GRAINS RESEARCH UPDATE

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Balaklava

Thursday 13 February

9.00am to 1.00pm

Balaklava Town Hall

8 Wallace Street

#GRDCUpdates

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Balaklava GRDC Grains Research Update convened by ORM Pty Ltd.

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GRDC Grains Research Update
BALAKLAVA
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Contents

Dealing with the Dry

As grain growers across Queensland and New South Wales and parts of Victoria and South Australia continue to be challenged by drought conditions, the GRDC is committed to providing access to practical agronomic advice and support to assist with on-farm decision making during tough times.

Visit our 'Dealing with the Dry' resource page for useful information on agronomy in dry times and tips for planning and being prepared when it does rain.

www.grdc.com.au/dealingwiththedry

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Program

9.00 am	**Announcements**	***Tim Bateman,*** *ORM*
9.05 am	**GRDC welcome and update**	***GRDC representative***
9:15 am	**What's the cost of Harvest Weed Seed Control for you?**	***Peter Newman,*** *Western Extension Agronomist, AHRI*
9:55 am	**Use of chemicals and residues arising**	***Gerard McMullen,*** *National Working Party on Grain Protection*
10:35 am	***Morning tea***	
11.05 am	**The hows and whys of deep ripping sandy soils**	***Brian Dzoma,*** *SARDI*
11:45 am	**Rapid post-event frost damage assessment - can it be achieved?**	***Glenn Fitzgerald and Audrey Delahunty,*** *Agriculture Victoria*
12.25 pm	**Integrating new chemistries in the field**	***Chris Preston,*** *The University of Adelaide*
1.05 pm	***Close and evaluation***	***Tim Bateman,*** *ORM*
1.10 pm	***Lunch***	

On Twitter? Follow **@GRDCUpdateSouth** and use the hashtag **#GRDCUpdates** to share key messages

HART 2020 EVENTS

Getting The Crop In

March 11, 2020

8am – 12:15pm

Industry guest speakers from across the county cover a wide range of topics, all relevant to broad-acre cropping. We always treat you to breakfast first!

Winter Walk

July 21, 2020

9am – 12pm

An informal guided walk around the trial site; your first opportunity to inspect the site post seeding, with guest speakers presenting their observations on current trials.
They are on hand to answer your questions and will also share their knowledge on all the latest cropping systems and agronomic updates.

Spring Twilight Walk

October 20, 2020

5pm followed by BBQ

Another informal opportunity to inspect the trial site, this time just prior to harvest, again with industry researchers & representatives presenting in the field.
This event is followed by drinks and a BBQ in the shed - a great opportunity to chat more about how your season is unfolding and to catch up with other farmers in our district and beyond.

HART FIELD DAY

September 15, 2020

9am – 3:30pm

Our main Field Day attracts hundreds of visitors from all over the Mid-North, South Australia and interstate.

With a rolling program of half hour sessions conducted simultaneously throughout the day, highly regarded specialists speak at each trial, backed up by a comprehensive take-home Field Day Book included in your entry fee.

Tailor your own program for the day to hear about the trials that interest you.

Plenty of parking; buses and group bookings welcome.

HART
SA's premier cropping field site

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We have a clear purpose

To deliver value to growers and make agriculture better (in productivity, sustainability & community).

We are committed to delivering on our vision

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Keep in touch with us to find out about the latest RD&E, news and events.

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The 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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What is your cost of Harvest Weed Seed Control?

Peter Newman.

WeedSmart.

Keywords

- harvest weed seed control, HWSC, cost, weed control.

Take home messages

- There is no single answer as to which HWSC tool is best. It depends!
- The Estimated Cost of HWSC model aims to give you the most accurate estimate of cost of HWSC based on what we know now.
- The total cost per hectare can be relatively small when all things are considered.
- Give the model (https://ahri.uwa.edu.au/whats-the-cost-of-hwsc-for-you/) a run with your numbers and see what you find.

Introduction

How much does it cost to run a car? It depends. Some cars are expensive to buy but have low maintenance and fuel costs, whereas others are cheaper to buy but guzzle the fuel and need a lot of work to keep them on the road. Harvest weed seed control (HWSC) is just the same. We need to look a bit deeper than the up-front capital cost to get the full story.

The do it yourself narrow windrow burning chute seems cheap at the time, but what is the true cost of this type of HWSC? The answer is, it depends on several factors!

The short answer: HWSC costs $7 to $19 per hectare and there are only minor differences in the cost between the various tools.

The slightly longer answer: For a large farm with lower yielding crops the cost is $7-$10/ha. For a small farm with higher yielding crops the cost is $18-$20/ha.

The whole story: The cost of HWSC depends on a whole range of factors that differs from farm to farm. AHRI have developed an interactive model that enables you to input your details and obtain the best cost estimate for different HWSC methods. The model can be downloaded from the September 2019 AHRI insight (https://ahri.uwa.edu.au/whats-the-cost-of-hwsc-for-you/).

Table 1 demonstrates an example output from the model along with some details explaining all of the assumptions used in the model.

Table 1. Cost ($/ha) of various harvest weed seed control (HWSC) tools. Data from the Estimated Cost of HWSC model. (https://ahri.uwa.edu.au/whats-the-cost-of-hwsc-for-you/). This data represents farms of different sizes and crop yields, all harvested with one harvester.

