate predictions of the StripeRustWM App, Horsham 2020.

Number	Fungicide Treatment[A]	Growth stage	Date
T1	At first sign of stripe rust in district	Z33	15/9/2020
T2	At trace of stripe rust in crop	Z39	28/09/2020
T3	At presence of stripe rust hot spots	Z49	13/10/2020
T4	At 10% of leaves infected with stripe rust	Z65	22/10/2020
T5	A second spray is applied when a trace of stripe rust found in T1 treated plots (5 weeks later)	Z65	15/9/2020 & 22/10/2020
T6	Untreated control	-	-

[A] *Prosaro 420 SC (210g/L prothioconazole, 210g/L tebuconazole) applied at 300mL/ha.*

Table 2. Stripe rust and Septoria severity (percentage leaf area affected) of wheat varieties Mace⊕ (SVS), Wyalkatchem⊕ (S) and Scepter⊕ (MSS) in response to Prosaro treatments applied at different disease levels after the first sign of stripe rust in the district at Horsham during 2020.

Treatments[A]	Stripe Rust severity (%)						Septoria severity (%)		
	Z65[B]			Z75			Z65		
	Ma.C	Wy.	Sc.	Ma.	Wy.	Sc.	Ma.	Wy.	Sc.
T1	6	3	5	50	9	14	5a	2a	4a
T2	0	1	1	1	1	0	5a	3a	5a
T3	27	19	20	34	16	17	28b	22b	21b
T4	43	33	29	78	53	43	24b	24b	24b
T5	4	4	6	20	6	10	4a	2a	4a
T6	58	33	27	91	63	38	25b	25b	32b
P =	0.759			<0.001			0.990		
LSD (0.05) =	*ns*			8.6			*ns*		

[A]Treatment are listed in Table 1 [B]Growth stages: Z65, mid flowering; Z75, milk development according to Zadoks et al. (1974). CMa = Mace⊕; Sc. = Scepter⊕; Wy = Wyalkatchem⊕.

Table 3. Comparison of StripeRustWM App predictions with actual grain yield of three wheat varieties in response to foliar fungicides (Prosaro) treatments applied at different levels of stripe rust infection, Horsham 2020.

Treatment[A]	Grain Yield (t/ha)					
	StripeRustWM Predictions			Field Experiment		
	Mace⊕ (SVS)	Wyalkatchem⊕ (S)	Scepter⊕ (MSS)	Mace⊕ (SVS)	Wyalkatchem⊕ (S)	Scepter⊕ (MSS)
T1	6.0	6.4	6.7	5.1[bc]	5.7[b]	6.3[b]
T2	5.5	6.1	6.5	6.0[cd]	6.3[bc]	6.7[bc]
T3	5.9	6.3	6.6	5.7[cd]	6.4[bc]	6.6[bc]
T4	5.5	5.8	5.9	4.3[b]	4.6[a]	5.7[a]
T5	6.2	6.5	6.8	6.4[d]	6.8[c]	7.0[c]
T6	2.9	3.4	3.9	3.0[a]	4.1[a]	5.4[a]
Loss %[B]	53	48	43	53	40	23
P =	-	-	-	<0.001	<0.001	<0.001
LSD (0.05) =	-	-	-	0.91	0.87	0.60

[A]Treatment are listed in Table 1. [B] Estimated loss percent (%) for each variety calculated using the highest and lowest yields predicted/actual in response to treatments. Within variety means with one letter in common are not significantly different.

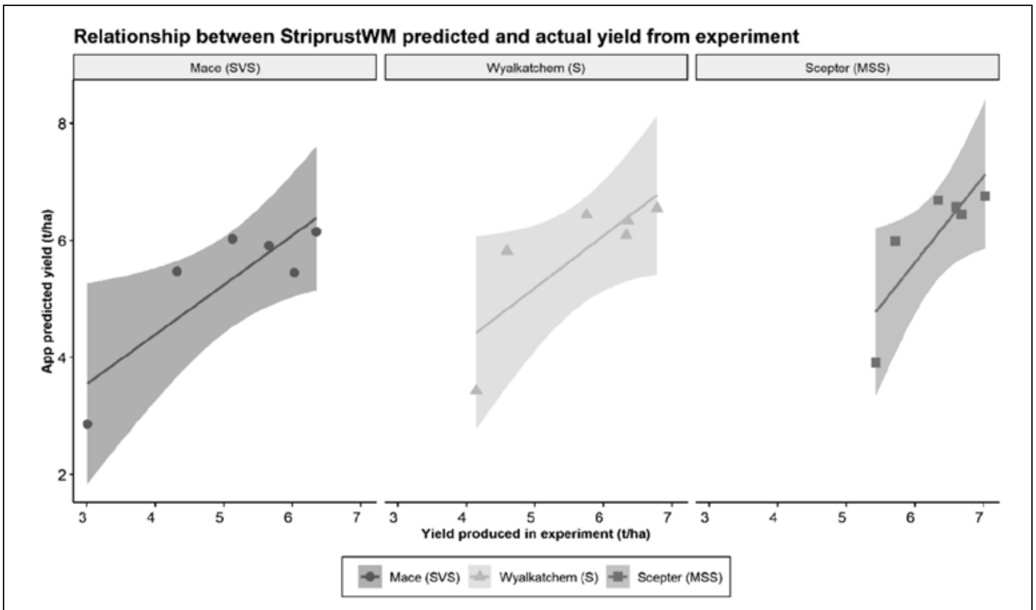

Figure 1. Comparison of grain yield of Mace⊕ (SVS), Wyalkatchem⊕ (S) and Scepter⊕ (MSS) between Horsham experiment and StripeRustWM App prediction, with shaded areas representing +/-10%.

Stripe rust management in 2021

Stripe rust will most likely require proactive management in 2021 due to increased risk compared to recent years. The summer rain, associated with the possible La Niña effect will support carry over of rust spores on volunteer cereals growing over summer, and combined with the increased susceptibility of many wheat cultivars, contribute to the heightened risk from stripe rust. It is therefore important that growers take the following steps to protect from rust:

1. Remove the green bridge (volunteer cereals) by mid-March.
2. Use a current cereal disease guide to revise resistance ratings as there have been many changes due to new strains.
3. Where possible avoid susceptible varieties.
4. Develop a fungicide management plan, keeping in mind management of fungicide resistance (see further discussion within this paper).
5. Download the StripeRustWM App for iPads and tablets.

Barley - net and spot forms of net blotch

During 2020, stubble-borne foliar diseases such as spot form of net blotch (SFNB), net form of net blotch (NFNB) and scald were common. Barley leaf rust was present in the high rainfall areas late in the season. Fungicides significantly reduced the impacts of these diseases in susceptible varieties. Inoculum of all these diseases will be present leading into the 2021 season, so proactive management will be needed where favourable conditions develop for crops and disease.

NFNB has become more common in Victoria due to the cultivation of susceptible varieties such as RGT Planet⦻ and Fairview⦻ and the moderately susceptible (MS) variety Compass⦻. A new virulence for Spartacus CL⦻ has also developed making it susceptible in some cases. The frequency of this new virulence was low in 2020, so growers should monitor at risk crops and be prepared to apply fungicides if favourable conditions develop.

NFNB most commonly causes losses during seasons where grain yield potential is greater than 5t/ha and there are wet conditions during spring. In high yielding crops, grain yield losses can be as high as 22% (2t/ha) while grain quality is also commonly affected with reduced grain size and weight.

Yield loss due to net blotches during 2020

During 2020, Agriculture Victoria conducted experiments at Curyo (with BCG) and Longerenong to determine potential losses for varieties with different resistance/susceptibility to NFNB in the Wimmera and Mallee regions of Victoria. NFNB was the target disease, however SFNB also developed due to infection from airborne spores from neighbouring paddocks and favourable seasonal conditions.

Within each experiment, six barley varieties and a NFNB very susceptible (VS) breeding line VB9613, were sown. Six replicates of two treatments were applied: 1) No disease, and 2) Disease to determine loss.

Severe NFNB developed at the Curyo site (Table 4) and moderate NFNB developed at the Longerenong site (Table 6) in the VS line VB9613 resulting in 17% and 8% grain yield loss, respectively and reductions to grain quality (Table 5). This demonstrated that NFNB can be a damaging disease in both the Wimmera and Mallee regions in susceptible varieties.

Moderate NFNB and severe SFNB infection developed in RGT Planet⦻ which is highly susceptible (SVS) to both diseases and resulted in 20% and 9% grain yield loss at the Curyo and Longerenong sites, respectively. These losses show that RGT Planet⦻ should be managed for multiple foliar diseases during favourable seasons to minimise losses. Varieties that were rated susceptible (S) or better to NFNB had very low levels of NFNB, thus demonstrating that avoiding the most susceptible varieties will decrease the risk of yield loss.

SFNB caused moderate infection and NFNB caused low infection in Commander⦻ (both sites) and Alestar⦻ (Curyo only) which resulted in significant grain yield losses. In both cases, it was likely the combination of SFNB and NFNB resulted in losses, again highlighting the need to proactively manage multiple barley diseases to minimise losses.

Fathom⦻, Maximus CL and SakuraStar⦻ had relatively low disease severity at both sites but significant yield losses were measured only at the Curyo site. The cause of this is difficult to determine, however it is likely that these resistant varieties diverted metabolic energy for disease resistance, instead of grain yield. This has also been observed in low rainfall regions of Western Australia (WA) and South Australia (SA).

Grain quality data was not available for the Longerenong experiment at time of reporting.

Table 4. Disease severity and grain yield of six commercial barley varieties and one breeding line very susceptible to net form net blotch in response to high and low disease treatments, Curyo 2020.

Variety	Rating		Disease severity (% leaf area affected) 6 October, Z85		Grain Yield (t/ha)		
	NFNB	SFNB	NFNB[a]	SFNB[b]	High Disease	Low Disease	% loss
Fathom⍉	MS	RMR	1	0	5.1	5.7*	10
Maximus CL	MS	MRMS	0	0	5.6	6.2*	10
Commander⍉	MS	MSS	2	8	4.8	5.8*	17
SakuraStar⍉	S	MS	1	0	4.9	5.5*	11
Alestar⍉	S	S	2	8	4.6	5.2*	8
RGT Planet⍉	SVS	SVS	5	19	5.2	6.5*	20
VB9613	VS	MR	39	0	4.4	5.3*	17

*= statistically significantly different at 5% when the high and low disease treatments were compared, [a]Average of the top three leaves of ten tillers per plot, [b]Average of single plot assessment per plot

Table 5. Grain quality of barley lines in response to net form of net blotch high and low disease treatments at Curyo, Vic during 2020.

Variety	Screenings (%<2.2mm)		Retention (%>2.5mm)		1000 grain weight (g)	
	High Disease	Low Disease	High Disease	Low Disease	High Disease	Low Disease
Fathom⍉	4	3	76	82	39	40
Maximus CL	4	2*	71	81*	36	37
Commander⍉	10	6*	63	76*	34	37
SakuraStar⍉	10	6*	64	75*	36	39*
Alestar⍉	5	2*	68	79*	34	37
RGT Planet⍉	10	2*	41	76*	34	39*
VB9613	18	4*	24	57*	33	37*

*= significantly different at 5% when the high and low disease treatments were compared

Table 6. Disease severity and grain yield of barley line with differing susceptible net form of net blotch and spot form of net blotch in response to high and low disease treatments at Longerenong during 2020.

Variety	Rating		Disease severity (% leaf area affected) 29 September, Z75		Grain Yield (t/ha)		
	NFNB	SFNB	NFNB[a]	SFNB[b]	High Disease	Low Disease	% loss
Fathom⍉	MS	RMR	0	1	6.1	6.3	0
Maximus CL	MS	MRMS	0	2	6.5	6.7	0
Commander⍉	MS	MSS	1	6	5.9	6.3*	6
SakuraStar⍉	S	MS	0	3	6.1	6.0	0
Alestar⍉	S	S	0	8	5.5	5.7	0
RGT Planet⍉	SVS	SVS	2	14	6.7	7.4*	9
VB9613	VS	MR	20	3	5.5	6.0*	8

*= significantly different at 5% when the high and low disease treatments were compared, [a]Average of the top three leaves of ten tillers per plot, [b]Average of single plot assessment per plot

Oat: - red leather leaf

During 2020, red leather leaf (RLL) was common in the medium and high rainfall zones of Victoria and bacterial blight was common in all regions. A survey of Victorian oat crops (Agrifutures investment project) identified that RLL was the most common foliar disease, being present in 80% of crops while bacterial blight was found in 55% of paddocks. Septoria, stem rust and crown rust were also found at low levels, in the high rainfall zone. Crown rust and stem rust were found in the North East, late in the season. Inoculum of these diseases will be present in 2021 and may cause losses if favourable conditions develop during the season.

RLL is the most common and damaging foliar disease of oat in Victoria. Two experiments were conducted near Horsham during 2020, with one investigating the grain yield and quality losses in six milling oat varieties and another Agrifutures' project to investigate the hay yield and quality loss in eight hay oat varieties. For each variety, six replicates each of two treatments, 1) High Disease and, 2) Low Disease were compared to determine losses.

Hay yield and quality loss

RLL infection was severe and caused significant reductions to stem thickness and hay yield losses at Longerenong during 2020 demonstrating that RLL should be managed in hay oats to maximise production. RLL severity was significantly more severe in varieties rated MS or worse , while disease severity was low in the MRMS rated Forester(b) and Tungoo(b) (Table 7). Stem thickness and hay yield were reduced by RLL in five of the eight varieties. Losses were very similar between varieties (10-13%), except for Kingbale(b) (17%). The reason for this was unclear as disease severity was the same as Wintaroo(b). The hay yield loss seen in Forester(b) was not due to disease, and more likely an effect of fungicides as the disease severity was low in this variety.

Milling oat yield and quality loss

All six oat varieties had significant grain yield loss due to RLL, demonstrating its potential impact and need for management during favourable seasons (Table 8). In general, grain yield loss was related to variety rating. Williams(b) (MS) had the lowest infection and grain yield loss, demonstrating the benefits of growing a moderately susceptible (MS) or better rated variety. Bannister(b) (MSS) and Kowari(b) (S) had losses of 15-16%, while Bilby(b) (S) and Yallara(b) (SVS) had losses of 20-21%. Mitika(b) (SVS) had less grain yield loss than its rating would indicate, likely due to faster maturity which allowed it to avoid some of the late infection.

Fungicide resistance management

Resistance to fungicides is becoming an increasing threat to cereal crops across Australia. There are five strategies that growers can adopt to slow the development of resistance in pathogen

Table 7. Red leather leaf severity (% leaf area affected) and stem thickness and yield of eight oat varieties at Longerenong, Victoria, 2020.

Variety	Rating	Red leather leaf severity[B] (%LAA)		Stem thickness (mm)		Hay yield (t/ha)		
		7 Sep Z51	15 Oct Z75	High Disease	Low Disease	High Disease	Low Disease	Loss %
Forester(b)[A]	MRMS	4	9	1.0	1.2*	5.9	6.8**	13
Tungoo(b)	MRMS	1	3	1.1	1.1	7.1	6.2	0
Brusher(b)	MS	7	29	1.0	1.2**	7.0	7.3	0
Williams(b)	MS	3	21	1.4	1.4	6.5	7.4**	12
Mulgara(b)	S	13	37	1.2	1.4**	7.0	7.8*	10
Yallara(b)	SVS	10	25	1.2	1.2	7.2	7.1	0
Winteroo(b)	SVS	12	30	1.0	1.1**	6.4	7.2*	11
Kingbale(b)	SVS	11	29	0.9	1.1**	6.4	7.7**	17

*** = statistically significantly different at 1%; *= statistically significantly different at 5% when the high and low disease treatments were compared, [A]Forester(b) was cut at Z65 and may have not reached its full yield potential, [B]Average of disease treatment.*

Table 8. Red leather leaf severity and grain yield loss of six milling oat varieties in response to high and low disease treatments at Longerenong, Victoria 2020.

Variety	Rating	Red leather leaf severity (%LAA)		Grain yield (t/ha)		
		29 Sep Z69	13 Oct Z75	High Disease	Low Disease	Loss (%)
Williams(b)	MS	8	11	5.5	5.8*	5
Bannister(b)	MSS	17	19	5.1	6.1*	16
Kowari(b)	S	17	14	4.4	5.2*	15
Bilby(b)	S	18	10	3.8	4.8*	21
Yallara(b)	SVS	16	14	3.7	4.6*	20
Mitika(b)	SVS	15	11	4.6	5.3*	13

**= statistically significantly different at 5% when the high and low disease treatments were compared* populations and therefore extend the longevity of the limited range of fungicides available:

1. **Avoid susceptible crop varieties.** Where possible select the most resistant crops suitable and/or avoid putting susceptible crops in high risk paddocks.
2. **Rotate crops.** Avoid planting crops back into or adjacent to the same stubble.
3. **Use non-chemical control methods to reduce disease pressure.** Delaying sowing, early grazing are examples of strategies that can reduce disease pressure.
4. **Spray only if necessary and apply strategically.** Avoid prophylactic spraying and spray before disease gets out of control.
5. **Rotate and mix fungicides/mode of actions.** Use fungicide mixtures formulated with more than one mode of action, do not use the same active ingredient more than once within a season and always adhere to label recommendations.

Conclusion

In the absence of proactive disease control, yield losses due to diseases can be greater than 20%. The risk from rust diseases is likely to be greater with a wet summer (La Niña) supporting volunteer cereals that carry rust inoculum from one season to the next. It is, therefore, important that plans are developed to effectively manage cereal diseases this season. Disease management plans should consider paddock and variety selection and, where the risk warrants it, the proactive and prudent use of fungicides that avoid overuse to protect their longevity.

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Useful resources

Current Victorian Cereal Disease Guide:

http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/cereal-disease-guide

Cereal seed treatment guide, 2020:

https://www.pir.sa.gov.au/__data/assets/pdf_file/0005/237920/Cereal_Seed_Treatments_2021.pdf

Cereal rust reports and mapping of rust reports:

https://www.sydney.edu.au/science/our-research/research-areas/life-and-environmental-sciences/cereal-rust-research/rust-reports.html

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Notes

Will I get an economic response from applying fungicide to canola for the control of blackleg?

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GRDC project codes: UOM1904-004RTX, UM00051, CSP00187, MGP1905-001SAX

Keywords

- stubble management, fungicide resistance, seed treatment, upper canopy blackleg, crown canker.

Take home messages

- The canola industry has become more reliant on fungicides to control blackleg, in some regions there is reduced emphasis on cultural practices to reduce disease.
- The decision to use a fungicide is not clear cut and should be based on the disease risk profile of the crop.
- Severe blackleg crown canker occurs when plants are infected during early seedling growth. Prior to sowing, use the BlacklegCM decision support tool to identify high risk paddocks and explore management strategies to reduce yield loss.
- Early vegetative (4-10 leaf) foliar fungicide application should be based on the risk profile of the crop, cultivar blackleg rating and estimation of the potential yield after scouting for leaf lesions.
- Fungicide application decision-making for upper canopy infection is separate to the decision process for crown canker. Fungicide applications to control upper canopy infection can result in variable yield responses. It is important to understand the disease risk before applying a fungicide.
- Knowledge on upper canopy infection is improving and it is likely that decision making will become more reliable. A decision support tool is expected to be released via GRDC investment when there is sufficient confidence on recommendations to aid decision making.

Will I get an economic return from applying a fungicide to my canola crop?

Recently, new fungicide actives and timing recommendations have produced large yield responses. However, these are variable ranging from nil to 20% yield increases in on-farm strip trials and nil to 40% yield increases in small-plot research trials. So how do you determine where your crop will sit in 2021 (i.e., within the nil to 40% response range)?

Predicting a yield response would be very accurate if you knew exactly how much disease will occur, but the level of crop damage caused by disease is determined by numerous interconnected factors. Additionally, other diseases such as Sclerotinia stem rot, white leaf spot, powdery mildew and alternaria can also influence economic returns.

The key is to identify the blackleg risk for each individual crop and then determine the cost of application compared to that of potential yield loss. In most years, this is relatively easy. For example, a low rainfall year is low risk and in a high rainfall year with high yield potential, it is very easy to gain an economic advantage from fungicide application. But in the decile 4 to 7 years there is lots to be gained or lost from fungicide decisions.

Blackleg crown canker

Do I need a seed treatment and/or fungicide amended fertiliser?

Risk factors:

1. **Canola growing region** – high canola intensity and high rainfall = high risk. One in four-year rotations and 500m isolation between this year's crop and last year's stubble reduces risk.
2. **Cultivar resistance** – cultivars rated resistant (R) to moderately resistant (MR) or above have very low risk of developing crown cankers. Moderately resistant will develop cankers but only if grown under high disease pressure for example, canola/wheat/canola in high rainfall.
3. **Blackleg population** – if you've grown the same cultivar for a number of years and crown canker severity is increasing, you will be at a higher risk of crown cankers if you then sow a cultivar from the same resistance group.
4. **Timing of crop emergence** - severe crown canker is most likely to develop when plants are infected during the early seedling stage (cotyledon to 4th leaf). The driving factors for seedling infection are the growth stage at which first infection occurs and the length of time that the plant is exposed to blackleg infection while in the vulnerable seedling stage. Therefore, the risk of seedling infection that leads to crown canker varies from season to season. For infection to occur, blackleg spores must be mature and ready to release from stubble, a process reliant on a combination of moisture and suitable temperatures. Fruiting bodies typically become ripe approximately three weeks after the break of the season when the stubble has stayed consistently moist. Once mature, spores are then released with each rainfall event. Temperature also determines the length of time that plants remain in the vulnerable seedling stage. Plants are significantly less vulnerable to crown canker after the 4th leaf stage. Older plants will still get leaf lesions, but the pathogen is less likely to cause damaging crown canker as it cannot grow fast enough to get into the crown. Typically, plants sown earlier in the growing season (April) will develop quickly under warmer conditions and progress rapidly past the vulnerable seedling stage compared to plants sown later (mid-May) which progress slowly and remain in the vulnerable seedling stage for an extended period.
5. **Farming system** - inter-row sowing with full stubble retention influences the timing and quantity of ascospores from stubble, which are a primary source of inoculum. Standing stubble stays drier between rainfall events compared to stubble that is lying down and in contact with the soil. Standing stubble delays spore maturation and reduces the release of spores early in the season at the time when fungicide applied to seed and fertiliser are most effective. Standing stubble produces more spores later in the season, however these spores are unlikely to produce severe crown canker but may increase severity of upper canopy blackleg. However, standing stubble that is knocked down 12 months later can then produce spores early the following growing season.

In summary

An economic return is unlikely if sowing an R rated cultivar in a one in four-year rotation in mid-April with >500m from the previous year's canola crop (and you don't retain stubble). If sowing a MS rated cultivar in a canola / wheat / canola rotation at the end of May, you will likely get a large return from your fungicide application. The challenge with seed treatments and fungicide-amended fertiliser is that the decision to use these products is made a long time before sowing (or you don't have any influence over it when you purchase commercial seed), and therefore, you will not know the emergence date, and therefore, the individual season risk. But you will know the risks associated with your canola region, cultivar blackleg rating and distance to last year's stubble.