Crop Area (ha)	Crop Yield	Seed Terminator cost ($/ha)	Vertical iHSD cost ($/ha)	Redekop SCU cost($/ha)	Chaffline cost ($/ha)	Chaff deck cost ($/ha)	Narrow windrow burn cost ($/ha)
2000	Low	$11.76	$9.66	$11.06	$9.94	$11.01	$22.21
2000	High	$19.14	$17.04	$18.44	$19.07	$20.14	$40.47
4000	Low	$7.56	$6.51	$7.21	$9.76	$10.38	$22.19
4000	High	$14.94	$13.89	$14.59	$18.89	$19.51	$40.46

n.b. crop area is 50% cereal, 25% legume and 25% canola.

Table 2. Assumptions used in the model to generate the results presented in Table 1.

	Low yield	High yield
Cereal	2t/ha	4t/ha
Legume	1.2t/ha	2.5t/ha
Canola	1.2t/ha	2t/ha
Reduction in harvest capacity due to mill	0%	10%
Harvest speed	12ha/hour	8ha/hour
Mill life	400 hours	400 hours
Harvest cost for harvester + chaser bin	$400/hour	$400/hour
Extra fuel to run a mill	0.5L/tonne grain	0.5L/tonne grain

Table 1 shows that the lowest cost of HWSC is achieved by larger farms with generally lower yields. This is because the capital cost of HWSC is spread out over a larger area, the nutrient removal costs are lower due to the lower yields, and harvest is not slowed by the mills due to the lower yields. In contrast, the highest cost of HWSC is associated with smaller farms with higher yields. In general, there's only a relatively small difference in cost between all of the HWSC tools except for narrow windrow burning, which is always the most expensive due to the highest nutrient cost. The 'bale direct' tool was not included in this comparison, but in general it is a very high cost and can be profitable if a large market for straw bales exists close to the farm.

Capital cost

The capital cost of HWSC tools are always quickly quoted, but it's important to remember that this is only part of the picture. Table 3 gives an estimate of the capital cost of the various tools but as the laws of competition come into play, these values will most likely change.

Table 3. Approximate capital costs of various harvest weed seed control (HWSC) tools.

HWSC tool	Capital cost
Narrow windrow burning chute	$500
Chaff line chute	$500 to $5000
Chaff deck	$17,000 to $20,000
Vertical iHSD	$90,000 fitted
Seed Terminator	$120,000 fitted
Redekop	$110,000 fitted
Bale direct (baler + Glenvar system)	$340,000

Nutrients

One of the most important, and sometimes overlooked costs of HWSC is the value of the nutrients contained within the crop residue that is removed in the process.

In 2011, the amount of nutrients found in a range of chaff cart dumps and narrow windrows was measured (Table 4). Nutrient analysis was conducted by CSBP, Western Australian fertiliser distributor.

Research by Dr. Michael Walsh has shown that chaff yield averages about 33% of grain yield. In other words, if you are harvesting a 1t/ha wheat crop, approximately 333kg of chaff will be diverted into the chaff cart or chaff line or seed impact mill. This assumption was used to calculate the value of nutrients per tonne of grain harvested (Table 5).

Table 3. The value of the nutrients contained in harvest residue per tonne of grain harvested based on 2019 fertiliser prices

	Value of nutrients in chaff per tonne of grain harvested
Cereal	$5.46
Legume	$7.38
Canola	$6.37

Table 4. Average nutrient content in chaff from chaff cart dumps in 2011 in Western Australia.

	Nitrogen	Potassium	Phosphorus	Sulphur
	units N per t chaff	units K per t chaff	units P per t chaff	units S per t chaff
Cereal	5	8	0.5	0.5
Legume	10	8	0.6	1
Canola	7	8	0.6	2

n.b. Legume = lupin

Nutrient spread

For chaff lining and chaff decks, the residue is not removed from the paddock but is placed in narrow zones that are not available to the whole crop, so it is assumed that the nutrients are lost. The nutrient cost of seed impact mills is assumed to be zero as the pulverised crop residue is returned to the field. However, if the mill cannot evenly redistribute these nutrients, perhaps this cost needs to be included. When observing the mill, it's important to consider if it's achieving an even spread.

Cost of ownership

To calculate the cost of purchasing a HWSC tool, depreciation and interest rate are added together and multiplied by the capital cost. This value is then divided by the hectares harvested by each harvester to give a $/ha cost. Consultants generally use a figure of 10% depreciation per annum for agricultural machinery (some machinery depreciates faster and some slower). At this point in time there is no measure of how fast weed impact mills depreciate, and therefore, the average of 10% is used. Interest rate is included in the cost of purchasing as there is an opportunity cost for the money used to purchase the tool.

Harvest cost

The cost of harvest is important because if the HWSC tool slows the time taken to harvest the crop, there is an increase in the cost of harvest per hectare.

Growers should estimate their own harvest cost and it should include depreciation, fuel, labour, repairs and maintenance, interest, etc. Also don't forget to include the cost of running the chaser bin as part of the harvest cost.

Reduction in harvest capacity

Some of the HWSC tools can slow harvest, although a wide range of stories have been reported from farmers. Most farmers with chaff carts comment that they do not slow harvest at all, whereas some farmers say they slow harvest a little bit by perhaps 5%. The seed impact mills can slow harvest if the harvester is limited by its horsepower. Some farmers chip the engine to boost horsepower and report no reduction in harvest capacity. In general, in lower yielding crops where horsepower is not limiting there is no reduction in harvest capacity with the use of HWSC tools. In higher yielding crops, 5 to 10% reduction in capacity is common, with some growers reporting as much as a 25% reduction.

Fuel

There are a range of extra fuel costs quoted for seed impact mills and chaff carts. The figure of 0.5L/tonne of grain harvested of extra fuel for the mills is assumed in the model. Growers interviewed for this study, quoted anywhere from 0.3L/t grain to 1.5L/tonne of grain.

Wearing parts of impact mills

Assuming the cost of wearing parts in impact mills is a moving target, now, due to the emphasis the manufacturers of the mills are placing on product development to reduce wear rates. A pair of mills costs in the order of $9000 to $11,000 to replace. Mill life can be anywhere from 150 to 700 hours with 400 hours being the current average. At 400-hour mill life and $9500 for a new set of mills, this works out to be roughly $3/ha.

Repairs and maintenance (R&M)

To estimate this cost, it is best to check with the seller of the machine. Values used in the model are an educated guess for all of the HWSC tools.

Other benefits of residue retention

There are benefits to the soil biology and moisture from retaining crop residue, however an accurate figure to use was not found.

Grazing chaff cart dumps, chaff lines and chaff deck with sheep

Grazing chaff can be both beneficial to the sheep and is likely to redistribute some of the nutrients back over the paddock. These benefits may negate some of the cost of these tools and in some cases may result in the HWSC tool being free; particularly in cases where grazing chaff dumps or lines reduces the cost of supplementary feeding of sheep.

Conclusion

There is no single answer as to which HWSC tool is best. It depends! The Estimated Cost of HWSC model aims to give you the most accurate estimate of cost of HWSC based on what we know now. Even though there can be a big difference in capital cost between the HWSC tools, the total cost per hectare can be relatively small when all things are considered. Give the model a run with your numbers and see what you find. The model can be downloaded at: https://ahri.uwa.edu.au/whats-the-cost-of-hwsc-for-you/

Acknowledgements

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

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NEW BOOK FOR LOW RAINFALL GROWERS IN AUSTRALIA

IS CTF WORTHWHILE IN THE LRZ?

This new publication addresses common questions about CTF in the LRZ, such as:

- » DO LRZ SOILS SELF-REPAIR OR IS AMELIORATION WORK NEEDED?
- » IS CTF FEASIBLE IN LOW INTENSITY SYSTEMS WITH VERY WIDE MACHINES?
- » DOES CTF REDUCE POWER AND FUEL USE IN LIGHT LRZ SOILS?
- » IS CTF COMPATIBLE WITH LIVESTOCK IN THE SYSTEM?

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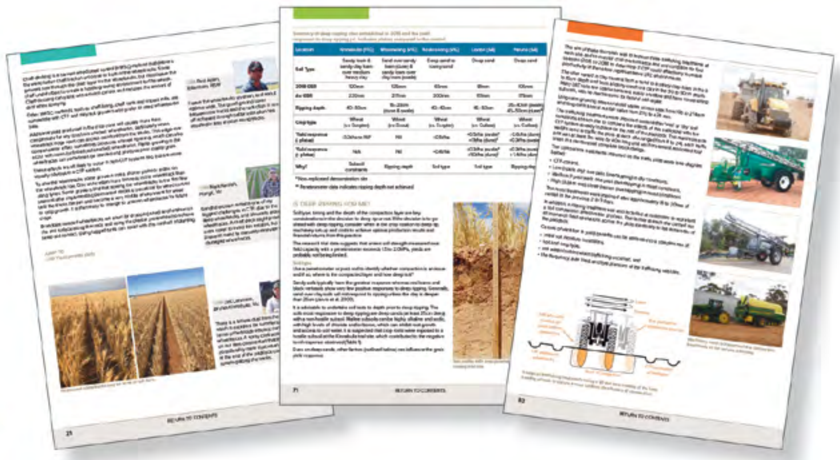
all relevant to the implementation of Controlled Traffic Farming in Low Rainfall Zones



Chemical residues and maximum residue limits (MRLs) – impact, understanding and potential trade issues

Gerard McMullen.

Chair National Working Party on Grain Protection (NWPGP).

GRDC project code: MCM00003 – Strategic oversight and coordination of grain protection chemicals

Keywords

- chemicals, maximum residue limits, MRLs, market access, domestic marketing, export marketing.

Take home messages

- It is a legal requirement to follow all label directions when applying any chemical.
- There are different perceptions and legal/contractual requirements of key domestic and export markets for chemical residues.
- There are market access implications when using chemicals; applying a chemical according to label directions does **not** necessarily mean that grain will meet market requirements.
- There is a need for advisers and growers to understand market requirements and seek advice on the MRLs that apply. Talk to your marketer if possible, before you intend to apply chemicals to a crop.

What is a maximum residue limit (MRL)?

A range of different types of chemicals are applied to crops for varying reasons. Chemicals may be used prior to planting, during the crop growth stage or following harvest. Only those chemicals registered in Australia for use on a particular crop may be applied. All chemicals registered in Australia must be used according to label directions (for example; crop type, application rates, withholding periods, etc.). This is a legal requirement in Australia.