Do I need a vegetative foliar fungicide application?

As with fungicides applied at sowing, vegetative foliar fungicides applied during 4-10 leaf growth stage are also designed to protect plants from crown cankers. The main advantage with this fungicide timing is that the level of disease risk can be assessed at the time of application, considering the blackleg rating of the cultivar, whether a seed treatment and/or fungicide amended fertiliser has been used and the prevalence and severity of leaf lesions observed in the crop.

1. Cultivars with effective major gene resistance will have none or very few leaf lesions even under high disease situations and will therefore be protected from crown canker. Cultivars are classified into Blackleg resistance groups (A, B, C, etc) according to their complement of major genes. An abundance of lesions in cultivars which are expected to have effective major gene resistance indicates that the resistance is being overcome and application of a foliar fungicide may be prudent as the underlying level of quantitative resistance is uncertain. In cultivars lacking effective major genes, the blackleg rating gives an indication of the level of quantitative resistance to crown canker, i.e., the level of resistance to crown canker in the plant following leaf infection. All cultivars that are reliant on quantitative resistance may get a similar level of leaf infection but a cultivar with an R blackleg rating will not develop crown cankers whereas an MR cultivar may develop some crown cankers and an MS-S cultivar may have severe cankering and lodged plants.
2. Fungicides applied at sowing will reduce crown canker even on crops with quite severe leaf lesions. In most cases, if a cultivar with adequate resistance is sown with a seed or fertiliser fungicide treatment then a vegetative foliar fungicide is unlikely to be necessary. Monitor your crop and make an in-season decision.
3. Leaf lesions are most damaging on the cotyledons and early leaves, and therefore, a foliar fungicide is most likely to give an economic benefit to protect this vulnerable stage.

Analysis of the fungicide trials clearly showed that fungicides only provided a yield benefit in high disease situations, such as:

1. You may have chosen to grow a cultivar with a lower blackleg rating because the cultivar is the highest yielding or you have chosen to retain seed, etc. For example, it is common practice to grow older cultivars with reduced blackleg resistance and then protect these cultivars with fungicide applications.
2. The pathogen population has changed to render major genes ineffective.
3. The season is very conducive for blackleg with spore maturity coinciding with emergence and the vulnerable stage of crop growth.

Use of the BlacklegCM App is recommended to help make blackleg management decisions. BlacklegCM is an interactive tool allowing users to compare scenarios and determine the likely yield response from altering various disease management strategies.

Upper canopy blackleg fungicide application

Blackleg Upper Canopy Infection (UCI) refers to blackleg infection of the upper stem, branches, flowers and pods. Although research is improving the understanding of these symptoms, there is still a lack of knowledge on how individual cultivars react to UCI in terms of yield loss. Furthermore, our research shows that similar symptoms of UCI can cause severe yield loss in one season and no yield loss in another. As such, our recommendations for managing blackleg UCI are constantly improving.

Should I apply a fungicide for UCI protection?

The question of whether to apply a fungicide for UCI protection is a real dilemma. Get it wrong and it will cost your crop a lot of money, but currently there is no way to accurately predict economic return from fungicide application. GRDC investment is working on improving knowledge, including determining the timing of infection leading to yield loss, weather parameters associated with yield loss and strategies for screening for genetic resistance.

Some factors however that are driving disease risk:

1. **Timing of flowering.**

   Earlier flowering crops are at a higher risk than later flowering crops as they flower in conditions more conducive for blackleg infection. Earlier flowering crops also have a longer period until harvest which allows the fungus to proliferate within the plant, thereby reducing yield potential.

2. **Spring rainfall and temperature.**

   Our preliminary data suggests that UCI, given enough time, will cause damage to the vascular tissue in the stems and branches, reducing yield potential by restricting water and nutrient flow to developing flowers, pods and seed. However, similar levels of disease can cause different amounts of yield loss depending on the weather during pod fill. Plants without moisture/heat stress can tolerate a higher disease load before it impacts on yield.

3. **Genetic resistance.**

   Genetic resistance is the missing piece of the puzzle. As with crown canker, effective major gene resistance protects against UCI. If it is ineffective or has been overcome, the crop may be completely susceptible to UCI, however, this should have become evident by the prevalence and severity of leaf lesions observed during the seedling stage. The effect of quantitative resistance for crown canker on UCI is currently under investigation. It is clear that cultivars with good quantitative resistance do get UCI symptoms, but we are unsure whether these cultivars have less damage to the vascular tissue than more susceptible cultivars. This could be similar to the way cultivars react at the seedling stage, whereby varieties with the same level of leaf infection develop different levels of crown canker.

4. **Fungicides.**

   Our work has shown a wide window of response times with good results (if you have a damaging level of disease) from fungicide application from first flower to 50% bloom. However, for several reasons, it is suggested that 30% bloom is aimed for. Firstly, the 30% bloom stage is as late as you can go and still get good penetration into the canopy; your main aim is to protect the main stem as this will have a greater impact on yield compared to individual branches. Secondly, this timing may provide some control of any initial infections that have already occurred. Thirdly, the 30% bloom timing will provide protection for a few weeks into the future by which stage any later infections are less likely to result in significant yield loss. Pod infection is unlikely to be controlled through fungicide application. However, there was some control of pod infection at some sites in 2020 by spraying at 30% bloom but this has not been observed in previous seasons. Pod infection occurs when there are rainfall events during podding and the fungal spores land directly on the pods to cause disease, this results in an additional yield loss of up to 20%. Unfortunately, there are no fungicides registered for application during podding due to maximum residue limit (MRL) regulations. Effective major gene resistance will control pod infection.

What are the steps to determining a UCI spray decision?

1. **Yield potential** – yield potential is an economic driver. A 1% return on a 3t/ha crop is worth more money than a 1% return on a 1t/ha crop.
2. **Leaf lesions** – presence of leaf lesions indicates that blackleg is present, and that the cultivar does not have effective major gene resistance. No leaf lesions = no reason to spray.
3. **New leaf lesions on upper leaves as the plants are elongating** – this observation is not critical, but it does give an indication that blackleg is active as the crop is coming into the susceptible window. However, numerous wet days at early flowering stage will still be high risk even if there were no lesions on new leaves up to that point. Remember it will take two to three weeks after rainfall to observe leaf lesions. More lesions = higher blackleg severity.
4. **Date of first flower** – the earlier in the season that flowering occurs = higher risk. This date will vary for different regions. Generally, shorter season regions can, more safely, commence flowering at an earlier date compared to longer season regions. Earlier harvest date results in less time for the fungus to invade the vascular tissue and cause yield loss. Consequently, if you're in a long growing season rainfall region and your crop flowers in early August and is harvested in December, you are in a very high-risk situation.

How can I determine if I should have sprayed for UCI?

1. UCI symptoms are most readily observed at windrowing or even later as the plants mature. They can progress very quickly during this time.
2. Check for external lesions and ensure correct identification.
3. Where lesions are present, slice open the branch/stem and check for blackened pith which is indicative of vascular damage and likely yield loss.
4. Observe darkened branches; these branches go dark after vascular damage and are indicative of yield loss.
5. Pod infection will cause yield loss, unfortunately there is nothing that can be done to prevent pod infection.

6. Leave unsprayed strips to check for yield returns.

Which fungicide active should I use?

There are two parts to the question of which fungicide active should I use? Firstly, in terms of which active will give better control, there are few side by side comparisons that have been undertaken for blackleg control. However, the GRDC blackleg rating project has undertaken comparisons for the seed treatment fungicides which indicate the succinate dehydrogenase inhibitors (SDHI) fungicides provide longer protection compared to the demethylation inhibitors (DMI) fungicides. Ultimately, crop development stage, determining your risk, and therefore, potential economic return are more important factors when choosing a fungicide.

The second aspect of choosing a fungicide active is in regards to managing the risk of fungicide resistance. Resistance towards the DMI fungicides has been detected in approximately 30% of Australian blackleg populations over the past three years whilst no resistance has been detected for the SDHI fungicides. However, excessive use of the SDHI fungicides has the potential to select for fungicide resistance more quickly than DMIs. Therefore, limitations on the number of applications for each fungicide active within a growing season have been developed and can be found at the CropLife website (https://www.croplife.org.au/resources/programs/resistance-management/canola-blackleg/).

If you use a SDHI seed treatment you cannot use a SDHI early foliar (4-8 leaf) application. At this point, SDHI seed treatment and SDHI 30% bloom spray is considered safe. Research will be testing these different scenarios to provide accurate data for modelling fungicide management.

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Useful resources and references

BlacklegCM App for iPad and android tablets (https://www.agric.wa.gov.au/apps/blacklegcm-blackleg-management-app)

GRDC Publication – Blackleg Management Guide (www.grdc.com.au/resources-and-publications/all-publications/publications/2020/blackleg-management-guide)

GRDC Groundcover - Canola: The Ute Guide (https://grdc.com.au/resources-and-publications/groundcover/ground-cover-issue-27/canola-the-ute-guide)

Marcroft Grains Pathology website: www.marcroftgrainspathology.com.au

GRDC National Variety TrialsTM website (www.nvtonline.com.au)

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Subsoil amelioration - update on current research

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GRDC project code: DAV00149

Keywords

- soil constraints, clay soils, economic risk, subsoil water, sodicity, soil dispersion.

Take home messages

- Long-term trials throughout south eastern (SE) Australia indicate plant-based manures improved grain yields by an average of 19%. Animal manures improved yields by an average of 26% but can also produce negative effects with a trend for the residual benefits to be shorter-lasting than for plant-based amendments.
- Responses to amelioration are strongly influenced by water availability (subsoil reserves, seasonal rainfall patterns and potentially water logging).
- Responses to amelioration with organic materials appear soil type specific requiring an assessment of both subsoil and topsoil soil properties, including dispersion.

Background

Current grain yields in many sections of the high rainfall zone (HRZ) of SE Australia, as well as parts of the medium rainfall zone (MRZ) remain below water limited yield potential. This failure to achieve yield potentials have been attributed to a range of factors including nitrogen (N) deficiency, disease and seasonal conditions including frost (Armstrong *et al.* 2019; Hochman *et al.* 2019). Many soils in this region also contain a range of physicochemical constraints, especially in subsoils which limit root growth and efficient use of soil water and nutrients (Adcock *et al.* 2007).

Previous research including that by Peter Sale and his colleagues at La Trobe University, summarised in Sale *et al.* (2021), have recorded significant yield benefits from the application of animal-based manures to subsoils (referred to as 'subsoil manuring'), especially in HRZ systems. Despite the strong interest in this approach by some growers, overall rates of on-farm adoption currently remain very low. This lack of adoption has been attributed to several major logistical constraints including an inability to source sufficient quantities (at a low price) of ameliorant stock, particularly animal manures, and a lack of suitable commercial scale machinery for placing the ameliorants into the soil (Nicolson 2016). Most importantly the unpredictability of grain yield responses ('when, where, how much and how long') mean that most growers are not willing to undertake the significant financial risk resulting from the initial high upfront investment (approximately $1200-1400/ha (Sale and Malcom 2015)) needed.

In 2017, two major projects commenced with the support of GRDC investment, examining the use of soil amelioration to improve long-term crop productivity: one project focused on sandy soils in the low rainfall zone (LRZ) (CSP00203) and the other on clay soils in the HRZ and MRZ of SE Australia (DAV00149). This presentation provides an update on some of the latest research arising from DAV00149.

Method

Analysis of long-term trials

An analysis was undertaken of a large number of field-based trials (greater than 70) that have been undertaken over recent years by different groups under a variety of initiatives in SE-Australia comparing different combinations of plus/minus deep ripping, with and without the use of amendments including animal manures, plant biomass and gypsum and different placement (surface or subsoil). Several criteria were used to determine which trials should be included in the analysis, including presence of an unamended 'control', an ability to track the providence of the trial (including when the trial was commenced) and an ability to accurately locate plots. A response was only recorded if statistically different (P = 0.05) or if no replication was used the response had to be greater than 20%. There were 40 trial years of data for legume organic matter (comprising 14 sites but with only six of these trials with data older than five years) and 71 for animal manure (comprising 20 sites but with only five sites older than five years). The majority of trials (55%) were sown to cereals (wheat and barley). This analysis was then used to graph the relative grain yield response to either the application of animal manure or legume amendments to the subsoil compared to the non-amended control.

The effectiveness of different amendments and placement strategies

A network of 'new field experiments' were established (two in 2017 and another six in 2018) with four located in the HRZ (Rand, New South Wales (NSW); Nile, Tasmania; Tatyoon, Victoria and Marrabel, South Australia (SA)) and four in the MRZ (Grogan, NSW; Condowie in SA and Kiata and Plant Breeding Centre (PBC) (Horsham) in Victoria). The equivalent of 20t/ha of organic amendment was applied at HRZ sites (except for Marrabel where 15t/ha was applied) and 15t/ha at MRZ sites. All experiments had a common set of amelioration treatments (as well as additional ones of local interest) including a deep-ripping 'check', surface and subsoil application of animal manure, legume plant based amendment and gypsum. In addition, all experiments had a nutrient only treatment (phosphorus (P) plus N rates equivalent to 50% of that contained in organic material with supplementary N applied over the subsequent three crops. This strategy accounted for a predicted 50% mineralisation rate of N from the amendment each year so that the sum of N applied was equivalent to that in the organic material after three years) and a treatment comprising wheat straw plus nutrients. Amendments were applied once so that the residual value could be assessed in subsequent years.

Subsoil water and response to amendments

The effect of subsoil water on crop response to amelioration treatments was assessed by establishing irrigated subplots (1.6m wide x 2.7m long) in five treatments (control, deep nutrients, topsoil nutrient enriched organic matter (NEOM), subsoil NEOM, wheat plus nutrients) in the PBC DAV00149 experiment in March 2020 using gravity-fed drip irrigation. A total of four irrigation events were applied, each equivalent to 46mm. Changes in profile soil water balance (using neutron probes), dry matter and normalised difference vegetation index (NDVI) throughout the growing season and grain yield were monitored in the irrigated subplots and compared to adjacent dryland main plots.

Results and discussion

Analysis of long-term trials

Grain yields were improved by an average of 19% following application of plant based (legume) amendments into the subsoil across a range of soil type and environments compared to the control (no amendment) (Figure 1). In many cases the plant manure produced a marked improvement in dry matter production, but this did not translate to a response in grain yield. In contrast animal manures improved yields on average by a greater amount (26%) but produces strong negative effects on yield at several sites, whereas organic amendments produced a negative effect in one case only. Furthermore, although influenced by a small number of sites, there appeared to be a trend for the residual benefits of applying plant-based amendments into the subsoil to last longer whereas the residual benefits of the animal manures were somewhat shorter term. There were very few positive benefits (3 out of 18) in grain yield to deep ripping alone (data not presented). Four sites produced large negative responses to ripping. The overall net effect was that overall ripping alone did not change crop productivity.

Although these findings were based on both replicated and non-replicated trials, they indicate the same general trends observed to date in 'new field experiments' reported later. Two major barriers to the widespread commercial scale adoption of soil amelioration is the lack of sufficient quantities of animal manures. This analysis suggests that plant based (predominantly legume) manures are nearly as effective as the animal manures. As well as being more readily available, the use of plant manures potentially reduces the financial risk associated with subsoil manuring as there were no marked negative impacts that can occur with animal manures, especially in medium rainfall systems and there was a trend towards a much longer residual benefit which is critical to offsetting the initial high upfront costs of subsoil amelioration.

The effectiveness of different amendments and placement strategies

No positive yield responses to amendments were recorded in 2020 at either Condowie (SA) nor Kiata (Victoria), reflecting continued low growing season rainfall (GSR) experienced at these sites since 2017 and 2018, respectively (data not presented). There were significant ($P<0.05$) grain yield responses recorded at Grogan, NSW (GSR = 426mm) where wheat straw plus nutrients was 15% and deep gypsum was 11% greater than the control (7.2t/ha of wheat) respectively and at the PBC (Victoria) site (GSR = 287mm; Decile 7) where deep manure and deep wheat straw plus nutrient were 11% greater ($P<0.05$) than the control (barley = 5.1t/ha). This yield response at Grogan, which corresponded with high GSR, contrasts with previous seasons where crops have been cut for hay due to frost and dry seasonal conditions.

Prior to 2020 there have been large (20 to 65%) yield responses to soil amendment at all HRZ sites with the exception of Tatyoon (Victoria), where responses were small (15%) or less. In 2020 for the three sites harvested to date, treatment effects were much smaller with a small treatment effect ($P=0.01$) at Marrabel (barley yield of control was 6.22t/ha; GSR = 393mm) and no significant effect at Tatyoon (average faba bean yield of 4.75t/ha; GSR = 404mm). In contrast, at Rand (NSW), where GSR = 401mm, had significant grain yield ($P<0.001$) responses to deep gypsum (19%) and deep wheat straw plus nutrients (20%) compared to the control (wheat = 6.9t/ha). Although overall responses were smaller in 2020 than in the previous three seasons (highest yield treatment from deep gypsum was 20% greater than the control), the pattern of treatment differences remained, since the experiment commenced in 2017, with an average of greater than 23% for the most productive treatments compared to the control (Figure 3).

Subsoil water and response to amendments

Since project experimentation commenced in 2017, the largest (on both an absolute and relative scale) crop biomass and grain yield responses have been recorded in the HRZ rather than MRZ. Prior to 2020, of the nine MRZ site x year trials conducted to date, the highest annual and growing season rainfall had been decile 5 (at PBC in 2019) with most sites recording Decile 2 to 3. In this time, no MRZ site has recorded significant subsoil water reserves prior to sowing.

At sowing (in May 2020) at PBC, the irrigation produced significant increases in volumetric soil water content to depths greater than 80cm. Interestingly, there was a trend for this increased

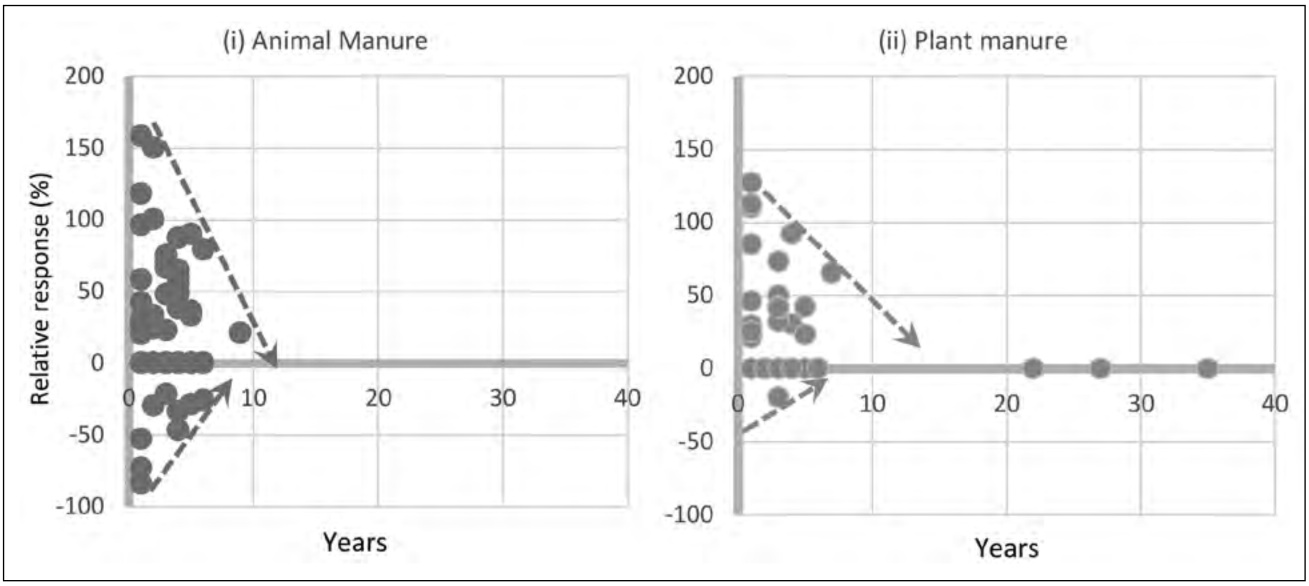

Figure 1. Relative grain yield response of crops to (i) application of animal manure and (ii) plant- based manures in a series of long-term fields in SE Australia.

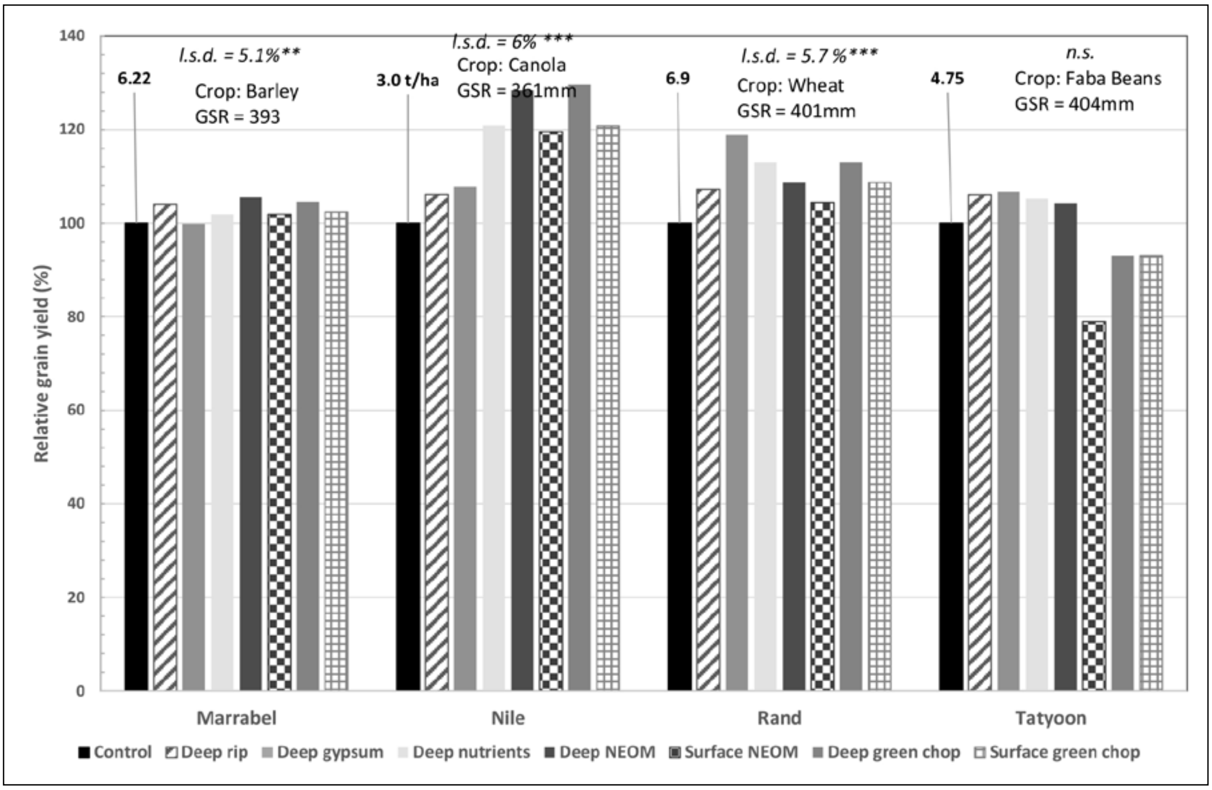

Figure 2. Relative grain yield response (%) to soil amendments (Control = 100%). Data is for the HRZ Tatyoon, Rand and Marrabel sites in 2020 and Nile in 2019 (2020 Nile trial had not been harvested at time of writing). Value above Control represents grain yield (t/ha). GSR = growing season rainfall.

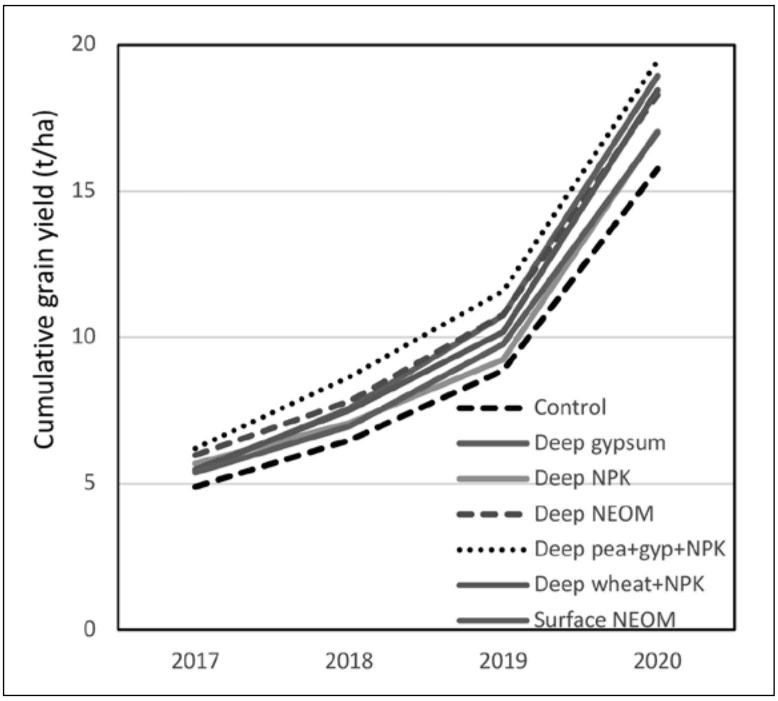

Figure 3. Cumulative grain yield responses to selected amendment treatments at Rand for 2017 (barley), 2018 (wheat), 2019 (canola) and 2020 (wheat).

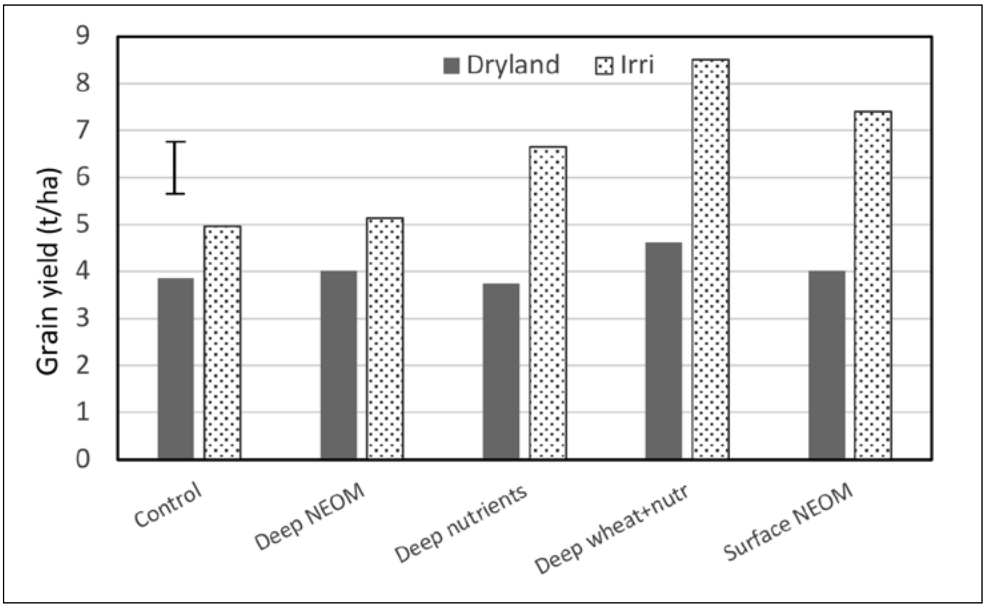

Figure 4. Effect of irrigation (prior to sowing) on grain yield responses of barley to soil amelioration (PBC, 2020). Vertical bar represents *l.s.d* (P=0.05 = 1.01 t/ha) for interaction between amendment and irrigation.

water to reach lower in the soil profile in amended treatments (applied to both topsoil and subsoil) compared with the irrigated control treatments (data not presented).

In the absence of subsoil water reserves, there was no significant difference ($P<0.05$) in wheat grain yield between soil treatments (mean = 4.05t/ha, dryland treatments) (Figure 4). In the irrigated microplots, grain yield increased on average by 2.48t/ha (61%). The impact of irrigating varied with the type of amelioration imposed, ranging from 28% in the control and Deep NEOM to 78% with Deep nutrients and 84% for both Deep wheat plus nutrient and Surface NEOM. The highest grain yields (8.51t/ha) were recorded for Deep wheat plus nutrient treatment. Differences in grain yield were reflected in total wheat biomass with a trend of lower harvest index in irrigated microplots ($P=0.073$).

Conclusion

The use of plant (legume) biomass appears to offer important advantages over animal manures when ameliorating clay subsoils in the MRZ and HRZ, because of the absence of potential negative impacts on grain yield and potentially longer residual value. Importantly, plant-based manures are generally easier to source than animal manures. Results over the past two years from several of the new field experiments in DAV00149 indicate that not only are legume residues effective but that applying wheat straw plus nutrients into subsoils can significantly improve grain yields.

Grain yield responses to soil amendment on these clay soils appear to be strongly influenced by soil water supply, with poor treatment responses in very dry seasons when there is very little subsoil moisture (as evidenced by the majority of MRZ experiments to date), or very wet seasons when crops can access sufficient moisture from the topsoil (as occurred at Tatyoon and Marrabel in 2020). Controlled environment experimentation has shown that the application of subsoil manures or nutrient rich plant-based materials can improve wheat growth in water-logged soils, possibly due to a reduction in soil redox potential. There was evidence that the presence of subsoil water appears to influence response to amendments. Soil amelioration can affect crop productivity by overcoming physicochemical constraints – nutritional, poor structure and potentially toxicities such as water logging, occurring in both the topsoil and subsoil. The effect of subsoil water on amendment response is not surprising given that subsoil water has the potential to produce twice the grain yield per mm of water used compared to surface soil water (Lilley and Kirkegaard 2007) and the finding that subsoil constraints can only limit grain yields when crops are reliant on subsoil water to realise yield potentials (Nuttall and Armstrong 2010).

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Faba bean agronomy and varieties

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GRDC project code: DAV00150

Keywords

- faba bean, canopy management, weed management, herbicide tolerance, disease resistance, soil constraints.

Take home messages

- Faba bean production has grown significantly in Victoria due to improved grower confidence with agronomy and varieties, which deliver profitable returns for the whole farming system.
- For commonly used varieties, sowing in April optimises grain yield in all rainfall zones across varying seasons, even in higher biomass production areas of the high rainfall zone (HRZ) (in the absence of lodging and when diseases are managed succesfully).
- In the HRZ of southwest Victoria, yield potential is likely to be limited at or above 25 plants/m^2 with any sowing date, suggesting that current practice is underutilising available light and moisture.
- To maintain a high yield potential across seasonal variability, growers should pursue growing manageably large canopies rather than trying to increase the pod-set of individual plants.
- In low rainfall areas, earlier flowering new varieties with higher yield potential and agronomic treatments that ameliorate soil constraints, like deep ripping on sands could give growers confidence to expand the area where faba bean is grown.
- Ongoing improvements in herbicide tolerance (PBA Bendoc⍉) and disease resistance (PBA Amberley⍉), combined with optimised agronomic management will improve economic yield and yield stability.

Background

Production of faba bean in Victoria has grown over the last 10 years from 35,000t produced from 22,000ha in 2009-10 season to 67,000t from 116,000ha in the 2018-19 season (Table 1). A peak in production was achieved in 2016-17 season with 220,000t and a peak in area sown was achieved at 147,000ha in 2017-18 season. These increases are due to improved grower confidence with agronomy and varieties which deliver profitable returns for the whole farming system. However, as illustrated by Table 1, the seasonal yield variability for faba bean is high due to a range of biotic and abiotic factors which when combined with price variability could constrain further growth and expansion.

Faba bean production across Victoria in 2020 was generally excellent with many crop yields of 4-5t/ha being reported within the medium and high rainfall zones. Unfortunately, prices have dropped dramatically from above $900/t in 2019, to less than $350/t in early 2021.

Most faba bean production occurs in the high and medium rainfall zones. However, there is increasing interest in the lower rainfall zones as new varieties with drought adaptation become available. Faba bean can be extremely profitable as a cash crop with long term average prices around $400/t, however prices can be volatile with peaks over $900/t in 2019 to a low of $220/t in 2018. An additional benefit reported by many growers is the higher growth rate of lambs grazed on bean stubbles, thereby providing additional profitability to the whole farm system. The 'break crop' benefits of faba bean also adds value to the following cereal crop and includes:

- Potentially, more than 100kg N/ha contributed to the following crop.
- Effective control of grass weeds.
- Effective break for many cereal foliar and root diseases.

When combined, these benefits are valued at improving yield of the following cereal crop by at least 0.5-1t/ha (Moodie *et al.* 2016).

To maintain a continued improvement in grower confidence to growing faba bean and support the growth in production and profitability several factors are being addressed through applied research and development activities to broaden the adaptability and improve the stability of faba bean yield. This paper presents some of the latest research findings that aim to overcome many of the key constraints across Victoria.

Results and discussion

Maximising yield potential through canopy management in southwest Victoria (HRZ)

Canopy size, plant size and yield potential

A substantial dataset has been generated over numerous years of trials in southwest Victoria where canopy size has been manipulated through time of sowing and sowing rate. The results from these trials suggest that growers should change their thinking on how canopy management affects faba bean yield potential.

For a canopy to maximise yield it must capture as many resources as possible and allocate them efficiently to grains. This can be increased by management options such as sowing earlier or increasing the plant density up to the point at which crop-to-crop competition becomes excessive.

At Inverleigh in 2020, results of trials showed that as plant density increased each individual plant was smaller and supported fewer pods/plant (Table 2). On balance however, having more small plants with fewer pods/plant increased overall pods/m^2 at the

Table 1. Area sown and production of faba beans in Victoria from 2009-2010 to 2018-2019. (Source: ABARES, 2021).

Year	Area '000 ha	Production kt	Price at Harvest $[A]
2009–10	22	35	n/a
2010–11	63	104	n/a
2011–12	49	99	n/a
2012–13	67	126	440
2013–14	59	127	400
2014–15	62	112	400
2015–16	75	57	500
2016–17	120	220	240
2017–18	147	196	220
2018–19	116	67	900

[A]*Based on prices offered in Horsham in December of that season*

Table 2. Grain yield, net return and pod-set of PBA Bendoc⍉ sown on 13 April, 2020 (199mm rainfall from 1 Aug to 31 Oct), at Inverleigh with four plant densities averaged across two row spacings (20cm and 40cm, n.s. *P*>0.05). Net return based on production costs of $340/ha, seed cost $0.59/kg, grain freight cost of $30/t and grain price of $300/t.

Plant density (pl/m^2)	Pods/plant	Pods/m^2	Grain yield (t/ha)	Net return ($/ha)
6	84 a	510 c	5.2 c	1026
16	38 b	615 bc	6.6 b	1361
26	31 b	786 ab	7.0 ab	1431
34	30 b	977 a	7.4 a	1501
Lsd (*P*<0.05)	14	227	0.8	-

canopy level. This resulted in a correlation between increased yield and increased plant density. This shows that crop-to-crop competition was not limiting up to 34 plants/m² (Table 2). At Rokewood in 2016, yield also increased with plant density up to 26 plants/m² (Table 3).

Previous research on faba bean crops from a wide range of environments shows that good growing conditions favour low plant densities by enabling high biomass production (Lopez-Bellido *et al.* 2005). The current grower practice in southwest Victoria is to sow between 15 and 25 plants/m², so it might be expected that 15 plants/m² would suit the high yielding years of 2016 and 2020. However, in the trials presented (Table 1 and Table 2), yield increased with higher density plantings of 26 plants/m2 (Table 3) and 34 plants/m² (Table 2). These crops were sown in April which also favours crop growth compared to a later sowing in May. These results suggest a density of at least 25 plants/m² could be required to maximise the yield potential of faba bean crops sown in favourable conditions.

Research has also shown that short or poor seasons favour high plant densities of faba bean because the high plant densities compensate for the loss in canopy growth (Lopez-Bellido *et al.* 2015). It does not appear to cause excessive growth when resources are limited. This has been observed in 'dry' seasons in the HRZ. For example, in a trial at Lake Bolac in 2018 where rainfall was below average (102mm during August 1 to October 31), yield increased with an increased plant density up to 45 plants/m² and was consistently greater following a 26 April sowing date compared to a 17 May sowing date (Table 4). A similar result was obtained in 2015, which was another season with a 'dry' spring (66mm during August 1 to October 31), and yield increased up to 35 plants/m² with no further increase in yield at 47 plants/m² (Table 5). These results suggest that sowing in late April, rather than mid-May, and increasing the plant density up to 35 plants/m² is likely to increase grain yield potential in unfavourable seasons.

Table 3. Grain yield and net return of Nura⁽ᵇ⁾ and PBA Zahra⁽ᵇ⁾ faba bean sown at Rokewood on 26 April 2016 (286mm rainfall from 1 Aug to 31 Oct), with five seeding rates. Net return based on production costs of $250/ha, $0.50/kg of seed sown and returns on grain of $240/t.

Plant density (pl/m²)	Grain Yield (t/ha)			Net Return ($/ha)		
	Nura⁽ᵇ⁾	PBA Zahra⁽ᵇ⁾	*Ave*	Nura⁽ᵇ⁾	PBA Zahra⁽ᵇ⁾	*Ave*
4	3.2	3.5	*3.4*	504	573	*538*
9	4.9	4.8	*4.9*	891	864	*877*
15	5.3	5.2	*5.3*	970	953	*962*
20	5.7	5.4	*5.6*	1052	985	*1019*
26	5.5	6.1	*5.8*	970	1118	*1044*
Ave	*4.9*	*5.0*	*5.0*	*877*	*899*	*899*
Lsd $(P<0.05)_{Var}$	ns			-		
Lsd $(P<0.05)_{SR}$	0.6			-		
Lsd $(P<0.05)_{VarxSR}$	ns			-		

Table 4. Grain yield and net return of PBA Samira⁽ᵇ⁾ sown on two sowing dates with three sowing rates at Lake Bolac in 2018 (102mm rainfall from Aug 1 to Oct 31). Net return based on production costs of $306/ha, seed cost $0.32/kg, grain freight cost $30/t, grain price of $330/t.

Plant density (pl/m²)	Grain Yield (t/ha)			Net Return ($/ha)		
	26 April	17 May	*Ave*	26 April	17 May	*Ave*
21	2.3	1.9	*2.1 c*	334	215	*275*
31	3.0	2.2	*2.6 b*	514	277	*395*
45	3.3	2.4	*2.8 a*	575	309	*442*
Ave	*2.9 a*	*2.2 b*		*474*	*267*	
Lsd $(P<0.05)_{TOS}$	0.2			-		
Lsd $(P<0.05)_{SR}$	0.2			-		
Lsd $(P<0.05)_{TOSxSR}$	ns			-		

Table 5. Grain yield and net return of PBA Zahra⁽ᵇ⁾ and PBA Rana⁽ᵇ⁾ sown at Westmere on 22 April, 2015 (66mm rainfall from Aug 1 to Oct 31). Net return based on production costs of $318/ha, seed cost $0.49/kg, grain freight cost $25/t, grain price of $400/t.

Plant density (pl/m^2)	Grain Yield (t/ha)	Net Return ($/ha)
16	2.3 c	488
26	2.8 b	644
35	3.0 a	691
47	3.0 a	655
Lsd $(P<0.05)_{SR}$	0.2	-
Lsd $(P<0.05)_{V}$	0.2	-
Lsd $(P<0.05)_{SRxV}$	n.s.	-

These disease-free trials suggest that typical commercial sowing rates of 15 to 25 plants/m^2 are underutilising available moisture and light resources. Although southwest Victoria is a relatively favourable environment for crop growth, individual faba bean plants are not compensating enough through high growth or pod-set at these densities for crop-to-crop competition to become limiting and penalise yield potential. Soil constraints (e.g., soil acidity), cool temperatures and/or limits of genetic potential in current varieties could also be contributing to this observation.

Regardless of seasonal conditions, earlier sowing increased yield, and increasing the sowing rate further increased grain returns despite the cost of extra seed. Within the sowing rate range of current industry practice, growers should focus on growing large canopies that fit their attitude to disease and lodging risk, while paying attention to extra seed costs and grain price variability. Trials have consistently demonstrated that late sowing or low plant densities will not compensate in yield potential through higher pod-set.

Higher sowing rates and/or earlier sowing could also add additional benefits to the farming system through greater competition with weeds, increased N fixation and increased feed availability for livestock post-harvest. These benefits should be weighed against the higher risk of lodging and disease.

Time of sowing and phenology

Early sowing generally increased crop biomass as well as enabling the key development phases of flowering and pod-set to occur earlier in the season. Compared to other pulses, faba bean are more tolerant to frost damage and cool temperatures, but more susceptible to heat damage and moisture stress. For instance, April sown trials out-yielded May sown trials in 2018, 2019 and 2020 which experienced high incidences of frost coinciding with flowering and pod-set, although the rainfall received during each spring differed.

At Lake Bolac in 2020, a time of sowing x variety trial found that across the seven cultivars tested an earlier time of sowing resulted in an increased grain yield (Table 6). AF12025 achieved the highest yield with the earliest flowering date of July 5 (compared to August 7 for PBA Samira⁽ᵇ⁾) in the TOS1 treatment but had a lower yield than PBA Samira⁽ᵇ⁾ with a 19 May sowing date.

Faba bean breeding trials are typically sown in a window between 27 April to 19 May and this is reflected in the high yield and yield stability of the popular variety PBA Samira⁽ᵇ⁾, and the recently released PBA Amberley⁽ᵇ⁾. The interactions between sowing date and cultivar type for yield indicate that more work can be done to match cultivars to a wider range of sowing dates for southwest Victoria. An exploration of phenological responses of current

Table 6. Grain yield of seven faba bean cultivars sown on three sowing dates at Lake Bolac in 2020.

TOS	PBA Samira⁽ᵇ⁾	AF12025	PBA Amberley⁽ᵇ⁾	PBA Nasma⁽ᵇ⁾	PBA Zahra⁽ᵇ⁾	Fiesta	PBA Bendoc⁽ᵇ⁾	*Mean (TOS)*
9-Apr	5.8	6.5	5.5	4.7	4.9	5.6	4.8	*5.4*
27-Apr	4.7	4.5	4.7	4.6	4.5	3.8	3.7	*4.4*
19-May	3.6	3.1	3.6	3.9	2.7	2.6	3.1	*3.2*
Mean (Variety)	*4.7*	*4.7*	*4.6*	*4.4*	*4.0*	*4.0*	*3.8*	
Lsd_{TOS} $(P<0.05)$	0.5							
$Lsd_{Variety}$ $(P<0.05)$	0.5							
$Lsd_{TOSxVAR}$ $(P<0.05)$	0.4							

and upcoming breeding lines was undertaken in southwest Victoria and Tasmania in 2020 in collaboration with Pulse Breeding Australia to begin understanding optimum flowering windows for these regions.

Managing herbicide residues and weed management in Victoria

Weed management and herbicide residues are important constraints to maximising the productivity and profitability of faba bean across Victoria. Leading growers have always taken a long-term view to minimise potential weed burden in faba bean by effectively controlling broadleaf weeds in the cereal phase of the rotation and utilising herbicides that are unlikely to create significant residual issues in the faba bean phase.

The faba bean breeding program has developed cultivars with improved tolerance to Group B imidazolinone herbicides. The release of PBA Bendoc$^{\Phi}$ in 2018, has increased options for the control of broadleaf weeds and enhanced tolerance to sulfonylurea residues. Several trials have been conducted over several years resulting in the registration of Intercept® for use in-crop. For example, in PBA Bendoc$^{\Phi}$ no significant visual damage was observed from the application of imidazoline products and a very low level of damage occurred from simulated sulfonylurea residues in trials at Horsham 2019 (Table 7). Further, grain yield loss was not significant in PBA Bendoc$^{\Phi}$ compared with the 'Nil' for any of the herbicide treatments, although the data indicates approximately 10% potential yield loss in the simulated residue treatment of metsulfuron-methyl compared to all other treatments. In comparison, severe crop damage and significant yield loss was observed for most herbicides applied to the conventional variety PBA Samira$^{\Phi}$.

Breeding programs are continuing to develop improved tolerance to Group I (e.g., clopyralid) and Group C (e.g., metribuzin) herbicides, which will further enhance weed control and herbicide residue management options. There have also been several new herbicides (e.g. Group G) registered and recently released which will continue to improve the ability of growers to maximise weed control in faba bean and throughout the whole farming system.

Adaptability to the LRZ of Victoria – genetic and agronomic solutions

Faba bean can be extremely sensitive to hot, dry conditions, particularly during the reproductive phase. Faba bean is also poorly adapted to deep sandy soils which are found in 20-30% of the low rainfall Mallee. Several years ago, the breeding program focussed on improving adaptation through earlier flowering and maturity, which resulted in the release of PBA Marne$^{\Phi}$, which shows improved yield under drier conditions, particularly in SA. In Victoria, another breeding line, AF12025, which can flower two weeks earlier than PBA Samira$^{\Phi}$, has consistently shown high grain yields in the southern Mallee across a range of cropping seasons. (Table 8). Potential gross margins were above $3,000/t in 2019 when high yields and prices were achieved concurrently.

Recent agronomic research has highlighted that practices such as deep ripping, which reduce

Table 7. Visual herbicide damage score (0, No symptoms – 100, Crop death) and grain yield (t/ha) of the new imidazoline tolerant variety, PBA Bendoc$^{\Phi}$, in comparison to the conventional variety, PBA Samira$^{\Phi}$, in response to application of imidazolinone products post sowing pre-emergent (PSPE) at four node crop growth and a sulfonyl urea applied to simulate potential residuals at Horsham in 2019.