When using these chemicals, residues may arise in the harvested grain. Residues may also arise when moving that grain using equipment such as augers and trucks that have previously held grain containing chemical residues.

The nature of residues arising are considered by the Australian Pesticides and Veterinary Medicines Authority (APVMA) and if necessary, an MRL is set for that chemical and crop commodity combination.

An MRL is the maximum concentration of a residue resulting from the registered use of an agricultural chemical which is legally permitted or recognised as acceptable to be present in or on a food, agricultural commodity or animal feed.

What are market requirements?

Chemical residues on imported food and food safety in general are arguably the key focus for markets at present.

When marketing grain in Australia or in an overseas country, residue levels must meet the regulated MRL and customer contract specifications of the destination country. These may differ to the Australian MRL.

Each market, whether it be in Australia or overseas, is responsible for ensuring the food that is imported and subsequently consumed is safe to eat in terms of chemical residues. Each market has their own chemical legislation based on their own particular chemical usage and consumption patterns. Hence different MRLs for the same chemical and commodity may apply in different markets.

There is a trend towards markets developing their own chemical regulations and not relying as previously implied on international standards, such as Codex Alimentarius. There is a trend towards requiring lower (or nil) residues on grain supplied. Markets are also increasing their level of monitoring of imported grain via sampling and testing to check compliance with their needs.

The increase in grain traded internationally may cause a market access issue for Australian grain where:

- The market has no MRL (missing MRL).
- The market doesn't apply a Codex MRL (divergent MRL).
- There is no Codex MRL for those markets that follow or default to Codex.
- The market does not have a default policy and hence a zero limit applies.
- The market applies a low level of detection (LOD).
- In some instances, contracts do not state the MRLs that apply. It is the responsibility of the supplier or the marketer of the grain to ensure that they know the regulations and that the grain supplied meets those requirements.

Implications for advisers and growers

Even though a grower may apply a chemical correctly and in accordance with label directions, the resulting grain residues may not meet market requirements.

In addition, there is the concern that in many situations the adviser/grower does not know the market requirement before they use the chemical?

All grain trading standards have wording in relation to chemical use that growers must comply with.

An example for the Grain Trade Australia Wheat Trading Standards is outlined as follows:

Chemicals not approved for Wheat – a nil tolerance applies, and this refers to the following:

- *Chemicals used on the growing crop in the State or Territory where the wheat was grown in contravention of the label*
- *Chemicals used on stored wheat in contravention of the label*
- *Chemicals not registered for use on wheat*
- *Wheat containing any artificial colouring, pickling compound or marker dye commonly used during crop spraying operations that has stained the wheat*
- *Wheat treated with or contaminated by Carbaryl, Organochloride chemicals, or diatomaceous earth*
- *Chemical residues in excess of Australian Commonwealth, State or Territory legal limits*

Residue testing is done either by the marketer or by the National Residue Survey on domestic grain and export grain shipments, the latter funded via a grower levy. If residues arise that exceed the market MRL, price penalties may occur, or the shipment may be rejected and returned to Australia. Costs may be passed from the marketer to the supplier of that grain where there is evidence of chemical misuse or false chemical use declarations. Sampling and testing of future grower loads and shipments

Table 1. Some key Australian markets and their chemical MRL regulations.

Market	Codex	Australia	China	EU	Indonesia	Japan	South Korea	Taiwan	Thailand	Vietnam
Regulation applied	Not adopted by all markets	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard	Own MRL Standard
Default MRL	No default	No default	No default	Default system	No Default	Default system	Default system	No default	Default system is complex	No default
If no MRL	ZERO	ZERO	ZERO	0.01	CRA / ZERO	0.01	0.01	ZERO	0.01	ZERO
MRL Updates	Yearly	Monthly – 6 weeks	Bi-annually	Often	Rarely	Often	Often	Approx. twice/year	Rarely	Rarely

Note: Above is as at 6 January 2020, variations exist for specific chemicals. MRLs quoted in mg/kg. CRA refers to a Country Recognition Agreement where Indonesia may accept Australian MRLs for some commodities may increase or additional segregations may need to be created, which all create extra costs. These increased costs may be passed onto the grower through the purchase price offered for the grain.

The post-farm gate sector expects that growers apply chemicals follow legal requirements. Sampling and testing of all deliveries for all possible chemicals used on-farm is not conducted due to the expense. Rather, targeted sampling and testing is conducted based on market risk. Thus, growers must provide accurate information on chemicals used on that crop. Growers are encouraged to complete Commodity Vendor Declarations correctly when details of chemicals used are sought by the trade. Failure to do so risks the supply of grain that fails to meet market requirements, a loss in reputation of Australian grain and increased costs for all along the supply chain.

Tools to assist with meeting market requirements

On behalf of industry, the NWPGP is the body responsible for providing management and leadership to industry in the areas of chemical use, post-harvest storage, market requirements and monitoring changing chemical regulations and their impact on market access.

The NWPGP is the linkage between Government and the industry providing:

- Feedback on issues of concern with chemicals.
- Advice on whether government to government submissions are required.
- Strategies for dealing with changing market requirements and actions by all in industry to address these.

An annual 2-day conference is held providing participants with the latest research and developments in the area of chemical usage, post-harvest storage and hygiene and outturn tolerances, international and domestic market requirements, and regulations. The outcomes are provided to industry to assist with market access compliance.