Active ingredient (g/ha)	Application Timing	Herbicide Damage (0-100)		Grain Yield (t/ha)	
		PBA Bendoc$^{\Phi}$	PBA Samira$^{\Phi}$	PBA Bendoc$^{\Phi}$	PBA Samira$^{\Phi}$
Nil (0)		0	0	4.49	4.50
Imazamox(25) & Imazapyr (11)	PSPE	0	3	4.38	3.74
	4 node	5	85	4.63	1.30
Imazethapyr (70)	PSPE	0	8	4.75	4.00
Metsulfuron-methyl (4)	Simulated Residue	18	72	3.91	0.49
Lsd $_{ChemTrt}$ (*P*<0.05)		*5*		*0.68*	
Lsd $_{Var}$ (*P*<0.05)		*2*		*0.09*	
Lsd $_{ChemTrt*Var}$ (*P*<0.05)		*8*		*0.73*	

Table 8. Grain yield (t/ha) and gross margin ($/ha) of selected faba bean varieties and breeding lines at Curyo (southern Mallee, Vic) from 2016 to 2020.

Variety	2016		2017		2018		2019		2020		Average	
	GY (t/ha)	GM[1] ($/ha)	GY (t/ha)	GM ($/ha)	GY (t/ha)	GM ($/ha)	GY (t/ha)	GM ($/ha)	GY (t/ha)	GM ($/ha)	GY (t/ha)	GM ($/ha)
AF12025	5.75	1079	3.12	386	0.43	87	5.22	3354	3.55	872	3.61	1156
Farah	4.54	790	2.73	301	0.43	87	4.06	2542	4.02	1027	3.16	949
PBA Bendoc$^{\phi}$			2.91	340	0.40	60	4.26	2682	4.37	1142	2.99	1056
PBA Marne$^{\phi}$	5.49	1019	2.59	270	0.40	60	4.18	2626	3.82	961	3.30	987
PBA Samira$^{\phi}$	4.12	688	3.13	389	0.47	123	3.42	2094	3.95	1004	3.02	859
PBA Zahra$^{\phi}$	4.42	762	2.99	358	0.28	-48	4.30	2710	4.50	1185	3.30	993
Lsd_{GY} (*P*<0.05)	*0.97*		*0.48*		*0.08*		*0.43*		*0.61*			
Grain Price ($)		240		220		900		700		330		
Rainfall Annual	471		397		275		230		359			
GSR	356		243		131		180		238			

[1] *Gross margins are based on estimated production costs of $300/ha)*

soil penetration resistance, can lead to substantial productivity gains of pulses on these deep sands. At Koolonong in 2020, ripping to 50cm prior to sowing improved faba bean grain yield by 300% in deep sand, increasing the yield from 0.5t/ha to 2t/ha (Figure 1). The yield on the ripped sand exceeded yields on the heavier swale soil in the flat of the same paddock by approximately 0.5t/ha. These examples highlight that with ongoing agronomic and genetic improvement, further expansion of faba bean is feasible.

Genetic solutions to disease management

Diseases, notably chocolate spot, are a significant obstacle to closing the yield gap of faba bean, particularly in the HRZ. A significant step has been made with the recent release of varieties with enhanced chocolate spot resistance. For example, when plant density was increased, which increased biomass, disease increased in faba bean canopies (Figure 2). However, the rate of increase in PBA Amberley$^{\phi}$ was smaller (2.3% more disease per 10 plants/m^2), than PBA Bendoc$^{\phi}$ (4.9% more disease

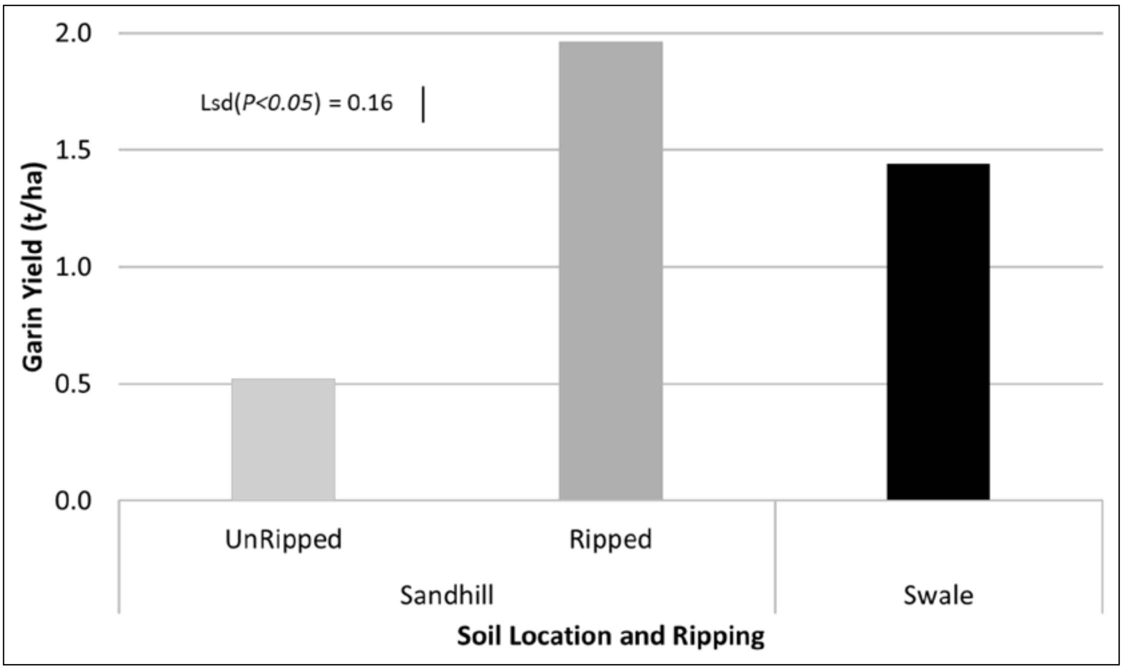

Figure 1. Effect of soil type and deep ripping sandy soils on the grain yield of faba bean at Kooloonong in 2020.

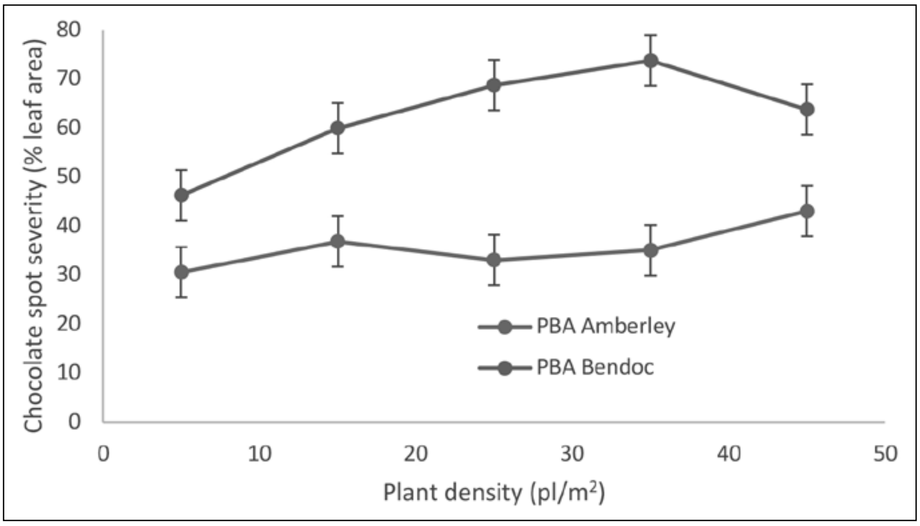

Figure 2. The effect of plant density on chocolate spot disease severity (% of canopy leaf area) evaluated on October 20, 2020 in PBA Amberly⁽ᴰ⁾ and PBA Bendoc⁽ᴰ⁾, which differ in their genetic resistance against diseases. Error bars are the l.s.d. for the Variety x Plant density interaction (P<0.05).

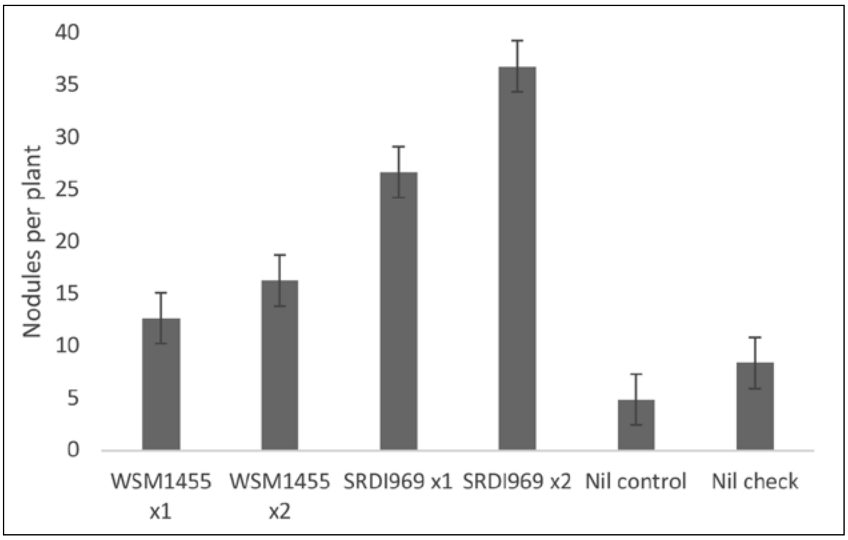

Figure 3. The effect of rhizobia strain and peat inoculation rate on faba bean nodulation at Winchelsea in 2020, compared to uninoculated and cross-contamination controls. Error bars are the Lsd of a one-way ANOVA (P<0.05).

per 10 plants/m^2). Therefore, genetic resistance can change the relationship between canopy size and disease pressure revealing an opportunity to close the yield gap through growing profitably large canopies in the HRZ. Agronomy packages will need to be tailored appropriately to protect the higher yield potential of these large canopies, and further work is needed to clarify what that will entail. Further disease management results are discussed at this GRDC Update by Josh Fanning.

Agronomic solutions to acid soil constraints

Acid soils are a significant constraint for faba bean production in southwest Victoria. Low soil pH reduces crop productivity directly by reducing nodulation and nitrogen fixation. An acid-tolerant rhizobia strain developed at SARDI has been shown to increase nodulation in these conditions. For instance, at Winchelsea in 2020 this acid-tolerant strain (SRDI969) stimulated greater overall nodulation (Figure 3). In addition to this, when the rate of inoculant was doubled, nodules increased from 27 to 37 nodules/plant. In this trial, the current commercial strain (WSM1455) did not respond to a doubled rate of peat inoculant and averaged 14.5 nodules/plant.

These levels of nodulation are however lower than the suggested optimum of 50 nodules/plant. This is because the soil pH at this site was

4.4 $CaCl_2$ at 0 to 20cm depth. Liming is recommended to achieve a pH of 5.5 $CaCl_2$ in the top 10cm of soil which will maintain soil pH above 5.0 in the top 20cm of soil. This will enable greater nitrogen fixation in addition to the other system benefits improved pH brings.

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The authors are also grateful to all growers who have hosted trials on their farms and the input of industry representatives and colleagues to trial ideas and treatments.

Additionally, the authors are thankful to the technical teams of Agriculture Victoria and Southern Farming Systems, who have managed these trials.

Useful resources

Faba Bean Southern Region - GrowNotes™, 2017. *Available on the GRDC website.*

Online Farm Trials – All trial results from the Southern Pulse Agronomy Research program are published here.

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

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Notes

Notes

Pulse disease research update

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Keywords

- faba bean, chocolate spot, chickpea, ascochyta blight, soil-borne disease.

Take home messages

- Selecting a more resistant variety will reduce grain yield losses caused by disease.
- The faba bean, PBA Amberley⨀ will require fungicide application to prevent grain yield losses.
- Fungicide strategies incorporating newer fungicide actives are providing equal or better disease control than older actives in faba bean and chickpea.
- Applying fungicides to prevent ascochyta blight in chickpea when grain yields are above 0.5t/ha resulted in an economic advantage in field experiments.
- Inter-row sowing into standing cereal stubble, compared to slashed stubble, is almost as effective at reducing chickpea grain yield losses due to ascochyta blight, as choosing a moderately susceptible variety compared to a susceptible variety.
- Numerous pathogens have been detected in pulse roots, and many *Fusarium* spp. and *Phoma/Didymella* spp. have been shown to cause root disease.

Background

Management of pulse diseases is essential to on-farm profitability, and this was especially the case during 2020. Consistent winter rainfall and foggy conditions provided conducive conditions for disease development in Victoria. In field experiments, 35% loss in grain yield was measured in faba bean at Lake Bolac (high rainfall) and 92% in the susceptible chickpea variety PBA Striker⨀ at Curyo (low rainfall), highlighting the importance of controlling pulse diseases in a range of environments.

The following report will provide an update on experiments investigating;

1. Effect of faba bean plant densities on disease severity,
2. Disease management options in chickpea and faba bean varieties utilising varietal resistance and fungicides,
3. The interaction of stubble height on chickpea ascochyta blight management, and
4. Soil-borne diseases in pulse crops.

Faba bean disease management

Sowing rate

Chocolate spot in faba bean is a large threat to yield, particularly in high rainfall areas. Chocolate spot disease development can occur at most growing season temperatures, but disease development is quickest when canopy humidity is high (greater than 70%) and temperatures are warm (15-25°C). These environmental conditions can differ between crops, depending on the prevailing weather but also the canopy density.

Field experiments at Lake Bolac and Lake Linlithgow showed that chocolate spot severity increased in faba bean plots as target plant densities increased from 5 to 45 plants per square metre, with similar results observed at both sites (Figure 1). The variety PBA Bendoc⁽ᵠ⁾ (rated moderately susceptible (MS)) had greater disease severity in all plant densities, compared to PBA Amberley⁽ᵠ⁾ (provisionally rated moderately resistant (MR)). Additionally, PBA Amberley⁽ᵠ⁾ had over 60% disease severity in high density (45 plants/m2) plots, equivalent to PBA Bendoc⁽ᵠ⁾ at a low density of 5-15 plant/m^2. This highlights that the ideal conditions for disease will still put pressure on the moderate resistance in PBA AmberleyA and result in grain yield losses. The chocolate spot resistance rating of faba bean is reviewed annually, so it is important to always check for up to date disease ratings.

Varietal resistance and fungicide strategy

With the recent release of PBA Amberley⁽ᵠ⁾ (provisionally rated MR to chocolate spot) and the newer fungicide actives, it was important to review fungicide strategies against varietal resistance to determine if the number of applications required to prevent grain yield loss can be reduced. At five locations across Victoria (Dookie, Nhill, Gymbowen, Lake Linlithgow and Lake Bolac) experiments were conducted to compare varietal resistance and fungicide strategies. Only the Lake Bolac and Gymbowen results are presented in this paper. Newer chemistries including, tebuconazole + azoxystrobin (Veritas®), bixafen + prothioconazole (Aviator® Xpro®) and fludioxonil + pydiflumetofen (Miravis Star® - registration submission awaiting approval from the APVMA) were compared against older chemistries including carbendazim or procymidone (Table 1). The aim was to compare the newer chemistries applied at early flowering with the older chemistries at canopy closure. All treatments received a 4-node tebuconazole application to prevent cercospora leaf rot. Treatments were applied at early flowering as these newer chemistries were expected to have longer efficacy and this timing is the latest some of these products can be applied to comply with label directions. The Lake Bolac and Gymbowen experiments were sown 19 April and 23 April 2020, respectively.

At Lake Bolac, additional applications of carbendazim and procymidone were applied in addition to the fungicide treatments, as conducive disease conditions continued throughout the season and this site needed additional fungicide controls. In other experiments on these sites, it was difficult to control chocolate spot in susceptible varieties, even with fungicides. This highlights the need for proactive disease management as disease epidemics can develop rapidly.

Disease epidemics varied between locations with no disease observed at Nhill and Dookie. Gymbowen, Lake Bolac and Lake Linlithgow all had chocolate spot, and a low level of cercospora

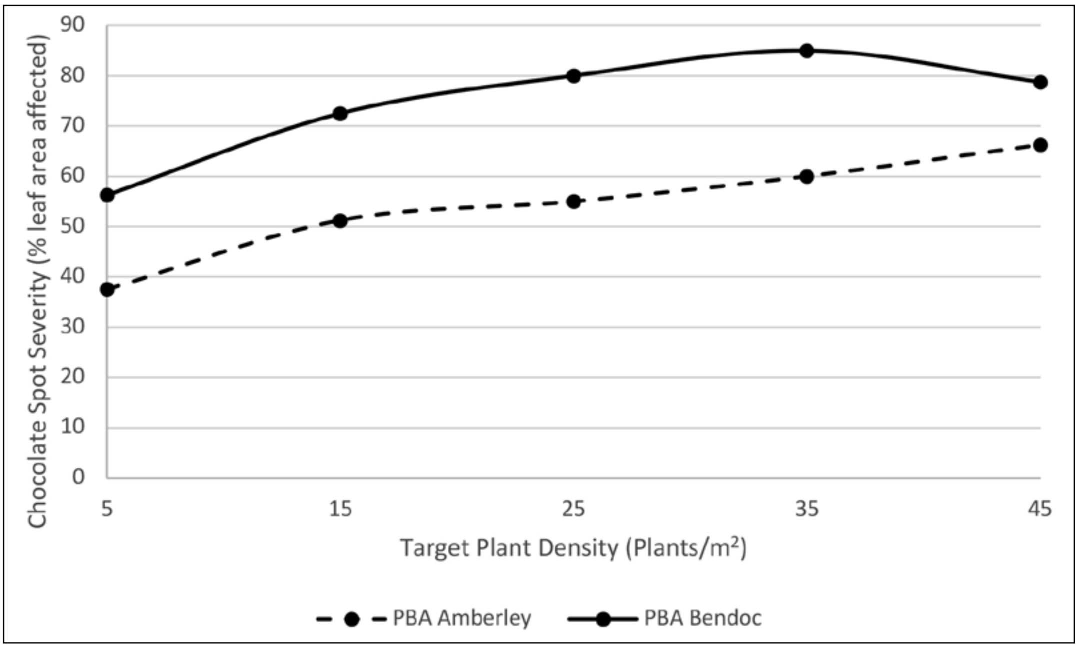

Figure 1. Increasing plant density resulted in increasing chocolate spot severity in unsprayed plots at Lake Bolac in a field trial planted 9 April 2020.

Table 1. Fungicide treatments and timings in faba bean experiments conducted at Lake Bolac and Gymbowen during 2020.

Treatment[A]	Rate (gai/ha)	Timing
Untreated (No fungicides)		
Carbendazim	250	Canopy Closure
Procymidone	250	Canopy Closure[B]
Tebuconazole + Azoxystrobin	200	Early Flowering
	120	
Bixafen + Prothioconazole	45	Early Flowering
	90	
Fludioxonil + Pydiflumetofen[C]	-[C]	Early Flowering
Full Control[D]		

[A] These fungicides are additional to all treatments receiving a tebuconazole application at the 4 to 6 node growth stage. At Lake Bolac there was significant disease pressure later in the season. Therefore, an additional two carbendazim (250 gai/ha) and an extra one procymidone (240 gai/ha, two extra procymidone applications on the carbendazim treatment) were applied alternately every 2-4 weeks to control the chocolate spot; [B]At Lake Bolac the first procymidone was applied at flowering; [C]This is a new product to Australia called Miravis Star® which is currently going through the registration and approval process; [D]The full control treatment is a rotation of fungicides applied to ensure minimal to no disease as a control in the experiment.

leaf spot. All three sites with chocolate spot demonstrated similar results, so Lake Bolac is highlighted where disease was moderate (Table 2). PBA Bendoc(D) had consistently more severe chocolate spot compared to the other varieties, with disease symptoms observed and progressing under the 'Full Control' fungicide treatment. In comparison, PBA Samira(D) and PBA Amberley(D) had the least disease severity. The fungicide treatment containing Fludioxonil + Pydiflumetofen resulted in disease severity similar to the 'Full control'.

These results highlight the requirement for fungicides to be applied to PBA Amberley(D) to prevent severe disease.

Faba bean grain yield recorded at Lake Bolac and Gymbowen indicated greater fungicide efficacy in the newer chemistries, with Fludioxonil + Pydiflumetofen, providing higher yield gains compared to the other fungicide strategies. Economic benefit of applying the new chemistries, was similar to the older strategy involving carbendazim (Table 3 and 4).

Table 2. Chocolate spot severity in four varieties with different fungicide strategies applied at Lake Bolac, assessed on 20 October 2020.

Treatment[A]	Chocolate Spot Severity (%)				
	Fiesta	PBA Bendoc(D)	PBA Samira(D)	PBA Amberley(D)	Mean
Untreated	64	65	54	56	60 a
Carbendazim	35	41	25	26	32 c
Procymidone	46	60	41	33	45 b
Tebuconazole + Azoxystrobin	48	61	39	28	44 b
Bixafen + Prothioconazole	43	61	36	24	41 b
Fludioxonil + Pydiflumetofen	16	23	13	6	14 d
Full control	11	28	7	3	12 d
Mean	37 b	48 a	31 c	25 c	
	P	LSD			
Variety	<0.001	5.8			
Treatment	<0.001	7.7			
Variety x treatment interaction	0.811	ns			

[A]These fungicides treatments are in addition to the tebuconazole application at the 4-6 node stage described in Table 1.

Table 3. Grain yield of four varieties, with seven different fungicide strategies applied at Lake Bolac during 2020. Percentage yield increase relative to untreated and economic advantage ($/ha) of each fungicide treatment is also presented.

Treatment[A]	Grain Yield (t/ha)					Yield Increase	Mean Economic Advantage[C]
	Fiesta	PBA Bendoc⁽ᶦ⁾	PBA Samira⁽ᶦ⁾	PBA Amberley⁽ᶦ⁾	Mean[B]		
Untreated	3.03	3.28	3.73	3.66	3.42 a	0%	
Carbendazim	3.96	4.25	4.90	4.25	4.34 b	27%	$258
Procymidone	4.23	4.30	4.90	4.9	4.58 b	34%	$371
Tebuconazole + Azoxystrobin	3.91	4.30	4.80	4.4	4.35 b	27%	$266
Bixafen + Prothioconazole	4.05	4.47	4.67	4.58	4.44 b	30%	$294
Fludioxonil + Pydiflumetofen	4.98	5.45	4.97	5	5.10 c	49%	
Full control	4.78	5.74	5.17	5.4	5.27 c	54%	
Mean	4.14 a	4.54 b	4.73 b	4.60 b			
	P	LSD					
Variety	<0.001	0.264					
Treatment	<0.001	0.350					
Variety x treatment interaction	0.49	ns					

[A]These fungicides treatments are in addition to the tebuconazole application at the 4-6 node stage described in Table 1; [B]Different letters indicate pairwise significance (P<0.05); [C]Economic advantage was calculated as the grain yield gains minus the cost of the fungicide treatments. Chemical prices were an average of three chemical resellers prices provided, grain price was assumed to be $400/ton, and an application cost of $10/ha.

Table 4. Grain yield of four varieties, with seven different fungicide strategies applied at Gymbowen during 2020. Percentage yield increase relative to untreated and economic advantage ($/ha) of each fungicide treatment is also presented.