A greater focus has been placed in the last two years on providing industry with knowledge of market requirements. This has involved significant communication and liaison with the pre- and post-farm gate sector. The gap between knowledge of the market requirements and what happens on-farm was recognised and communication to the pre-farm gate sector has increased through development of Fact Sheets and presentations to a range of stakeholders throughout Australia. This has occurred via NWPGP, GRDC and various government departments. Further communication with the grower and the adviser sector will continue to benefit all in the industry.

Conclusion

Given the changing nature of market regulations, all stakeholders along the supply chain need to be aware of market requirements in relation to MRLs. Given the implications of incorrect chemical use, there is a need for greater transparency and understanding by growers and advisers of the impact of chemical use on market access.

Going forward there will be a focus on ensuring all supply chain participants understand the risks of non-compliance with label directions and removing the gaps in networking; including chemical registrants, re-sellers, agronomists, growers and their advisers.

Growers need to talk to their adviser/agronomist and storage agent/marketer and where needed other experts, when seeking advice on market requirements.

Acknowledgement

This project is undertaken solely as a GRDC project and is made possible by the significant contribution of growers through the support of the GRDC. The author would like to thank growers and the GRDC for their continued support.

Useful resources

On-farm Stewardship Guide ‘Growing Australian Grain’ http://grainsguide.grainproducers.com.au

National Working Party on Grain Protection www.graintrade.org.au/nwpgp

National Residue Survey https://www.agriculture.gov.au/ag-farm-food/food/nrs

APVMA https://apvma.gov.au

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TOP 10 TIPS

FOR REDUCING SPRAY DRIFT

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.

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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.

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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*.

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Recommendations for deep ripping sandy soils

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GRDC project code: DAS00169-BA: Improving sustainable productivity and profitability of Mallee farming systems with a focus on soil improvements.

Keywords

- deep ripping, soil compaction, sandy soils, subsoil.

Take home messages

- Deep ripping is most effective in deep sandy-textured soils, when the ripper tines go beyond the compacted layer (+60cm). Grain yield increases usually persist for several years on deep sands.
- Based on 2 years of limited data in SA, ripping with narrow (30cm) or wide (60cm) tine spacing resulted in similar grain yield responses, and therefore, wide ripping should be considered as it requires less machinery horsepower and less operational costs.
- A potential downside associated with deep ripping in low rainfall areas is that it increases the risk of crops 'haying off' when soil water reserves are rapidly exhausted and the finish to the season is harsh and dry.

Background

Sandy soils dominate the landscape across the low rainfall region of south-eastern Australia and soil compaction mainly caused by heavy machinery is a widespread constraint to root growth. Other constraints that may occur simultaneously on these soils include water repellency and acidity. Compaction inhibits root growth and reduces the storage and supply of water and nutrients, especially from the subsoil. It increases soil bulk density and soil strength, decreases porosity, water infiltration and water holding capacity, and can also adversely affect soil biological activity. In the absence of compaction forces some sandy soils have a natural tendency to form hard layers in the subsurface, thought to be caused by physical and/or chemical cementation processes.

Deep ripping is most effective treatment to loosen compacted subsoils and allow roots to access soil moisture and nutrients at depth. Significant benefits to crop growth from deep ripping are frequently measured on compacted sandy-textured soils, however responses on other soils are often smaller and less frequent (Paterson and Sheppard, 2008). For example, Isbister et al. (2018) reported that responses to deep ripping in Western Australia (WA) were greater in sandy soils (20-37% yield increase) than loamy duplex soils greater than 30cm deep (22%) or shallow duplex soils (4%). For sodic clays and prone to dispersion, ripping is often detrimental to crop growth.

Tine spacing, working depth, shallow leading tines or discs, soil moisture content, timing and soil type all need to be considered to maximise productivity gains and make the process off deep ripping cost effective. Research by the Department Primary Industry and Regional Development (DPIRD), supported by investment from the GRDC, estimates that the costs associated with deep ripping can range from $50-60 per hectare for standard ripping at 50cm spacing to a depth of 30-40cm, and up to $70-90/ha for ripping at narrower spacings and/or a depth of 50-70cm, depending on machinery and soil conditions. Therefore, the challenge that growers face is refining how best to ameliorate compacted soils while keeping costs down, but at the same time maximising and prolonging the benefits. It is important to note that if the soil contains other constraints in, or below the ripping depth such as acidity, poor structure from sodicity or subsoil salinity, the benefits of deep ripping may not be fully realised unless these are also addressed.

This paper summarises the results from replicated trials conducted in different low – medium rainfall cropping regions of Australia to gain insight into how deep ripping is impacting crop performance and how to maximise the benefits on different soil types. Collation of data from these trials will assist in developing guidelines for growers which address key questions around if and why they should be considering deep ripping as a soil amelioration strategy. Once the decision is made to proceed with a ripping program, trial results will also help inform growers of how best to undertake the ripping to achieve sustainable and improved crop yields and sound returns for every dollar invested.