Treatment[A]	Grain Yield (t/ha)					Yield Increase	Mean Economic Advantage[C]
	Fiesta	PBA Bendoc⁽ᶦ⁾	PBA Samira⁽ᶦ⁾	PBA Amberley⁽ᶦ⁾	Mean[B]		
Untreated	6.31	6.13	6.38	5.93	6.19 a	0%	
Carbendazim	6.80	6.72	7.14	6.98	6.91 bc	12%	$258
Procymidone	6.59	6.72	6.98	6.67	6.74 b	9%	$182
Tebuconazole + Azoxystrobin	7.00	6.61	7.04	7.22	6.97 bc	13%	$260
Bixafen + Prothioconazole	6.79	6.80	7.48	6.95	7.01 bc	13%	$269
Fludioxonil + Pydiflumetofen	7.08	6.73	7.20	7.22	7.06 c	14%	
Full control	7.21	7.25	6.74	7.39	7.15 c	16%	
Mean	6.83	6.71	6.99	6.91			
	P	LSD					
Variety	0.072	ns					
Treatment	<0.001	0.290					
Variety x treatment interaction	0.295	ns					

[A]These fungicides treatments are in addition to the tebuconazole application at the 4-6 node stage described in Table 1; [B]Different letters indicate pairwise significance (P<0.05); [C]Economic advantage was calculated as the grain yield gains minus the cost of the fungicide treatments. Chemical prices were an average of three chemical resellers prices provided, grain price was assumed to be $400/ton, and an application cost of $10/ha.

Disease management of ascochyta blight in chickpea

Varietal resistance and fungicide strategy

New fungicide chemistries for use in pulses may have curative effects and could potentially reduce fungicide use in chickpea to control ascochyta blight. Experiments were established to determine the newer chemistries' efficacy applied after the signs of ascochyta blight infection compared with the traditional control method of preventative fungicide applications. These newer fungicides were also compared to older chemistries applied before infection (Table 5). Experiments were conducted from 2018 to 2020 at Curyo and Horsham.

Disease epidemics were observed at Curyo and Horsham in each year, resulting in significant grain yield losses (Table 6 and 7). The grain yield results highlight the importance of selecting a less susceptible variety such as Genesis 090 compared to the susceptible variety PBA Striker(b) and the importance of using fungicides to prevent/control disease.

The calculated figures for the economic advantage show that in most years the application of any fungicide is more profitable than not applying fungicides (Table 8). However, under low yield potential conditions associated with low rainfall, such as at Curyo in 2018 (<0.5t/ha), fungicide application treatments were not economically beneficial. In comparison, at the Horsham site in 2018, grain yields were slightly greater than 0.5t/ha, and the application of fungicides resulted in an economic benefit.

These results also highlight the potential use of a post-infection fungicide application in lower rainfall environments such as the Victorian Mallee. During 2018-2020, the post-infection fungicide applications were profitable at both sites. In paddock situations, particularly in lower rainfall environments, where disease pressure may be lower, these post infection fungicide applications may provide a lower input system for growers. However, growers must be ready to apply fungicides in a timely manner. Additionally, post-infection fungicide applications are a higher risk strategy as disease severity can increase quickly in conducive conditions, and therefore, care must be taken if following this fungicide application strategy.

Standing stubble can reduce ascochyta blight

In the last several years it has been observed that when planting chickpea into cereal stubble rows, ascochyta blight spread was confined to the row. Adjacent rows often remained disease free.

Table 5. Fungicide treatments and the number of applications applied for each treatment to assess control of ascochyta blight (AB) in chickpea at Curyo and Horsham during 2018-2020. All treatments had a Thiram (0.72 gai / kg seed) + Thiabendazole (0.4 gai / kg seed) seed treatment applied.

In Season Fungicide	Rate (g ai/ha)	Timing [B]	Number of Sprays					
			Curyo			Horsham		
			18[D]	19	20[D]	18[D]	19	20
Captan™ [A]	1000	Strategically	2+1	2	2+1	2+1	2	2
Chlorothalonil	1080	Strategically	3+1	2	2+1	2+1	2	2
Tebuconazole	200	Strategically	2+1	2	2+1	2+1	2	2
Azoxystrobin	120							
Bixafen	45	Strategically	2+1	2	2+1	2+1	2	2
Prothioconazole	90							
Tebuconazole +	200	Post Infection	1+1	1	2+1	1+1	1	1
Azoxystrobin	120							
Bixafen	45	Post Infection	1+1	1	2+1	1+1	1	1
Prothioconazole	90							
Full Control [D]								

[A] Captan is registered for control of Ascochyta blight in chickpeas at this rate under permit PER81406; [B] Strategic sprays were applied before rainfall events, at key growth stages (4th node and late vegetative / early flowering stage), to maximise foliage protection. Post infection sprays were applied when the first AB lesions were observed and at flowering. Trials were inspected at least weekly. [C] The full control treatment is a rotation of fungicides applied to ensure minimal to no disease as a control in the experiment

[D] In addition to the fungicides listed an additional podding Chlorothalonil at 1080 gai/ha was applied to protect seed quality.

Table 6. Yield response of two chickpea varieties to 10 different fungicide application strategies at Curyo during 2018 to 2020. Where there was a significant difference (P<0.05) the percentage grain yield gain was calculated. Different letters indicate pairwise significance (P<0.05). All treatments (except untreated) had a Thiram + Thiabendazole seed treatment applied.

Treatment	Timing	2018				2019				2020				
		Grain Yield (t/ha)			Yield Gain Mean	Grain Yield (t/ha)			Yield Gain Mean	Grain Yield (t/ha)			Yield Gain	
		Genesis 090	PBA Striker	Mean		Genesis 090	PBA Striker	Mean		Genesis 090	PBA Striker	Mean	Genesis 090	PBA Striker
Untreated		0.37	0.37	0.37 a	0%	1.35	0.56	0.95 a	0%	1.02 cd	0.22 a	0.62	0%	0%
Captan		0.49	0.48	0.49 c	39%	1.36	0.88	1.12 ab	39%	1.53 efg	0.51 ab	1.02	138%	98%
Chlorothalonil		0.51	0.46	0.49 c	39%	1.57	1.16	1.37 bcd	39%	2.11 i	1.41 def	1.76	553%	159%
Tebuconazole + Azoxystrobin	Strategically	0.56	0.50	0.53 c	53%	1.63	1.07	1.35 bcd	53%	1.8 fghi	0.94 bcd	1.37	335%	248%
Bixafen + Prothioconazole	Strategically	0.46	0.43	0.45 abc	26%	1.65	1.30	1.48 cd	26%	2.03 hi	1.28 de	1.66	494%	293%
Tebuconazole + Azoxystrobin	Post-Infection	0.49	0.44	0.47 bc	32%	1.56	0.94	1.25 bc	32%	1.98 ghi	1.29 de	1.63	497%	126%
Bixafen + Prothioconazole	Post-Infection	0.51	0.45	0.48 bc	36%	1.76	1.20	1.48 cd	36%	1.78 fghi	1.24 de	1.51	476%	174%
Full Control		0.47	0.48	0.47 bc	35%	1.94	1.87	1.9 e	35%	2.65 j	2.86 j	2.75	159%	1222%
Mean		0.48 a	0.45 b			1.63 a	1.11 b			1.86	1.15			
		P		LSD		P		LSD		P			LSD	
Variety		0.062		0.036		<0.001		0.063		<0.001			0.149	
Treatment		0.010		0.080		<0.001		0.140		<0.001			0.334	
Variety x treatment interaction		0.991		0.114		0.412		ns		0.030			0.472	

Table 7. Yield response of two chickpea varieties to 10 different fungicide application strategies at Horsham during 2018 to 2020. Where there was a significant difference (P<0.05) the percentage grain yield gain was calculated. Different letters indicate pairwise significance (P<0.05). All treatments (except untreated) had a Thiram + Thiabendazole seed treatment applied.

Treatment	Timing	2018				2019				2020				
		Grain Yield (t/ha)			Yield Gain Mean	Grain Yield (t/ha)			Yield Gain Mean	Grain Yield (t/ha)			Yield Gain	
		Genesis 090	PBA Striker	Mean		Genesis 090	PBA Striker	Mean		Genesis 090	PBA Striker	Mean	Genesis 090	PBA Striker
Untreated		0.42	0.18	0.3 a	0%	0.79	0.57	0.68 a	0%	1.58 de	0.44 a	1.01	0%	0%
Captan		0.53	0.41	0.47 b	58%	1.02	0.69	0.85 ab	26%	1.82 efgh	0.86 b	1.34	16%	98%
Chlorothalonil		0.50	0.49	0.49 bc	66%	1.81	1.24	1.53 cd	126%	2.26 ij	1.13 bc	1.69	43%	159%
Tebuconazole + Azoxystrobin	Strateg-ically	0.61	0.39	0.5 Bc	69%	1.45	1.01	1.23 bcd	82%	2.11 fghi	1.52 cde	1.81	34%	248%
Bixafen + Prothioconazole		0.58	0.52	0.55 bcd	84%	2.36	2.36	2.36 e	249%	2.30 ij	1.71 ef	2.01	46%	293%
Tebuconazole + Azoxystrobin	Post-Infection	0.60	0.50	0.55 bcd	85%	1.25	0.76	1.00 abc	49%	1.73 efg	0.98 b	1.36	10%	126%
Bixafen + Prothioconazole		0.60	0.51	0.56 bcd	87%	1.79	1.33	1.56 d	131%	1.69 e	1.19 bcd	1.44	7%	174%
Full Control		0.65	0.60	0.62 d	108%	2.06	2.19	2.12 e	214%	2.56 j	2.33 ij	2.45	62%	436%
Mean		0.57 a	0.45 b			1.60 a	1.22 b			2.04	1.27			
		P		LSD		P		LSD		P			LSD	
Variety		<0.001		0.093		0.002		0.234		<0.001			0.129	
Treatment		<0.001		0.042		<0.001		0.523		<0.001			0.289	
Variety x treatment interaction		0.303		ns		0.772		ns		0.049			0.409	

Table 8. Economic advantage ($/ha) of foliar fungicide applications to control chickpea Ascochyta blight at Curyo and Horsham during 2018 to 2020. Economic advantage was calculated as the grain yield gains minus the cost of the fungicide treatments. Chemical prices were an average of three chemical resellers prices provided, grain price was assumed to be $600/ton, and an application cost of $10/ha.

Treatment	Timing	Curyo				Horsham			
		2018	2019	2020		2018	2019	2020	
		Mean	Mean	Genesis 090	PBA Striker	Mean	Mean	Genesis 090	PBA Striker
Captan	Strategically	$8	$40	$205	$81	$6	$45	$85	$195
Chlorothalonil	Strategically	-$36	$178	$548	$611	$12	$439	$337	$343
Tebuconazole + Azoxystrobin	Strategically	$24	$168	$357	$329	$18	$263	$251	$578
Bixafen + Prothioconazole	Post-Infection	-$39	$229	$480	$520	$29	$924	$349	$678
Tebuconazole + Azoxystrobin	Post-Infection	$23	$143	$468	$539	$81	$162	$56	$294
Bixafen + Prothioconazole	Post-Infection	$22	$273	$332	$496	$78	$488	$24	$410

The effect of inter-row sowing chickpea into standing (30cm tall) versus slashed cereal stubble, with two chickpea varieties (PBA Striker$^{(\mathrm{l})}$ (S) and Genesis 090 (MS)), and a complete disease control (no disease/full fungicide) or untreated (diseased/no fungicide) plots was investigated. To inoculate the disease plots, six ascochyta infested stubble pieces (10cm length) were pinned in the geometric centre of plots. The ascochyta blight severity and grain yield were measured.

Inter-row sowing into standing cereal stubble resulted in 31% yield loss due to ascochyta blight compared to 55% in slashed stubble (Table 9). In this experiment, the magnitude of the yield increase due to standing stubble was almost as much as changing from a susceptible variety to a moderately susceptible variety (Table 10).

These results highlight the importance of not only selecting more resistant varieties but combining this with good agronomy practices.

Table 9. Grain yield of chickpea inter-row sown into standing versus slashed cereal stubble with and without disease at Dooen during 2020. There was a significant interaction (P=0.001) between stubble and fungicide. Different letters indicate a significant difference in a pairwise analysis between fungicide and stubble.

Fungicide	Stubble Slashed	Standing
Disease Free	2.10 c	2.00 c
Diseased	0.96 a	1.38 b
Yield Loss (t/ha)	1.15	0.62
Yield Loss (%)	55%	31%

Table 10. Grain yield of two chickpea varieties with and without disease at Dooen during 2020. There was a significant interaction (P<0.001) between variety and fungicide. Different letters indicate a significant difference in a pairwise analysis between fungicide and stubble.

Fungicide	Variety	
	Genesis090	PBA Striker$^{(\mathrm{l})}$
Disease Free	2.16 d	1.95 c
Diseased	1.56 b	0.78 a
Yield Loss (t/ha)	0.61	1.16
Yield Loss (%)	28%	60%

Soil-borne disease

Growers and agronomists have reported patches of poor performing crops and, in some situations, crop failures. Preliminary investigations into these poor performing areas identified that soil-borne disease may be the cause. In response to these concerns, a national soil-borne disease project investigated the presence of soil-borne pathogens (pathogens cause disease) on pulse crops.

Detecting pathogens in pulse roots

Throughout Australia, root samples of poor performing pulse crops were sent to local pathologists for visual assessment and then to SARDI for molecular identification of pathogens present. In 2020, 533 samples were processed, root health was scored and photographed, and molecular techniques were used to determine the pathogens present in pulse crops.

The most common pathogens detected using qPCR were *Pythium* spp., *Pratylenchus* spp. (root lesion nematodes), *Rhizoctonia solani* AG8, and *Phoma pinodella*. *Pythium* and P*ratylenchus* spp. are known to have broad host ranges. *R. solani*

AG8 prefers cereals but will infect a broad range of plant types. *Phoma pinodella* along with *Didymella pinodes* causes blackspot of field pea, but it has a much broader host range. These pathogens are very often present together in the one root system ('disease complex').

There were also infrequent detections of *Aphanomyces* and *Phytophthora* genera. These genera have been reported to cause severe and widespread yield losses in pulses in Europe and North America. During 2020, *Aphanomyces euteiches* was detected in six faba/broad bean samples from South Australia (SA) and New South Wales (NSW) and one lentil sample from Victoria; the collecting agronomists reported significant yield loss in many of these paddocks.

Phytophthora medicaginis, a known problem in northern NSW, was detected in 26 (25 chickpea, 1 faba bean) samples from northern NSW; *P. megasperma* was detected in 33 samples (multiple crop types) across Australia, and *P. drechsleri* (tentative identification), was detected in 14 samples, mostly lupins from Western Australia (WA); this species was also detected in SA, Victoria and southern NSW. SARDI is currently undertaking work to confirm the identity of this species.

Confirming the cause of disease

To confirm the role of specific organisms in causing root diseases in pulses, the pathogens were isolated from the diseased pulse samples and then inoculated onto soil, in which various pulses were grown. Pathogens which re-infect the seedlings are termed pathogenic. This study aimed to identify and confirm pathogenicity of isolates that are likely to be the main causes of symptoms observed in growers' paddocks.

Fusarium avenaceum isolates were highly pathogenic on all crops tested, with just one strain appearing non-pathogenic (Table 11). *Fusarium oxysporum* and *F. redolens* isolates' pathogenicity varied between crops, but all isolates of both species were highly pathogenic on chickpea. *Fusarium tricinctum* isolates were highly pathogenic on chickpea and moderately pathogenic on faba bean, lentil and lupin. *Phoma. pinodella* isolates were highly pathogenic on chickpea, field pea and lentil, but less so on faba bean and lupin (Table 12).

Further work will investigate yield losses and control options to ensure growers have management options to reduce grain yield losses due to soil-borne diseases.

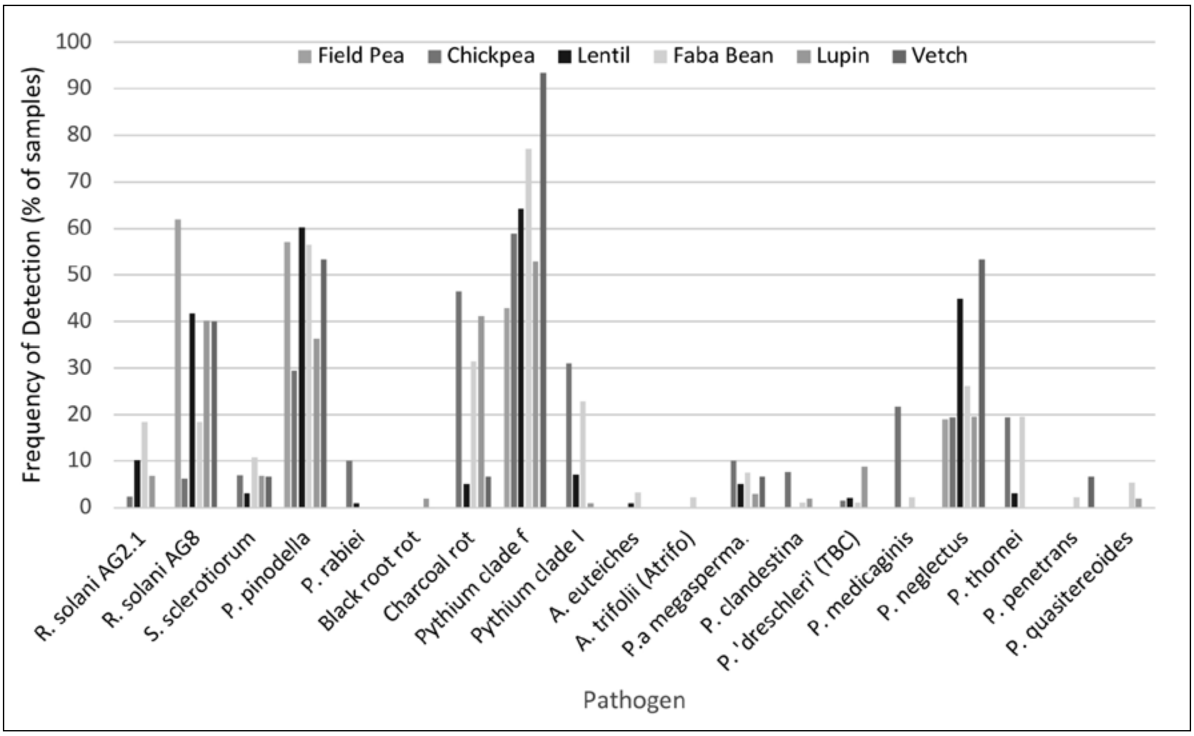

Figure 2. Frequency of detection over threshold levels of pathogens using molecular tools in pulse samples received nationally during 2020.

Table 11. Frequency of detection of *Fusarium* spp. in 2019 survey samples and pathogenicity (ability of the pathogen to infect plant) of representative isolates collected from 2018-2019 crop samples. Pathogenicity on each crop is indicated as "-" non-pathogenic, "+" weakly pathogenic, "++" moderately pathogenic or "+++" highly pathogenic.

Species	Isolates Collected	Isolates Tested	Chickpea	Field pea	Faba bean	Lupin	Lentil
F. acuminatum	12	5	56%	77%	84%	71%	89%
			-/+	-/+	-/+	-/+	-/+
F. avenaceum	6	5	6%	31%	63%	29%	27%
			-/+++	-/+++	+/+++	-/+++	-/+++
F. culmorum	1	1	6%	8%	21%	7%	6%
			++/+++	+/+++	+/+++	+/+++	-/+
F. equiseti	4	4	48%	69%	72%	55%	49%
			-/++	-/+	-/++	-/+	-
F. oxysporum	17	14	91%	100%	91%	80%	73%
			++/+++	-/+	-/+	-/++	-/++
F. redolens	2	2	31%	0%	16%	9%	29%
			++/+++	-/+	-/++	-/++	-/+
F. solani	4	4	70%	0%	19%	36%	13%
			-/+	-/+	-/+	-/+	-/+
F. tricinctum	4	4	5%	31%	37%	30%	2%
			+++	-/+	-/++	+/++	+/++

Table 12. Frequency of detection of *Phoma* spp. in 2019 survey samples and pathogenicity (ability of the pathogen to infect plant) of *P. pinodella* isolates collected from samples 2018-2019 toward common pulse crops in a controlled environment assay. Pathogenicity is indicated as either non-pathogenic "-", weakly pathogenic "+", moderately pathogenic "++" or highly pathogenic "+++".

Species	Unique Isolates	Isolates Tested	Chickpea	Field pea	Faba bean	Lupin	Lentil
Phoma/Didymella spp.	20	16	53.13%	100.00%	90.70%	67.86%	75.00%
			++/+++	++/+++	+/++	-/++	++/+++

Conclusion

Without a disease management plan that incorporates varietal resistance, paddock rotations, good agronomy practices and fungicides, grain yield losses of greater than 90% can be experienced. The results from these projects show the importance of varietal resistance in both chickpea and faba bean to minimise grain yield losses. The importance of fungicides, both type and timing of application play a critical role in disease control. However, the importance of good agronomy cannot be understated with ensuring that disease management plans incorporate planting densities and orientation of stubble (standing versus slashed). Inter-row sowing chickpea into standing cereal stubble was shown to be almost as effective as changing resistance classification of the variety from S to MS as compared to sowing into slashed stubble.

Investigations into soil-borne diseases in pulses are still continuing, with both *Fusarium* spp. and *Phoma/Didymella* spp. identified as pathogens of significance. Following these investigations, control methods will be investigated.

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Useful resources

Pulse disease guide: https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases/pulse-disease-guide

Victorian Crop sowing guide: https://grdc.com.au/resources-and-publications/all-publications/publications/2020/2021-victorian-crop-sowing-guide

Crop Protection Products including Minor Use Permits, can be viewed at the Australian Pesticides and Veterinary Medicines Authority (APVMA) website; www.apvma.gov.au

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

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Notes

New tool to predict the likelihood of an inoculation response to Group E and F rhizobia

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Keywords

- rhizobia, DNA, nodulation, nitrogen fixation, pea, bean, lentil, vetch.

Take home messages

- A new DNA soil testing service, PREDICTA® rNod has been developed to measure Group E and F rhizobia numbers in soil to assist growers to identify the need to inoculate field pea, faba bean, lentil and vetch crops.
- PREDICTA rNod is available to South Australia (SA) and Victoria (Vic) growers via PREDICTA® B accredited agronomists in 2021 and will be launched to growers nationally in 2022.
- The DNA test will be a valuable research tool to investigate how soil chemistry and management practices affect the survival of Group E and F rhizobia in soil, nodulation and pulse performance.
- DNA tests for chickpea and lupin rhizobia are also currently under development.

Background

The number of rhizobia present in soil is a key determinant of legume nodulation, growth and nitrogen fixation and where rhizobia numbers are low, they must be delivered in inoculants applied to the seed or soil.

Rhizobia levels in soil are affected by the frequency of host pulse crops, soil type, soil pH and high temperatures. The lack of a reliable way to estimate rhizobia populations has resulted in many growers applying inoculants as an ‘insurance policy’, with some of this inoculation likely to be ineffectual. On the other hand, some growers don’t inoculate where rhizobia levels are too low which will compromise the nodulation of the pulse crop. Recent expansion of the pulse industry is seeing crops grown in new and marginal environments that are responsive to rhizobial inoculation.

A DNA test that can accurately and rapidly estimate the number of *Rhizobium leguminosarum* bv. *viciae* in the soil has been developed for growers and researchers. This is the species of rhizobia provided in the commercial inoculant Groups E (strain SU303) and F (strain WSM-1455). The test will help growers identify paddocks where field pea, faba and broad bean, lentil and vetch crops will need to be inoculated before sowing or not.