Justification for deep ripping

Research conducted in the 1970s and 80s demonstrated that on deep sands and sandy loams in WA, wheat roots can extract water from depths ranging from 1.4 to 2.5 metres (Hamblin et al. 1982; Hamblin et al. 1988). In moisture limited environments the capacity of roots to extract water and nitrogen from such depths is critical on soil types with relatively low water holding capacity, or where the use of deep subsoil moisture is critical for grain filling. In compacted sandy soils where penetration resistance exceeds 1500kPa, crop root growth is restricted and yield potentials cannot be realised. In these situations, deep ripping can break up that compaction, improve root penetration and ultimately crop performance. Resistance values of 1500-2500kPa are considered moderate, 2500-3500kPa severe and >3500kPa extreme.

During the 1980s, peak soil strength in deep sands and sandy earths typically occurred at depths of 30 to 35cm and reached strengths of 2000 – 2500kPa as shown in Figure 1 (right). Since then, as farms have got larger and machinery sizes and axle loads have increased, the severity of the compaction problem has continued to worsen. Recent soil strength measurements indicate that peak soil strength now occurs at depths as shallow as 20cm, with strengths ranging from 3000 to 3500kPa (Figure 1 left and right). Therefore, when considering shattering soil compaction, deeper ripping past the compacted layer is recommended in order to maximise the benefits.

Crop responses to deep ripping

Reviews of deep ripping trials conducted 20-30 years ago have shown substantial benefits with cereal yield increases of 22 to 37% in the first year (Crabtree 1989; Davies et al. 2006; Jarvis 2000).

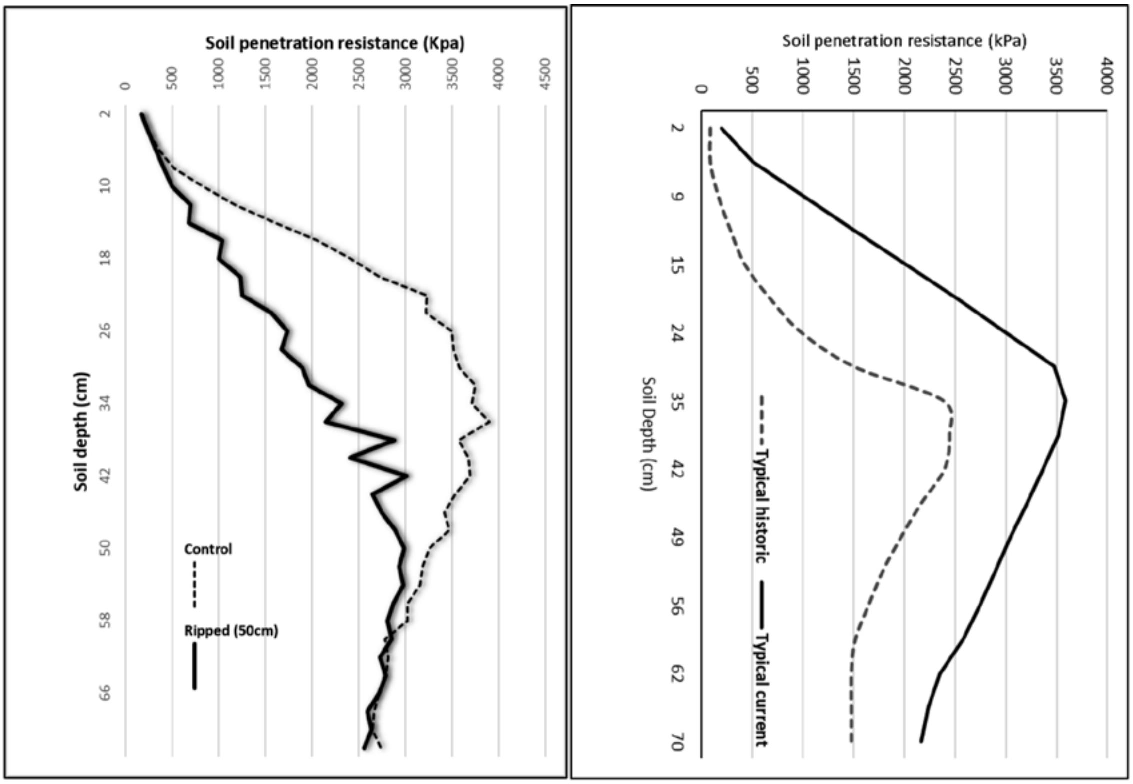

Figure 1. Plots showing penetration resistance for a sandy soil at Loxton, South Australia (SA) (left), and typical historical (1980s) and current soil penetration resistance measures for deep WA sandy soils (right).

Table 1. Crop yield responses to deep ripping at different depths and the impact of topsoil slotting (with inclusion plates). Trials conducted in WA during 2014 to 2016 (Davies et al., 2017).