When the test indicates soil rhizobia levels are adequate, growers will be able to consider applying fungicides or trace elements to the seed and/or dry sowing, knowing these practices pose a negligible risk to legume nodulation.

The test will also enhance research capacity to understand how inoculation and agronomic practices (e.g., liming or rotation) influence rhizobia number in the soil and affect the performance of pulse crops.

This paper describes the development and evaluation of the DNA test that measures the number of *Rhizobium leguminosarum* bv. *viciae*, in soil.

Methods

The new rhizobia DNA test is based on a qPCR assay (TaqMan MGB), specific for *Rhizobium leguminosarum* bv. *viciae* (hereafter referred to as E and F rhizobia).

Specificity of the test was investigated using DNA extracted from 83 cultures of rhizobia, comprising 42 strains of E and F rhizobia and 41 strains of non-target closely and distantly related rhizobia (Table 1).

Sensitivity of the DNA test and correlation with viable rhizobia numbers per gram of soil were determined by calibrating the DNA test against the Most Probable Number (MPN) plant nodulation bioassay (Vincent 1970), using vetch cv. Timok⁽ᵇ⁾ as the trap plant. This study used 41 field soil samples collected from cereal stubbles between December 2019 and February 2020.

Nitrogen (N) fixation capacity of the soil rhizobial communities was also determined in a greenhouse experiment. Shoot dry weight of field pea (cv. Kaspa⁽ᵇ⁾) and faba bean (cv. Samira⁽ᵇ⁾) reliant on the soil rhizobia for growth was compared with the shoot dry weight of plants inoculated with commercial inoculant strains SU-303 (Group E for pea) or WSM-1455 (Group F for bean).

Spatial variation of E and F rhizobia across paddocks, and on and off row was measured in three grower paddocks using the DNA test, to determine suitable paddock sampling strategies.

Results and discussion

Specificity of the DNA test

A DNA test has been designed to detect only E and F rhizobia that nodulate field pea, faba bean, lentil and vetch (Table 1). The test does not detect strains of the closely related clover rhizobia (*Rhizobium leguminosarum* bv. *trifolii*). This is important because both biovars often coexist in many paddocks. Additionally, the test does not detect more distantly related rhizobia.

Sensitivity and correlation to viable rhizobia in soil

The DNA and MPN plant bioassay methods were significantly correlated across 41 soil samples.

The MPN test was more sensitive at lower levels of rhizobia (<200 rhizobia/g soil), with several instances of detection by the plant bioassay, but not the DNA test (Figure 1).

The DNA test was able to reliably detect around 1,000 cells/g soil and was more precise than the MPN test when rhizobia DNA levels exceeded this level. Overall, there was a high correlation (adjusted R^2=0.86) between the log transformed measures of the MPN and DNA tests.

As few as 100 rhizobia/g soil are sufficient to nodulate pulse crops in the field, similar to the number applied with peat inoculant on seed. The testing service will use conservative thresholds; soils with >1,000 to 5,000 rhizobia/g ($\log_{10}$ >3 to 3.7) will be assigned a low likelihood of response to rhizobia inoculation, and >5,000 rhizobia/g soil to indicate a negligible likelihood of inoculation response.

Based on previous surveys of E and F rhizobia in soils (Drew *et al.* 2012), it was expected that around 30% of soils will be classified as having a low or negligible likelihood of response to inoculation with E and F rhizobia.

For the soils tested, several unexpected results were noted. These included instances of high E and F rhizobia numbers (2,971/g soil) despite no known history of a pulse host crop and conversely, low rhizobia numbers (111/g soil) despite inoculated faba bean having been grown in 2015. These variations underline the value of the new test in helping better target the inoculation of pulse crops.

Nitrogen fixation capacity of soil rhizobia

Ten of the field soils in Figure 1 were estimated to contain more than 1,000 E and F rhizobia/g soil (after conversion from raw DNA data), and therefore, were predicted to have a low likelihood of response to rhizobia inoculation. The N-fixation capacity of the

Table 1. Specificity results (detected, not detected) for the DNA test targeting E and F rhizobia, includes 14 rhizobia species and 83 strains.

Legume (rhizobia Group)	Strains tested	Detected	Not detected
Pea, vetch, bean, lentil (Group E & F)	42	42	0
Clovers - close relative (Group B & C)	20	0	20
Medic and lucerne (Group AM & AL)	8	0	8
Ten other rhizobia species	13	0	13

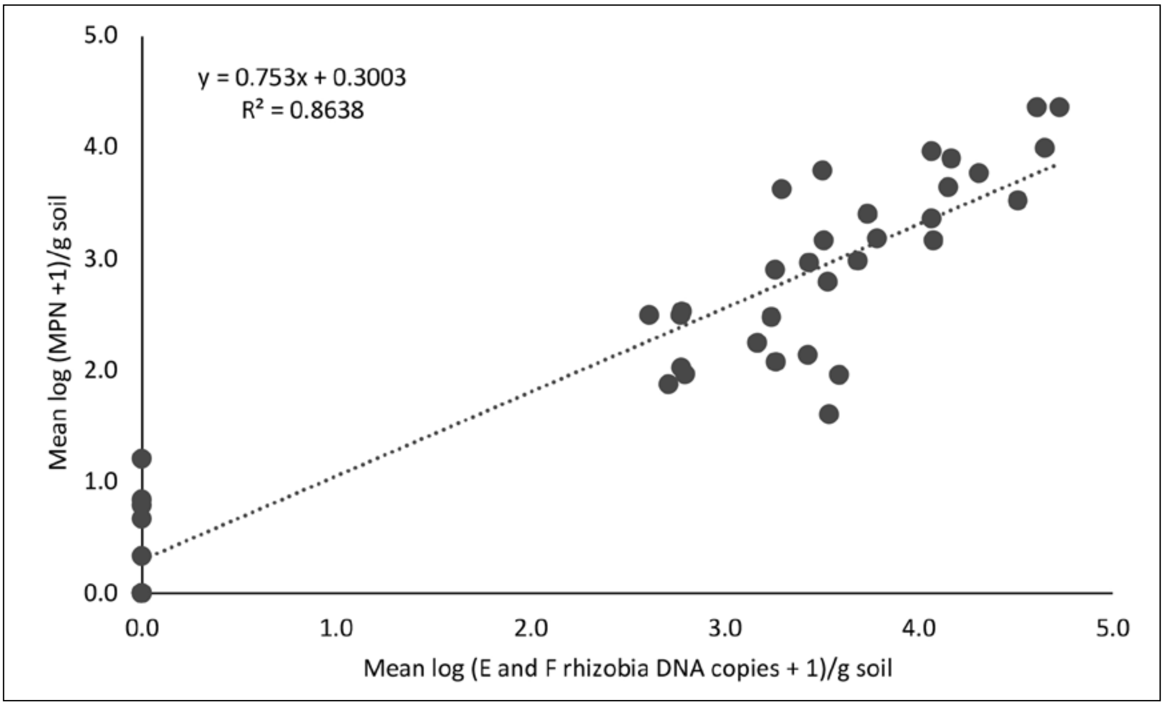

Figure 1. Relationship between E and F rhizobia DNA copies/g soil measured by DNA test and rhizobia number/g soil measured by Most Probable Number (MPN) plant nodulation bioassay, for 41 soils collected between December 2019 and February 2020.

rhizobial communities in these soils with field pea and faba bean is shown in Table 2.

With field pea, N–fixation capacity ranged for 64 to 99% relative to inoculant strain SU-303, and with faba bean from 39 to 107% relative to WSM-1455. With the exception of Soil 10, the N-fixation capacity of the soil communities should be high enough to supply sufficient fixed N for field grown plants, because plant growth rate and demand for N is lower in the field compared to plants grown in the greenhouse. Even though the rhizobia in Soil 10 were less effective, the site would be unlikely to respond to inoculation due to competition from the soil rhizobia community, so the DNA test prediction of a low likelihood of inoculation response remains reasonable.

Soil sampling

Several aspects of soil sample collection have been examined to develop suitable sampling protocols.

Table 2. Nitrogen fixation capacity of E and F rhizobia (*Rhizobium leguminosarum* bv. *viciae*) communities predicted by the DNA test to exceed 1000/g soil. N-fixation capacity calculated as % of shoot dry weight for field pea inoculated with SU-303 and faba bean inoculated with WSM-1455.

Soil	DNA copy number #/g soil	Predicted MPN E/F rhizobia/g soil	N-fixation capacity Pea, % SU-303	N-fixation capacity Bean, % WSM-1455
Soil 1	49,201	6,792	74	104
Soil 2	47,284	6,592	92	107
Soil 3	32,331	4,951	69	78
Soil 4	20,728	3,542	72	85
Soil 5	16,410	2,971	99	107
Soil 6	13,380	2,547	70	84
Soil 7	12,710	2,451	70	89
Soil 8	11,493	2,272	97	76
Soil 9	4,740	1,166	94	73
Soil 10	4,187	1,062	64	39

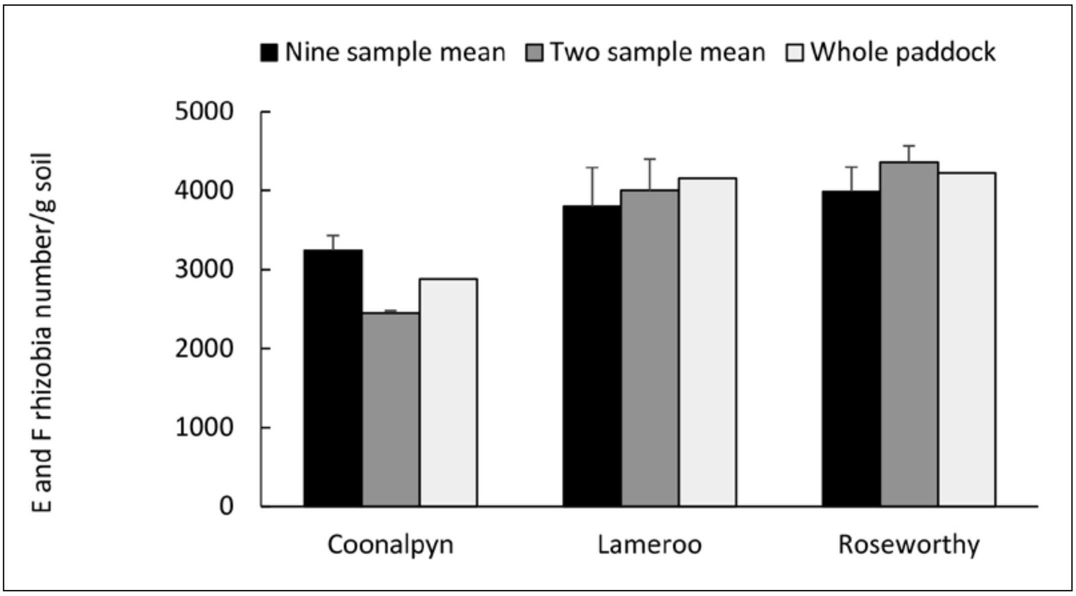

Figure 2. Effect of paddock sampling frequency (nine, two or one sample locations) at three field sites on mean predicted E and F rhizobia number/g soil. Bars above columns indicate standard error.

Spatial variation across paddocks

Where there are obvious differences in soil type or management zones within a paddock, each zone should be sampled separately for testing. This requirement is illustrated in the following examples:

- Samples from areas in a paddock that differed in pH_{Ca} (5.0 or 7.1) also varied in predicted E and F rhizobia number, 288 and 2,971/g soil, respectively.
- Samples collected from hills and flats in a paddock, varied in predicted E and F rhizobia number, 375 and 1,062/g soil, respectively.

In both examples, E and F rhizobia numbers in the different zones would be assigned to different categories of inoculation requirement in the report generated for growers.

Where paddocks were 'uniform' in soil type and management, mean E and F rhizobia numbers were similar, regardless of whether the paddock was sampled as a whole (single test sample of 500g, 45 cores), as a split paddock (two 500g test samples) or from nine different sectors (Figure 2).

The effect of sampling within or between cereal stubble rows on the number of E and F rhizobia was also investigated. Levels were not different between locations (P = 0.218) in three different paddocks (Table 3). Hence, samples for the E and F rhizobia DNA test can be taken from either position.

Time of sampling

Results to date have been based on dry soil samples collected in February preceding the pulse crop, by which time rhizobia populations have declined to levels approximating numbers persisting at the break of season.

Investigations are currently underway to determine if earlier sampling times (Oct-Nov) in the year before the pulse crop can provide a reliable estimate of rhizobial number persisting through to the next season. This timing will align with the timing of inoculant orders.

Table 3. Effect of sample position, within or between rows of cereal stubble, on the predicted number of E and F rhizobia/g soil at three field sites. Each value is the mean of nine 500 g paddock samples.

Location	Predicted E and F rhizobia number/g soil (0-10 cm)	
	Within stubble rows	Between stubble rows
Coonalpyn, SA	3,914	3,238
Lameroo, SA	4,391	3,802
Roseworthy, SA	4,832	3,991
Mean of all sites	4,028	3,677

Recommended PREDICTA rNod soil sampling protocol

For 'uniform' production zones, it is recommended that a composite 500g soil sample made up of three cores (10 mm wide x 100mm depth) is collected at each of 15 locations within a production zone or soil type (total 45 cores/sample). Unlike disease testing, there is no need to target the rows of the last crop or to add stubble.

Research applications

The rhizobia DNA test for E and F rhizobia will improve the efficiency of research programs and provide agronomists with a tool to understand the impact of management practices, such as liming, on soil health. The test has already been used successfully to:

- Select trial sites free of rhizobia group E and F for inoculation experiments.
- Compare the colonisation of soils by different inoculant strains.
- Quantify nodulation on legume roots to compare management practices.

As commercial and research sample results become available, it will be possible to generate regional summaries of rhizobia status, on a scale that has not previously been possible.

Conclusion

A new DNA test has been developed to measure E and F rhizobia numbers in soil prior to sowing field pea, faba and broad bean, lentil and vetch.

The E and F rhizobia test will form the basis of a new service, PREDICTA rNod, which will be available to SA and Vic growers from February 2021, via PREDICTA B accredited agronomists.

The test will indicate that inoculation responses are unlikely when E and F rhizobia numbers exceed 1,000 cells/g soil. Soil pH and texture results will also be reported to assist with interpretation.

Soil samples can be collected from the start of February, when rhizobia numbers should approach levels persisting at the break of season. Use PREDICTA rNod kits to submit a composite 500g soil sample made up of three cores (10 x 100mm) collected at each of 15 locations within a production zone (total 45 cores/sample).

More soils are being added to the calibration data set to support the release of the test nationally.

Further work is also being undertaken to investigate earlier sampling for growers who want to know inoculant requirements at least six months before seeding a pulse crop.

Tests for chickpea and lupin rhizobia are under development and are expected to be released in 2022.

Acknowledgements

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The authors would also like to thank the following agronomists and growers for their support and provision of soil samples; Andy Bates, Michael Hind, Simon Mock, Jeff Braun, Mick Faulkner, Andrew Heinrich, Sam Trengove, Stuart Sherriff, John Matheson, Peter Maynard and Neville Kernick.

Useful resources

Inoculating Legumes: A Practical Guide:

https://grdc.com.au/resources-and-publications/all-publications/bookshop/2015/07/inoculating-legumes

PREDICTA B Agronomist Broadacre Soilborne Disease Manual V10.4: http://rootdisease.aweb.net.au/

PREDICTA rNod kits available from PREDICTA B accredited agronomists and Russell.burns@sa.gov.au

References

Drew EA, Denton MD, Sadras VO, Ballard RA (2012) Agronomic and environmental drivers of population size and symbiotic performance of *Rhizobium leguminosarum* bv. *viciae* in Mediterranean-type environments. Crop and Pasture Science. 63: 467-77.

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Vetch agronomy and management

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GRDC project code: DAS1711-015RTX

Keywords

- vetch, *Vicia*, break crops, agronomy, management practices.

Take home messages

- Choose the species of vetch and variety depending on your end goals, or desired end-use.
- Each vetch species requires different management and agronomy to achieve optimum production.
- There is no 'one size fits all' approach with vetch, the diversity of end-uses and environments in which vetch is grown, require different agronomic approaches and tools.

Background

Traditionally vetch has been a low rainfall legume best suited to sandy, neutral to alkaline soils. However, trials conducted by the National Vetch Breeding Program (NVBP) and others, across a wide range of environments and soils types have demonstrated that vetch can be productive across many farming environments, offering farming systems in many areas all the benefits associated with a productive and reliable legume in their rotations.

Vetch gives growers an extra tool in the fight against herbicide resistant weeds and cereal diseases while still offering the opportunity for a profitable enterprise in the cropping year and benefits that flow on for two to three subsequent crops.

With the increasing use of vetch in numerous different farming systems, an increasing diversity of approaches and agronomic practices are being used to get the most out of the crop. Its diversity of end-uses means that there is no one right way to do everything. However, there are some basic agronomic practices to get right before getting too creative. Your planned end-use does not have to be locked in, flexibility can come with getting the basics right and seeing how the season develops.

The most important point to remember is to treat it as a crop, not a break in the cropping regime. The more you put into the crop the better your potential return, be it yield or the ancillary benefits that come from legumes.

Paddock selection and planning are vital, knowing the weed burden/profile along with the desired/preferred end use, dictates many subsequent decisions. Vetch can be used to fill in, provide extra feed or just replace fallow, but if you are looking to maximise benefits and outputs it's important that you put the planning in.

Once you have selected the paddock, choose the vetch species and variety that best suits your conditions and major objectives. For specific details on vetch variety characteristics please refer to the 2021 Crop Sowing Guide relevant to your state or area, these can be found online at:

https://grdc.com.au/resources-and-publications/all-publications/crop-variety-guides.

Choose disease resistant varieties wherever possible, all varieties released from the NVBP are resistant to rust.

If you have hostile soils or a poor legume history, inoculate seed with appropriate rhizobia. New acid tolerant strains of rhizobia are being released (expected release date 2022) which will assist with inoculation in areas with low pH soils to get the best out of legumes.

All legumes benefit from phosphorus (P) but do not require significant amounts of nitrogen (N), so choose appropriate fertiliser to reflect these requirements. Vetch can 'make do' with residual fertiliser from previous cereals but will benefit from well placed P, helping development and vigour.

When looking at different end-uses, time of sowing (TOS) can play an important role in strategic planning. If the crop is to be grazed, early sowing is vital to get the crop up while the soil is warm, as early growth is vital. This also applies to using the crop for green or brown manure; the bigger the biomass the better and early canopy closure is important to out compete weeds.

For hay production, TOS helps dictate when the cutting and drying window will occur. This is a balance between getting the best growing conditions and the timing for drying when the weather warms in late September. In 2020, several areas had excellent rains in March enabling very early sowing (mid-March-early April), this resulted in large dense crops developing early. Canopy closure occurred in some cases in early-mid June, however this resulted in perfect conditions for disease development. As canopy closure occurred so early, fungicide applications could not penetrate the canopy after this point, allowing disease to proliferate and causing significant damage particularly to hay crops. This shows the importance of planning TOS around your preferred end-use, as grazing early may have helped to keep canopies open longer and helped with disease suppression.

For more detailed information on disease management please refer to the paper 'Vetch Disease Management' within this publication.

Chemical selection, particularly for broadleaf weed control is still limited in vetch. Pre sowing, incorporation by sowing (IBS) chemicals and post sowing pre-emergence (PSPE) chemicals offer the best options and results. There are now in-crop options for broadleaf control, but their use will set the crop back for a period of time. It is recommended to talk to local agronomists for chemical advice specific to your soil type and region.

Rolling is recommended post sowing, depending upon the tillage system used. Rolling prepares the paddock for hay or grain harvest and can also improve seed to soil contact, but care should be taken with some tillage systems, as it can push soil back into the seed row, concentrating chemicals over the seed, potentially causing issues if there is good rainfall following sowing.

Growth regulators are becoming more commonly used in crop production to control/influence plant development. In vetch, gibberellic acid (GA) is the most common growth regulator that is used. Gibberellic acid artificially substitutes/increases the natural occurring hormone (gibberellins) in the plant promoting elongation of plant cells, it therefore elongates the plant cells and stretches the plant out, with the aim of increasing plant height. It has been used in vetch for several reasons; to increase plant height to facilitate cutting for hay, to promote growth and development after grazing and to delay onset of flowering which helps delay the cutting window for hay production. Its use should not be seen as essential, but as a tool to use in specific situations.

The Southern Pulse Agronomy group (SPA) from Clare conducted trials in 2020 looking at the interaction between GA and vetch. This trial was at two sites in one season, 2020, they found it had a significant impact on plant height for up to six weeks after application, however it did not increase fodder yields significantly and was found to have a negative impact on grain yield (pers. comms. Sarah Day). This data will be published in the 2021 Eyre Peninsula Farming Systems Summary.

For GA to work it requires moisture and nutrients to be available and timing of application is vital, particularly when attempting to delay flowering. Application to achieve this must be just prior to the commencement of flowering, however there is only anecdotal evidence on the length of the delay to flowering caused by GA. This needs further investigation.

Vetch is not vetch

There are three different species of vetch grown in Australia, common vetch (*Vicia sativa*) and woolly pod vetch (*Vicia villosa*) being the two most popular species, and purple vetch (*Vicia benghalensis*) which represents a much smaller part of the market. These different species all have different characteristics, and therefore, need different management and suit different conditions, but all produce good fodder and can return large amounts of N to the soil. The hard seed levels of woolly pod vetch and purple vetch should be a major consideration when choosing this species of vetch to sow.

Common vetch

Varieties of common vetch (CV) include Studenica⦶, Morava, Timok⦶, Volga⦶, Rasina⦶, Blanchefleur and Languedoc

Common vetch is the most widely grown species of vetch, predominately grown in low rainfall areas in South Australia (SA), Victoria (Vic), Western Australia (WA) and New South Wales (NSW), where it is seen as a good, reliable legume option in farming systems. It offers flexibility to the grower and is an excellent tool in a grower's fight against issues like soil borne diseases and herbicide resistant grass weeds, while still offering good returns in the form of fodder/grazing, hay, improved soil N and organic matter levels.

Common vetches are generally shorter season than the other species (varieties flower between 85 and 115 days) and are more tolerant to grazing. They are palatable at any growth stage, either green or dry, and the grain is a high protein feed (on average 29% crude protein and 12.5MJ/kg DM metabolisable energy) that can be used for all ruminants.

The Australian bred and released varieties Studenica⦶, Morava, Timok⦶, Volga⦶ and Rasina⦶ are all resistant to rust. Older varieties like Blanchefleur and Languedoc are highly susceptible to this disease. Rust can drastically reduce yields and may induce abortions in pregnant livestock if they are fed heavily infested plant material, it is therefore important to grow rust resistant varieties whenever possible.

In higher rainfall areas monitor for Botrytis symptoms, this disease can greatly reduce yields.

In all common vetches regrowth after grazing is very dependent on seasonal conditions, good moisture and favourable environmental conditions.

Woolly pod vetch

Varieties of woolly pod vetch (WPV) include Capello, Haymaker Plus, RM4⦶ and Namoi.

These varieties are better suited to medium-high rainfall areas, doing best in regions receiving a minimum of 450mm annual rainfall. All the varieties of WPV are later developing than the CV varieties, not flowering until around 125 days after sowing. Regions looking for later hay varieties should consider WPV. They have superior hay yields to CV, on average yielding approximately 1.5t/ha more dry matter in the same environment compared to CV (yields between 5-12t/ha can be achieved). However, grain yields are much lower than CV (0.8t/ha average) and the grain can be difficult to harvest/thresh.

Woolly pod vetch grows well in mixed crops situations and can tolerate some shading from plant competition, which makes it a good companion plant in forage mixes.

The grain of WPV varieties should not be fed to any livestock, as it contains high levels of toxin and can cause death in ruminants if consumed at high levels. These varieties/species should not be grazed before 15 nodes of growth or after pods have formed seed, due to the toxicity of the grain. There is no data available on what is a safe level of this grain in a dietary/fodder mix.

Care should be taken when grazing, as this species is susceptible to over grazing early in its development due to its slower growth through winter.

Management issues to consider

Make sure paddocks are relatively free of broadleaf weeds as there are limited options for control in WPV, especially in-crop and it is a poor competitor for weeds in early growth stages. The best option is to use registered herbicides post sowing pre-emergent.

Don't graze early (before 15 nodes) and ensure you cut the hay or graze before pods start to set seed.

Be aware this species has hard seeds, with hard seededness percentage of common varieties ranging from 5-7% RM4⦶ to >30% Namoi and they can appear as volunteers in subsequent crops. This species is cross pollinated, and if you are producing or/multiplying seeds from RM4⦶, isolation from higher hard seed varieties like Namoi needs to be >1km.

Purple vetch

Varieties of purple vetch (PV) include Popany, Benatas and Barloo.

Crop development of this species is similar to WPV, with later flowering time (>125 days) compared with CV. It is suited to medium to high rainfall areas with a good finish and is a high fodder producer in these areas. It is not, however, suited to lower rainfall zones. Purple vetch can tolerate some waterlogging compared to other vetch species. Similar to WPV, grain cannot be fed to ruminants but there is a small market as birdseed.

Management issues to consider

Like WPV this species has very slow winter growth and does not compete well with weeds early. One advantage is that Broadstrike® is registered for use in the variety, Popany allowing for control of a range of broadleaf weeds in crop. It should not be grazed before 10 nodes or grazed/cut for hay after pods start to set seed.

For specific details on vetch variety characteristics please refer to the 2021 Crop Sowing Guide relevant to your state or area, these can be found online at:

https://grdc.com.au/resources-and-publications/all-publications/crop-variety-guides

Conclusion

Vetch has the ability and potential to fit into modern farming rotations in most areas, particularly in mixed farming systems where growers are looking for a versatile break option that still allows for strategic action against specific cropping problems. Unlike pulses and other break crops, its end use is not solely focussed on grain production.

A successful vetch crop can:

- Increase yields and grain protein of following cereal and oilseed crops.
- Allow an extended phase of cropping.
- Decrease many cereal diseases – grass-free vetch crops can break the life cycle of root diseases, preventing multiplication and build-up of disease levels.
- Provide an opportunity to control grass weeds especially in forage use; hay is cut before many grasses set seed providing a chemical free option to avoid weed resistance. Green/brown manuring can be used with vetch to control competitive weeds which are difficult to control in other crops, e.g., brome grass and barley grass.
- Available soil N is maintained and can be improved by an average of 56, 92 and 145kg/ha after grain, hay and green manuring, respectively (data from 3yrs x 5 sites).
- Grain and hay/silage from CV varieties can be used to feed ruminants without limits.

The key to a successful vetch crop and achieving the maximum benefits from its growth is to treat it as a crop, not as a set and forget break option. Inoculate with appropriate rhizobia, control weeds where possible and monitor for insects and disease.

When successfully grown, vetch can be an effective risk management tool on farm. Allowing for a reduction in fertiliser and chemical use in following crops, reducing costs and the risks involved with in-crop N applications. This can have a large impact on profitability and the stress levels associated with input application decisions.

Acknowledgments

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

Useful resources

2021 Crop Sowing Guide (https://grdc.com.au/resources-and-publications/all-publications/crop-variety-guides).

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Vetch disease management

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Keywords

- Ascochyta blight, botrytis grey mould.

Take home messages

- Grain yield losses in vetch of on average of 26% were observed in plots with no disease control.
- Selecting resistant varieties and applying foliar fungicides will reduce grain yield losses.

Background

The main diseases that affect vetch are Ascochyta blight (AB) and botrytis grey mould (BGM). Other diseases which are also known to affect vetch in the Southern region include rust, Sclerotinia white mould, root lesion nematodes and rhizoctonia root rot. Research into vetch diseases is very limited. Therefore, most of our knowledge on disease management is extrapolated from studies in other crops. Newer varieties, from SARDI's vetch breeding program, have excellent rust resistance, but improvements in disease resistance for other diseases is still desirable.

Similar to other crops, the key to vetch disease management is that the cost of disease control is not higher than the potential loss from the disease. This involves thinking of the end use of the crop (hay, grain, grazing or manure) and potentially changing this end use in seasons that are very conducive to disease. In addition to affecting grain/hay yield, the disease may affect the crop quality and palatability for stock.

This paper will discuss the diseases; AB and BGM.

Grain and biomass yield losses in vetch

During 2020, a 26% reduction in grain yield due to disease was measured in a field experiment at Nhill. In this experiment there were early infections of AB (Table 1), while BGM became more dominant later in the season. Biomass differences were not significant on the 14 October (Table 2), despite significant BGM severity observed in plots at that time (Table 1). Despite variation in grain yield between vetch varieties, the interaction between grain yield and treatment was not significant, highlighting no significant difference in grain yield losses between varieties.

With two diseases present in the experiment, the 26% grain yield losses cannot be attributed to one disease definitively. However, this experiment highlights the need to control foliar diseases in vetch if the crop is to be harvested for grain. Interestingly, despite a 0.6t/ha reduction in biomass in plots with no disease control, this reduction was not significant and will require further investigation.

Table 1. Severity of natural Ascochyta blight and botrytis grey mould infection (% Leaf area affected) in three vetch varieties at Nhill during 2020. The two treatments investigated were: 1) a complete disease control (Complete) and 2) no disease control (Nil).

Variety	Ascochyta Blight Leaf area affected (%)			Botrytis Grey Mould % Leaf area affected (%)					
	7/9/2020			13/10/2020			4/11/2020		
	Complete[A]	Nil[B]	Mean	Complete	Nil	Mean	Complete	Nil	Mean
Benetas	0 a[C]	3 a	1	0 a	12 ab	6	0	37	18
Morava	1 a	3 a	2	0 a	42 c	21	0	63	32
Timok(b	0 a	18 b	9	0 a	17 b	8	0	50	25
Mean	0	9		0	46		0 a	46 b	
	P Value	LSD		P Value	LSD		P Value	LSD	
Variety	<0.001	3.4		0.034	10.5		0.083	ns	
Treatment	<0.001	2.4		<0.001	7.4		<0.001	8.9	
Interaction	<0.001	4.8		0.034	14.9		0.083	ns	

[A]Complete treatment had multiple fungicide applications with the aim of no disease; [B]Nil treatment had no fungicides applied; [C]Different letters indicate a significant difference in a pairwise analysis between treatment, variety or the interaction within a disease assessment date.

Table 2. Grain and biomass yields (t/ha) in three vetch varieties (3 replicates) at Nhill during 2020. The two treatments investigated were: 1) a complete disease control (Complete) and 2) no disease control (Nil).

Variety	Grain yield (t/Ha)				Biomass (t/ha) [A]		
	Complete[B]	Nil[C]	Mean	Yield Loss (%)[D]	Complete	Nil	Mean
Benetas	1.53	0.75	1.14 a[E]	51%	5.28	4.83	5.06 a
Morava	3.07	2.19	2.63 b	29%	8.08	7.63	7.86 b
Timok(b	4.17	3.06	3.61 c	27%	8.55	7.57	8.06 b
Mean	3.31 a	2.46 b		26%	7.31	6.67	
	P Value	LSD			P Value	LSD	
Variety	<0.001	0.607			0.013	2.013	
Treatment	<0.001	0.429			0.347	ns	
Interaction	0.859	ns			0.945	ns	

[A]Biomass was measured 14 October 2020, at peak biomass for Morava and Timok(b, but Benetas had not reached peak biomass; [B]Complete treatment had multiple fungicide applications with the aim of no disease; [C]Nil treatment had no fungicides applied; [D]The variety x treatment interaction was not significant, and therefore the % yield loss between varieties is also not significant. [E]Different letters indicate a significant difference in a pairwise analysis between treatment, variety or the interaction within a disease assessment date.

Ascochyta blight

Ascochyta blight affects vetch crops early in the season with cooler wet conditions favouring disease development. When temperatures increase and the canopy dries out later in the season, visual symptoms of AB reduce. This is thought to be from the infected leaves dropping off and the vetch plant growth increasing, thus reducing the overall percentage of infected leaves.

There is significant variation in the resistance of varieties to AB, with Morava, Timok(b and Rasina(b being more susceptible than other released varieties (Figure 1). Consult the latest Agriculture Victoria Pulse Disease guide (https://agriculture.vic.gov.au/biosecurity/plant-diseases/grain-pulses-and-cereal-diseases/pulse-disease-guide) for up-to-date resistance ratings.

The risk of infection by AB can be reduced by choosing a more resistant variety and ensuring that there is at least three years between vetch crops. In susceptible varieties, it is thought that if severe symptoms are observed a fungicide may be warranted to prevent large biomass losses.

Botrytis grey mould

Botrytis grey mould in vetch is difficult to control due to early sowing and canopy closure. As a result of early canopy closure there is higher canopy humidity, which is conducive to disease development along with increasing difficulty of uniform fungicide coverage, even if a high-water rate is used. Although a higher temperature (>15 degrees Celsius) is optimal for BGM development, at lower temperatures the disease can develop, just at a slower rate.

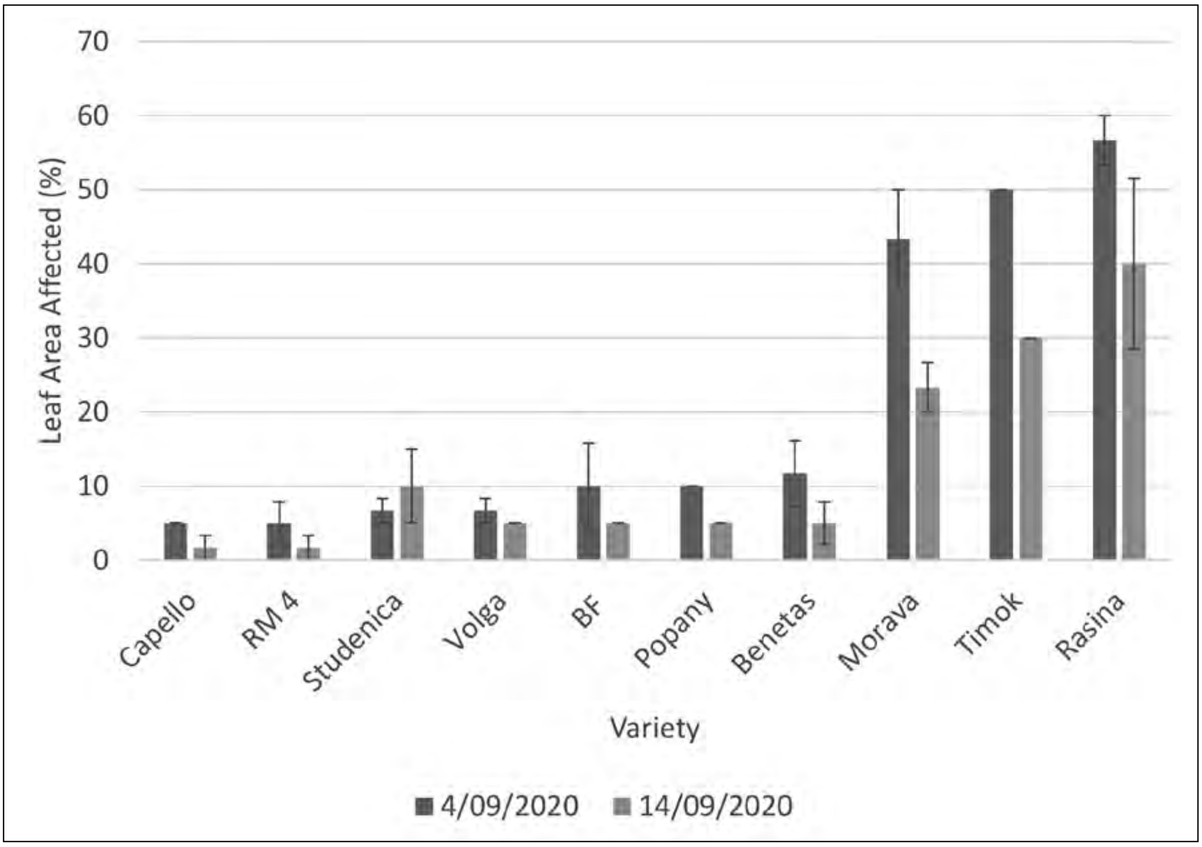

Figure 1. Mean Ascochyta blight infection in vetch varieties at Horsham during 2020.

Although most vetch varieties are susceptible to BGM there are several management practices which can be utilised to reduce disease severity in vetch crops, including:

1. Crop rotation

   As the same pathogens cause BGM in vetch, faba bean and lentil this needs to be considered when planning rotations to allow sufficient time for stubble breakdown between affected crops. This time will vary between rainfall zones.

2. Time of sowing

   Time of sowing can help to determine when canopy closure occurs. If sown too early and not grazed, canopy closure can occur too early, not allowing fungicide penetration into the crop when BGM starts to spread in late autumn/early spring.

3. Foliar fungicides

   The best defence against disease in vetch crops is a foliar fungicide applied just prior to canopy closure to prevent disease development. In other crops, newer released fungicide actives have provided longer protection against disease and may also provide longer protection in vetch. In conducive disease years, multiple fungicides may be required. It is important to check product registrations and withholding periods, especially when the vetch crop is to be grazed or cut early for hay.

4. Grazing

   Grazing may open up the canopy to reduce the canopy humidity and thus disease risk. This may be particularly relevant in early sown crops.

Conclusion

Vetch disease can cause large grain yield losses, with 26% observed during 2020 at Nhill. There are several disease control management practices that can be utilised, but it is always important to remember the end use of the crop (i.e., manured, grain, hay or grazed) as this will dictate the economic viability of the control options.

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The National Phenology Initiative: predicting cultivar phenology at point of release

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GRDC project code: ULA00011

Keywords

- optimal flowering period, time of sowing, simulation modelling.

Take home messages

- Optimising flowering time of wheat and barley cultivars is one of the most cost-effective ways for growers to maximise yield.
- The National Phenology Initiative (NPI) is improving Agricultural Production Systems sIMulator (APSIM) Next Gen so that it can accurately predict cultivar phenology classification and optimal sowing dates across Australia at point of release.
- The improved APSIM Next Gen model, parameterised and validated using NPI data, is more accurate at simulating phenology than APSIM Classic or the baseline APSIM Next Gen model.
- Work on the improved model is ongoing and it will be available to growers and advisers in 2022.
- In addition, the NPI is working to develop a new cultivar phenology classification scheme and new scale of cereal development.

Background

Flowering time is a critical determinant of grain yield in wheat and barley. When crops flower in the optimal period, yields are maximised by minimising losses due to frost, heat, drought and insufficient radiation (Flohr *et al.* 2017). Flowering time is determined by interactions between genetics, environment and management: the development speed of the cultivar, the environment in which it is grown, and the time of sowing. To ensure crops flower in the optimal period, accurate information on a cultivar's development speed is needed, but this information is currently not available when new cultivars are released to the market. Instead, a cultivar's development speed or classification is determined using time of sowing experiments over multiple sites and years. These experiments are costly, time consuming and environment specific. In addition, flowering time models like APSIM (Keating *et al.* 2003) perform poorly outside a narrow range of validated scenarios.

The NPI is improving the APSIM Next Gen model (Holzworth *et al.* 2018) of wheat and barley development so it is possible to accurately predict cultivar classification and optimal sowing dates across Australia at the time at which cultivars are released to the market. The improved APSIM Next Gen model will be able to be rapidly parameterised with controlled environment phenotypic data, molecular markers and/or other genomic data, removing the need for time of sowing field experiments. The NPI will deliver a tool for growers

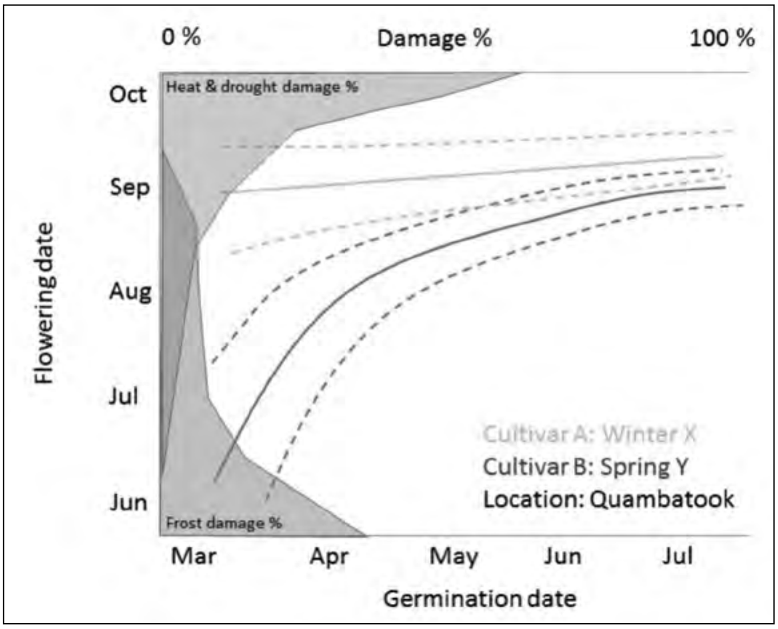


Figure 1. A mock-up of the APSIM Next Gen model output that would be available at point of cultivar release.

and advisers to more accurately predict optimal sowing date that will be available in 2022 (Figure 1). This tool will allow growers to make informed decisions about cultivar selection and time of sowing in their specific environment. It will also help to quantify the consequences of non-optimal sowing dates.

In addition to the improved APSIM Next Gen model, the NPI is also developing an improved cultivar phenology classification scheme and a new scale of cereal development.

Project methodology

The NPI is a collaborative, cross-disciplinary project led by La Trobe University with project partners from CSIRO, Plant & Food Research NZ, South Australian Research and Development Institute, NSW Department of Primary Industries, Department of Primary Industries and Regional Development WA, and Statistics for the Australian Grains Industry (SAGI) West. The NPI team includes field agronomists, crop physiologists, geneticists, modellers, and software engineers.

The NPI is using an Australian Phenology Panel comprising 64 wheat and 32 barley cultivars that have been selected to represent the diversity in both genotype and development patterns in these crops. Phenotyping of the Australian Phenology Panel has been carried out in controlled environments with factorial combinations of photoperiod (8 and 17 h) and vernalisation (nil and 8 weeks at 5°C) to derive plant development parameters (leaf emergence, time to heading, time to anthesis). These controlled environment data are being used to parameterise the APSIM Next Gen phenology routine.

A comprehensive model validation dataset has been compiled using field experiments conducted in Yan Yean (Victoria (Vic)), Wagga Wagga (New South Wales (NSW)), Callington and Urrbrae (South Australia (SA)) and Merredin and Dale (Western Australia (WA)) in 2019 and 2020. In each experiment, the Australian Phenology Panel was sown at eight times of sowing from 1 March to 15 June. Emergence and heading dates were collected on all 96 cultivars, and leaf emergence and anthesis dates were collected on a subset of 12 wheat and six barley cultivars.

All cultivars in the Australian Phenology Panel are being genotyped using molecular markers for major development gene alleles and assayed for single nucleotide polymorphisms (SNPs). Genome wide association analysis is being used to identify genetic associations with plant development parameters, with the view to incorporating these genetic parameters into the APSIM Next Gen model or using them as a proxy for phenotypic parameters.

The improved APSIM Next Gen model for predicting cultivar phenology

The APSIM Next Gen model is currently being parameterised using the controlled environment data and then validated against observations of heading date from the field experiments. Incremental improvements to the phenology routine and investigations into sources of error are underway, with promising results. To date, the APSIM Next Gen model has been improved with the addition of two new development stages related to vernalisation saturation and heading, the development of a new phyllocron model and the inclusion of short-day vernalisation.

Figure 2 shows the comparison of simulated and observed heading dates for Mace^Φ, Trojan^Φ and Wedgetail^Φ at the four field sites in 2019. The simulated heading dates were modelled using APSIM Classic 7.10, the baseline APSIM Next Gen, and the new APSIM Next Gen model with improvements made using NPI data. In most cases the new APSIM Next Gen model had the most accurate prediction of heading dates. The poor performance of WedgetailA at early times of sowing is suspected to be due to mis-simulation of devernalisation (when vernalised plants experience warm temperatures, resulting in a delay in heading). The modelling team are in the process of improving this aspect of model performance.

New cultivar phenology classification scheme

One of the additional outputs from the NPI is the development of an objective and nationally consistent cultivar phenology classification scheme being developed in collaboration with the Australian Crop Breeders. Until the new NPI tool for predicting phenology is available on the NVT website, these classifications are still important because they help growers make decisions around time of sowing.