Location, crop	Soil type	GSR (mm)	Control yield (t/ha)	Ripped 30-40cm		Ripped 50-70cm		Ripped 50-70cm + topsoil slotting	
				Yield (t/ha)	%	Yield (t/ha)	%	Yield (t/ha)	%
Moora, canola	Loamy sand	177	1.9	2.2	16	2.8	47	2.9	53
Wubin, wheat	Deep sand	228	2.1	2.7	29	3.0	43	-	-
Binnu, wheat	Deep sand	219	0.8	0.8	0	1.4	75	1.8	123
Binnu, wheat	Loamy sand	219	2.1	2.1	0	2.8	33	3.6	71
Beacon, wheat	Sandy duplex	240	3.8	3.9	3	3.5	-11	4.5	15
Broomehill, wheat	Sandy duplex	227	1.8	2.0	11	3.0	67	-	-
Munglinup, wheat	Sandy duplex	280	3.6	3.6	0	3.6	0	4.2	17
Meckering, wheat	Sand over gravel	323	2.7	-	-	3.4	26	-	-
Meckering, wheat	Deep sand	323	2.4	-	-	3.4	46	-	-
Meckering, wheat	Sand over gravel	323	2.2	2.5	15	3.0	38	3	38
Walkaway, lupin	Deep sand	219	1.2	-	-	2.3	92	-	-

In recent experiments conducted in WA (Davies et al., 2017) during 2014 to 2016, ripping increased average wheat yields by 8% for shallow ripping (30 to 40cm), 35% for ripping to depths of 50cm or more, and 53% for deep ripping with topsoil slotting (Table 1). Topsoil slotting is produced when inclusion plates are bolted behind ripping tines with the top of the plate working 100mm below the soil surface, thereby keeping the ripping slot open while allowing topsoil to fall down towards the bottom of the slot.

SA Mallee trials

Similar grain yield improvements with deep ripping (+60cm) were previously reported at Waikerie (McBeath et al., 2018). However, intervention to 60cm did not provide any significant yield benefits over a depth of 30cm at several other South Australian (SA) and Victorian (Vic) sites (Moodie et al., 2018; McBeath et al., 2019).

As part of this study five replicated field trials (Table 2) were conducted during the 2018 and 2019 cropping seasons on sandy soils across the SA northern and southern Mallee, and the upper Eyre Peninsula (UEP). Trial 1 (depth x spacing) was set up at Peebinga (2018 and 2019) and at Buckleboo (2019) to investigate the impact of depth of ripping and tine spacing on crop productivity and the longevity of the amelioration benefits.

Trial 2 was set up at Loxton as a crop rotation experiment with three different crop types (wheat, barley and field peas each year), with the aim of assessing which crop types respond best to deep ripping in the 1st, 2nd and 3rd year after amelioration.

Deep ripping treatments were imposed using a straight tine ripper on 11 May and 21 May 2018 at Loxton and Peebinga, respectively and at Buckleboo on 10 April 2019. Penetration resistance readings were taken on 7 August 2018 at both Mallee sites using a Rimik CP40 (II) cone penetrometer to estimate the magnitude and depth of compaction and the impact of the ripping treatments. The

Table 2. Deep ripping locations and treatment details for 2018 and 2019 cropping seasons.

Year	Trial #	Location (crop)	Region	Treatments
2018	Trial 1	**Peebinga** (barley)	southern Mallee	Depths (0, 20, 40, 60, 70cm) Tine spacings (Narrow = 30cm and wide = 60cm)
	Trial 2	**Loxton** (wheat, barley, peas)	northern Mallee	Ripped (50cm) vs compacted (control) Tine spacing 50cm
2019	Trial 1	**Peebinga** (wheat)	southern Mallee	Depths (0, 20, 40, 60, 70cm) * Tine spacings (Narrow = 30 cm and wide = 60 cm)
		Buckleboo (barley)	upper EP	
	Trial 2	**Loxton** (wheat, barley, peas)	northern Mallee	Ripped (50cm) vs compacted (control) Tine spacing 50cm

Growing season rainfall: 2018 Loxton (105mm), Peebinga (116mm); 2019 Loxton (93mm), Peebinga (152mm), Buckleboo (143mm).

depth of compaction layer was measured around 18 – 20cm at Peebinga and Loxton in 2018. To get accurate data, penetration resistance measurements are recommended to be done when the soil moisture is at or near field capacity. Due to the nature of the season with inconsistent low rainfall, no measurements were taken in 2019 at all sites. In-season assessments of crop density, dry matter (DM) production, grain yield and quality were undertaken to understand the effect of ameliorating compaction in typical deep sands of the SA Mallee.

With total growing season rainfall (GSR) ranging from only 93 to 152mm, crop growth and productivity were severely limited at all sites. However, visual and positive responses in crop establishment and biomass to ripping were evident throughout the growing season in all trials. No harvestable grain yield was achieved in field peas at the Loxton site for 2018 and 2019 because of severe frost which resulted in pod damage.

Despite the dry conditions and poor yields, the trials demonstrated that ameliorating compacted sandy soils in low rainfall environments can lead to substantially improved crop biomass (data not shown) and grain yield in cereals. Deep ripping increased wheat yields by up to 135% for shallow (20-40cm) ripping, and up to 235% for deeper ripping to depths of 50cm or more. Barley grain yield was increased by up to 93% for shallow (20-40cm) ripping, and up to 193% for deeper ripping to depths of 50cm or more (Table 3). Only shallow ripping did not cause large grain yield gains.

Averaged over all ripping depths, deep ripping with tines spaced at 30cm resulted in a significant increase in early and late shoot DM (data not shown). However, this benefit did not carry through to grain yield (Figure 2). Deep ripping has the potential to promote early biomass growth but in moisture limited environments, one of the greatest potential downsides associated with deep ripping is that it increases the risk of 'haying off' when soil water reserves are low and the finish to the season is dry (Davies et al., 2017). In some situations, faster water use and increased vegetative biomass caused by deep ripping can leave inadequate stored soil water for grain filling resulting in 'haying off' and reduced yields.