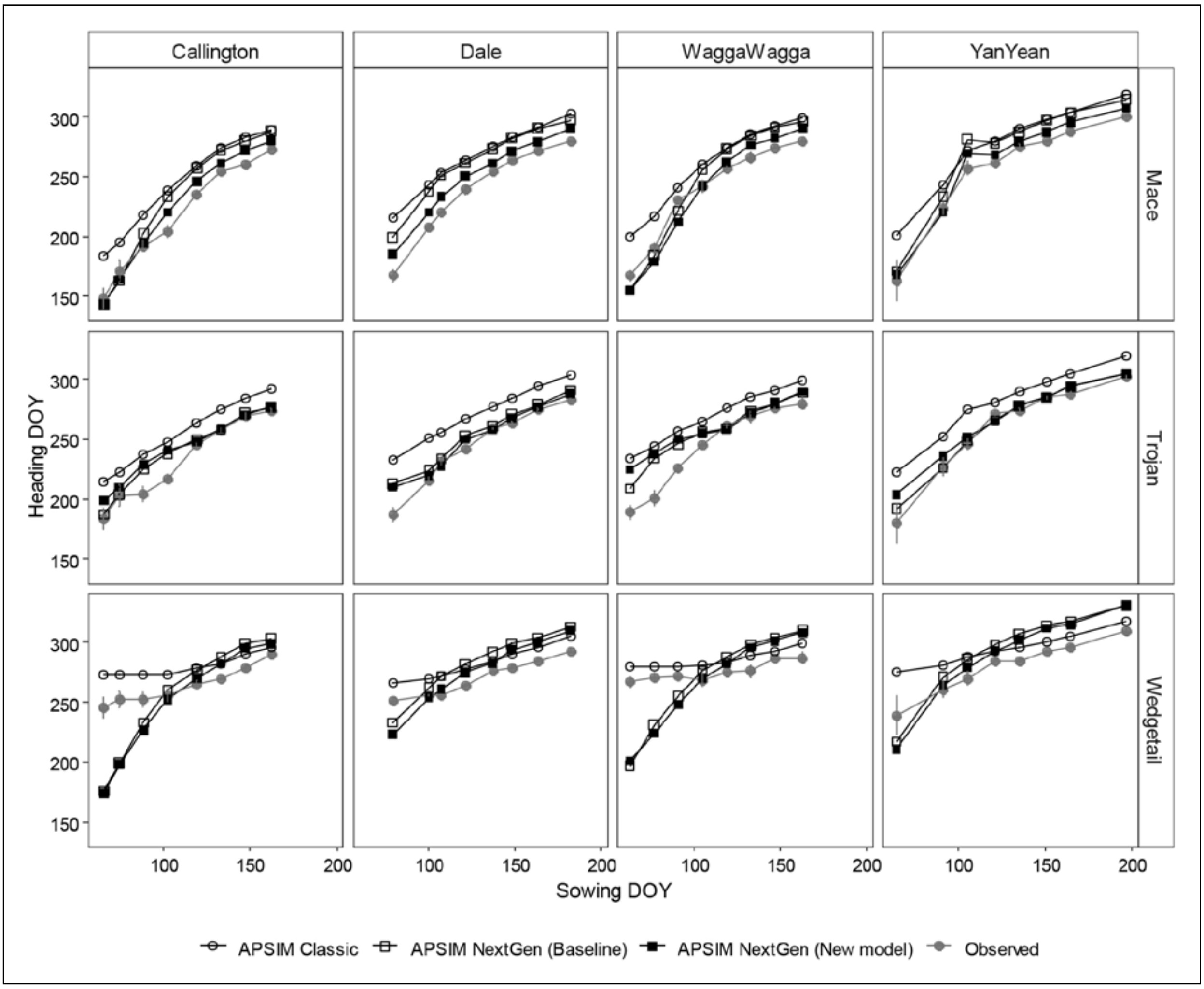


Figure 2. Comparison of ability of APSIM Classic 7.10, APSIM Next Gen (baseline) and APSIM Next Gen (new model) to simulate field observations of phenology. DOY is day of year.

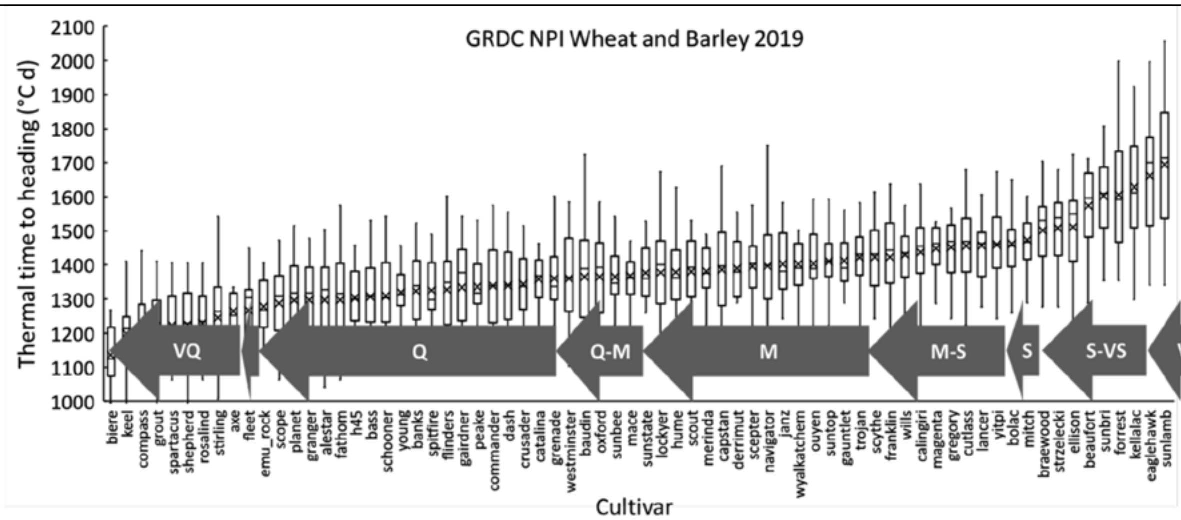
However, the terminology used to describe cultivar maturity or development speed is not consistent across states (e.g., 'early maturing', 'fast maturing', 'short maturity') and the classifications are subjective. In addition, the relative time to heading changes with environment and time of sowing which makes assigning classifications difficult.

Using data from the 2019 NPI field validation experiments (five times of sowing from four field sites in SA, Vic, NSW and WA), cultivars were classified based on their degree days to heading (Figure 3). Wheat and barley cultivars in each environment were ranked according to their relative time to heading and then assigned to phenology groups ranging from 'very quick' to 'very slow'. For each classification an exemplar or type cultivar was selected from the middle of the range.

This new phenology classification scheme is being developed in collaboration with the Australian Crop Breeders' Industry Guide for Wheat Variety Maturity Description (ACB, 2021) and both resources have been used to inform the 2021 GRDC Crop Sowing Guides for South Australia and Victoria (GRDC, 2021). The scheme will be further refined in 2021 using field data from 2020.

New scale of cereal development

The second additional output from the NPI is the production of a new scale of cereal development. Existing scales of crop development like Zadoks' decimal code (Zadoks *et al.* 1974) tend to be ambiguous, subjective, qualitative and non-repeatable. While these scales are useful for describing the development state of an individual plant at a given point in time, they are not designed for identifying the timing of key development stages in a population of plants. For the NPI it was necessary to develop a new scale of cereal development to ensure that data collection was consistent across different experiments, years and operators; to accurately determine the timing of key development stages, and so that data could integrate with the APSIM Next Gen model.



MALLEE				March				April				May				June	
Type	Speed																
Winter	Mid																
Winter	Quick																
Spring	Mid-Slow																
Spring	Mid																
Spring	Quick																
Spring	Very Quick																

Figure 3. The new cultivar phenology classification scheme ranks cultivars according to thermal time to heading using data from four field sites in SA, VIC, NSW and WA and five times of sowing from mid-April to mid-June. Cultivars can then be assigned into a phenology class using the Australian Crop Breeders maturity guide. This information can then be used to give regional sowing time information as per the annual GRDC Crop Sowing Guides.

The new scale of cereal development has clear protocols for objective, quantitative assessment of each stage that were developed and tested using different operators in the geographically distant NPI field experiments. It identifies the median timing of key development stages; for the NPI, these were the dates of emergence and heading for each cultivar × time of sowing × environment. The scale can be applied to any population of culms. For example, in this new scale of cereal development, 'heading date' in wheat is defined as the date on which 50% of a population of culms have completed heading, with the spike fully emerged. To assess this accurately a fixed population of culms needs to be identified on which regular, repeated assessments are performed so that the population median timing can be identified.

The new development scale is currently being finalised with co-authors and will be submitted for publication this year.

Conclusion

By 2022 the NPI will deliver a tool for growers and advisors that will be able to accurately predict optimal sowing dates for different cultivars across Australia at the point of release. This will allow growers to more readily achieve optimal sowing dates and maximise yields. Underpinning this tool will be an improved APSIM Next Gen model that has been parameterised with controlled environment phenotypic data and genetic data and validated against national time of sowing field experiments. The NPI is also working to develop a new cultivar phenology classification scheme and scale of cereal development that are quantitative and objective.

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, and the authors would like to thank them for their continued support.

Useful resources

Groundcover April 2020 "Optimal sowing times for wheat and barley cultivars may soon be at our fingertips"

https://groundcover.grdc.com.au/crops/cereals/national-phenology-initiative-to-quantify-optimal-sowing-times-for-wheat-and-barley

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TOP 10 TIPS

FOR REDUCING SPRAY DRIFT

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01 **Choose all products in the tank mix carefully**, which includes the choice of active ingredient, the formulation type and the adjuvant used.

02 **Understand** how product uptake and translocation may impact on coverage requirements for the target. Read the label and technical literature for guidance on spray quality, buffer (no-spray) zones and wind speed requirements.

03 **Select the coarsest** spray quality that will provide an acceptable level of control. Be prepared to increase application volumes when coarser spray qualities are used, or when the delta T value approaches 10 to 12. Use water-sensitive paper and the Snapcard app to assess the impact of coarser spray qualities on coverage at the target.

04 **Always expect** that surface temperature inversions will form later in the day, as sunset approaches, and that they are likely to persist overnight and beyond sunrise on many occasions. If the spray operator cannot determine that an inversion is not present, spraying should NOT occur.

05 **Use weather forecasting** information to plan the application. BoM meteograms and forecasting websites can provide information on likely wind speed and direction for 5 to 7 days in advance of the intended day of spraying. Indications of the likely presence of a hazardous surface inversion include: variation between maximum and minimum daily temperatures are greater than 5°C, delta T values are below 2 and low overnight wind speeds (less than 11km/h).

06 **Only start spraying** after the sun has risen more than 20 degrees above the horizon and the wind speed has been above 4 to 5km/h for more than 20 to 30 minutes, with a clear direction that is away from adjacent sensitive areas.

07 **Higher booms increase drift**. Set the boom height to achieve double overlap of the spray pattern, with a 110-degree nozzle using a 50cm nozzle spacing (this is 50cm above the top of the stubble or crop canopy). Boom height and stability are critical. Use height control systems for wider booms or reduce the spraying speed to maintain boom height. An increase in boom height from 50 to 70cm above the target can increase drift fourfold.

08 **Avoid high spraying speeds**, particularly when ground cover is minimal. Spraying speeds more than 16 to 18km/h with trailing rigs and more than 20 to 22km/h with self-propelled sprayers greatly increase losses due to effects at the nozzle and the aerodynamics of the machine.

09 **Be prepared** to leave unsprayed buffers when the label requires, or when the wind direction is towards sensitive areas. Always refer to the spray drift restraints on the product label.

10 **Continually monitor** the conditions at the site of application. Where wind direction is a concern move operations to another paddock. Always stop spraying if the weather conditions become unfavourable.
Always record the date, start and finish times, wind direction and speed, temperature and relative humidity, product(s) and rate(s), nozzle details and spray system pressure for every tank load. Plus any additional record keeping requirements according to the label.

THE 2020-2022 GRDC SOUTHERN REGIONAL PANEL

January 2021

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CHAIR - JOHN BENNETT

Lawloit, VIC

Based at Lawloit, between Nhill and Kaniva in Victoria's West Wimmera, John and his family run a mixed farming operation across diverse soil types. The farming system is 70 to 80 per cent cropping, with cereals, oilseeds, legumes and hay grown. He wants to see RD&E investments promote resilient and sustainable farming systems that deliver more profit to growers and ultimately make agriculture an exciting career path for young people.

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Kate is a partner in a large grain producing operation in Victoria's Southern Mallee region and produces wheat, canola, lentils, lupins and field peas. Kate has been an agronomic consultant for more than 20 years servicing the Mallee and northern Wimmera. Kate is passionate about producing high quality grain, whilst enhancing the natural ability of the soil. Kate is passionate about research and the extension of that research to bring about positive practice change to growers.

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Michael runs a family farming enterprise at Nile in the Northern Midlands of Tasmania, having successfully transitioned from a dryland grazing enterprise to intensive mixed farming. He has broad experience in resource management, strategic planning and risk profiling, human resource management and operational logistics. He was a member of the GRDC high rainfall zone RCSN (now Grower Network) for six years. Michael was a GRDC-supported Nuffield Scholar in 2012 studying systemisation and expansion models. He served on the Board of Nuffield Australia for two years, acted as state chair for three years, and regularly leads the China leg of the Nuffield Global Focus tour.

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Andrew is Managing Director and a shareholder of Lilliput AG, and a Director and shareholder of the affiliated Baker Seed Co, a family-owned farming and seed cleaning business. He manages a 2500ha mixed cropping enterprise south of Rutherglen. Lilliput AG produces wheat, canola, lupin, faba bean, triticale, oats and sub clover for seed and hay. Andrew served on the GRDC's medium rainfall zone RCSN (now Grower Network) and has held many leadership roles. He holds a Diploma of Rural Business Management and an Advanced Diploma of Agriculture.

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Jon has worked in agriculture for the past three decades, both in the UK and in Australia. He has managed Grainsearch, a grower-funded company evaluating European wheat and barley varieties for the high rainfall zone, and his consultancy managed the commercial contract trials for Southern Farming Systems (SFS). Jon was a member of the GRDC's HRZ (RCSN (now Grower Network) and became a GRDC Southern Panel member in 2015. In 2020 Jon set up an independent consultancy, TechnCrop Services.

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Lou is a farmer based at Lameroo in the Southern Mallee of South Australia. With her parents and partner, she runs a mixed farming enterprise which includes export oaten hay, wheat, barley, a variety of legumes and a self-replacing Merino flock. Prior to returning to the family farm, Lou had a 10-year agronomy career, servicing the Upper South East and Mallee. She is passionate about her industry, particularly in recognising the role that women play in the industry and on the land.

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Andrew is a research agronomist, based at Port Lincoln on SA's Eyre Peninsula. He started his career with the South Australian Research and Development Institute (SARDI) at the Minnipa Agriculture Centre, and then spent time at CSIRO in Adelaide. Andrew managed the family farm on Lower Eyre Peninsula for 10 years before returning to SARDI in late 2009. In 2019, Andrew started his own research company EPAG Research, delivering applied research across Eyre Peninsula. Andrew received the GRDC Southern Panel's Emerging Leader award in 2018, and prior to joining the Panel he served on the GRDC's low rainfall zone RCSN (now Grower Network).

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Pru was raised on a mixed farm at Diapur in Victoria's Wimmera region. She has worked at the Victorian Department of Primary Industries and GRDC, where she implemented GRDC's first social media strategy. She then worked at Birchip Cropping Group, managing and supporting extension projects. She has recently started her own business focusing on extension, project development and management.

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Michael is a third-generation grain grower based at Cummins on South Australia's Eyre Peninsula, where he grows wheat, barley, canola, beans, lupins and lentils on a range of soil types. He has been involved in the South Australian Grains Industry Trust, the Lower Eyre Agricultural Development Association and the South Australian No Till Farmers Association. He believes research and development underpins profitability in Australian farming systems and the GRDC is pivotal in delivering research outcomes that support growers.

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In February 2020 Professor Michelle Watt was appointed the Adrienne Clarke Chair of Botany at the University of Melbourne. From 2015 to 2019, she was Director of the Plant Sciences Institute at the Helmholtz Centre and Professor of Crop Root Physiology at the University of Bonn in Germany. Prior to 2015 Michelle was at CSIRO. She has been in multi-partner projects with Australia, the USA, India, the Philippines, UK and Germany in the under-studied but critical area of plant roots. She is President of the International Society of Root Research and Co-Chair of the Root Phenotyping

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AGT

Agriculture Victoria

FMC

Intergrain

Nufarm/Nuseed

UPL Australia

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ADAMA Australia

ADAMA Australia is a leading global manufacturer and distributor of crop protection solutions, with a heritage of nearly 70 years.

We understand that farming is complex and full of ever increasing challenges. We recognise that in order to make a genuine difference, we can't do this alone. Neither can farmers. So we work together with our partners in Australia and around the world to find ways to simplify it.

Together, we develop simple, practical and innovative solutions in crop protection and beyond to make the complex job of farming a little easier. www.adama.com/australia

Trade display supported by

FMC Australia Boilerplate

FMC is an agricultural sciences company – but it is not just an agricultural sciences company. It is part of the community, and part of the solution to the challenges of global food security.

FMC advances farming directly, through innovative and sustainable crop protection technologies. And it advances farming indirectly, by supporting the communities that farmers rely on.

From our industry leading discovery pipeline, to unique application systems, we are passionate about bringing new solutions to growers around the world, while looking after our own people by creating opportunity and supporting diversity.

Our six Core Values define who we are and how we do business: Integrity, Safety, Sustainability, Respect for People, Agility, and Customer Centricity. As individuals and as a team of over 100 people across Australia and New Zealand we are guided by these values. It's what sets FMC apart and it's the key to our long-term growth and sustainability as a company.

FMC has manufacturing operations throughout the world, working to strict safety, environmental and quality control standards. For the Australian and New Zealand markets, the company has a local manufacturing plant located one hour north of Sydney. The Wyong facility has more than thirty years history of quality crop protection manufacture, including herbicides, fungicides, insecticides and adjuvants. To learn more, please visit www.fmccrop.com.au

InterGrain - Cereal Breeding Leaders

As one of the leaders in cereal breeding in Australia, InterGrain exists to deliver grower value through the delivery of market leading wheat, barley and oat varieties. Our highly successful wheat, barley and oat breeding programs are designed to target the major cereal growing regions of Australia. We believe that the continuous development of improved crop genetics is fundamental to ensuring a highly competitive grains industry in Australia.

InterGrain's shareholders are the WA State Government (62%) and GRDC (38%). InterGrain employs 45+ staff and has offices in Perth and Horsham. We also have marketing staff based in Northam, Adelaide and Wagga Wagga.

Nuseed

WE'RE AUSTRALIAN, JUST LIKE OUR SEED.

The Nuseed story began in the heart of Australia's grain growing country, so we're deeply connected with the needs of Australian farmers.

Since that first seed was sown in 2006, we have grown into a global seeds business with Nuseed germplasm now planted by farmers across the globe. In Australia, our dedicated crop breeding teams work with the best available genetics to produce a pipeline of varieties that perform in Australia's tough conditions.

At our state-of-the-art Innovation Centre in Horsham, Victoria, our R&D team works hard on developing new canola varieties to give you more choice in your cropping program, like our new triazine tolerant hybrids now available under the HyTTec® brand. We're also one of the only seed companies in Australia still developing new open pollinated TT varieties, because we know they're an important part of many growers' crop plans. And we're working on some exciting new projects that are going to offer plant-based solutions to some pressing consumer needs as part of our BEYOND YIELD™ strategy.

UPL

The fifth agrochemical company in the world, after the acquisition of Arysta LifeScience, UPL is a global leader in global food systems.

The new UPL offers an integrated portfolio of both patented and post-patent agricultural solutions for various arable and specialty crops, including biological, crop protection, seed treatment and post-harvest solutions covering the entire crop value chain.

With a revenue of US$3.14 billion, UPL is now present in 130+ countries.

We have market access to 90% of the world's food basket and are focused on ushering growth and progress for the complete agricultural value chain including growers, distributors, suppliers and innovation partners.

The new UPL is a solutions company. It's about what we can do with our customers, with farmers, with the whole network to drive world agriculture to the next level.

Connect with us

Keep in touch with us to find out about the latest RD&E, news and events.

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GRDC PODCAST

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GRDC's podcast series features some of the grain sector's most pre-eminent researchers, growers, advisers and industry stakeholders sharing everything from the latest seasonal issues, to ground-breaking research and trial results with on-farm application.

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Prefer to provide your feedback electronically or 'as you go'? The electronic evaluation form can be accessed by typing the URL address below into your internet browsers:

www.surveymonkey.com/r/BendigoGRU

To make the process as easy as possible, please follow these points:

- Complete the survey on one device
- One person per device
- You can start and stop the survey whenever you choose, **just click 'Next' to save responses before exiting the survey**. For example, after a session you can complete the relevant questions and then re-access the survey following other sessions.

2021 Bendigo GRDC Grains Research Update
Evaluation

1. Name

ORM and/or GRDC has permission to follow me up in regards to post event outcomes

2. How would you describe your <u>main</u> role? *(choose one only)*

- ❑ Grower
- ❑ Agronomic adviser
- ❑ Farm business adviser
- ❑ Financial adviser
- ❑ Communications/extension
- ❑ Grain marketing
- ❑ Farm input/service provider
- ❑ Banking
- ❑ Accountant
- ❑ Researcher
- ❑ Student
- ❑ Other* (please specify)

Your feedback on the presentations

For each presentation you attended, please rate the content relevance and presentation quality on a scale of 0 to 10 by placing a number in the box (**10 = totally satisfactory, 0 = totally unsatisfactory**).

DAY 1

3. In the wake of the China barley tariffs: *Pat O'Shannassy*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

4. Glyphosate resistant annual ryegrass update- 2020 season: *Peter Boutsalis*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

5. Group G herbicides – how to fit them into the farming system: *Chris Preston*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

6. Harvest Weed Seed Control – getting the best results: *Chris Davey*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

7. Addressing the rundown of nitrogen and soil organic carbon: *Mark Farrell*

Content relevance ☐ /10 Presentation quality ☐ /10

Have you got any comments on the content or quality of the presentation?

8. Nitrogen fertiliser use efficiency 'rules of thumb' - how reliable are they? *Roger Armstrong*

Content relevance ☐ /10 Presentation quality ☐ /10

Have you got any comments on the content or quality of the presentation?

9. Hyper Yielding Crops Focus Farms – a great pathway to adoption*: Jon Midwood*

Content relevance ☐ /10 Presentation quality ☐ /10

Have you got any comments on the content or quality of the presentation?

10. 2020 - the year of the armyworm: *Paul Umina*

Content relevance ☐ /10 Presentation quality ☐ /10

Have you got any comments on the content or quality of the presentation?

DAY 2

11. Cereal disease update 2021: *Mark McLean and Grant Hollaway*

Content relevance ☐ /10 Presentation quality ☐ /10

Have you got any comments on the content or quality of the presentation?

12. Will I get an economic response from applying fungicide to canola for the control of blackleg? *Steve Marcroft*

Content relevance ☐ /10 Presentation quality ☐ /10

Have you got any comments on the content or quality of the presentation?

13. Subsoil amelioration - update on current: *Roger Armstrong*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

14. Faba bean agronomy and varieties: *Jason Brand and James Manson*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

15. Pulse disease research update: *Josh Fanning*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

16. New rhizobia testing tool to predict the likelihood of a legume inoculation response to Group E and F rhizobia: *Ross Ballard*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

17. Vetch agronomy and management: *Stuart Nagel*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

18. The National Phenology Initiative: predicting cultivar phenology at point of release: *James Hunt*

Content relevance /10 Presentation quality /10

Have you got any comments on the content or quality of the presentation?

19. Did the inclusion of the agronomist commentary panel add local information and/or application to the topics being presented? Please circle Y or N

Comments

Your next steps

20. Please describe at least one new strategy you will undertake as a result of attending this Update event

21. What are the first steps you will take?
e.g. seek further information from a presenter, consider a new resource, talk to my network, start a trial in my business

Your feedback on the Update

22. This Update has increased my awareness and knowledge of the latest in grains research

Strongly agree	Agree	Neither agree nor Disagree	Disagree	Strongly disagree
❑	❑	❑	❑	❑

23. Do you have any comments or suggestions to improve the GRDC Update events?

24. Are there any subjects you would like covered in the next Update?

25. ☐ **Yes I'm interested in contributing to the next Bendigo GRDC Grains Research Update planning committee (provide your name in Q1).**

Thank you for your feedback.