There was a consistent trend of increasing grain yield with increasing ripping depth across all sites in the two years of conducting these trials (Figure 3). But the cumulative grain yields over the two seasons showed that the deepest ripping treatment (70cm) achieved the highest yield. This is attributed to increased plant root growth, and increased access to nutrients and water down the soil profile. Similar results of improved grain yields with deeper ripping have generally been reported by several authors (Davies et al., 2017; Isbister et al., 2018; McBeath et al., 2018; McBeath et al., 2019; Moodie et al., 2018). However, it is important to note that the highest yielding treatment does not necessarily translate to the most profitable and most sustainable tillage strategy. In addition, the optimum depth of ripping will depend upon the depth of the compaction. For example, there is point in ripping to 70cm if the compacted layer is only between 20 and 30cm.

Table 3. Deep ripping trials conducted during 2018 and 2019, showing grain yield responses to ripping at varying depths and tine spacings.

Year	Location	Crop	Tine spacing (cm)	Control	Ripped 20cm		Ripped 40cm		Ripped 50cm		Ripped 60 - 70cm	
				Yield (t/ha)	Yield (t/ha)	% change	Yield (t/ha)	% change	Yield (t/ha)	% change	Yield (t/ha)	% change
2018	Loxton	Wheat	50	0.58	*	*	*	*	0.69	**19**	*	*
	Loxton	Barley	50	0.54	*	*	*	*	1.08	**100**	*	*
	Peebinga	Barley	30	0.27	0.46	**70**	0.52	**93**	*	*	0.79	**193**
	Peebinga		60		0.23	**-15**	0.43	**59**	*	*	0.77	**185**
2019	Loxton	Barley	50	0.13	*	*	*	*	0.18	**38**	*	*
	Loxton	Wheat	50	0.22	*	*	*	*	0.56	**155**	*	*
	Peebinga	Wheat	30	0.2	*	*	0.47	**135**	*	*	0.67	**235**
	Peebinga		60		0.28	**40**	0.29	**45**	*	*	0.62	**210**
	Buckleboo	Barley	30	2.13	2.79	**31**	2.88	**35**	*	*	3.35	**57**
	Buckleboo		60		2.38	**12**	3.46	**62**	*	*	3.33	**56**

*n.b. *no statistically significant response (i.e. no different to the control).*

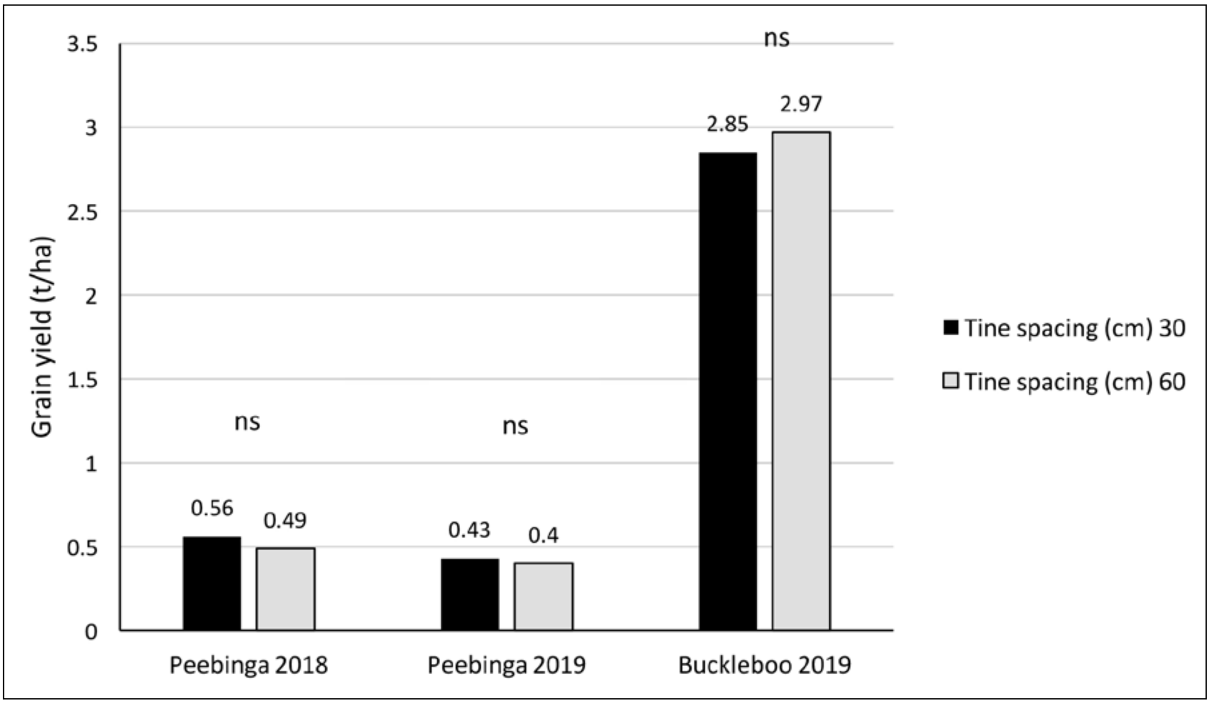

Figure 2. Mean cereal grain yield (t/ha) on 30cm and 60cm tine spacing at Peebinga and Buckleboo

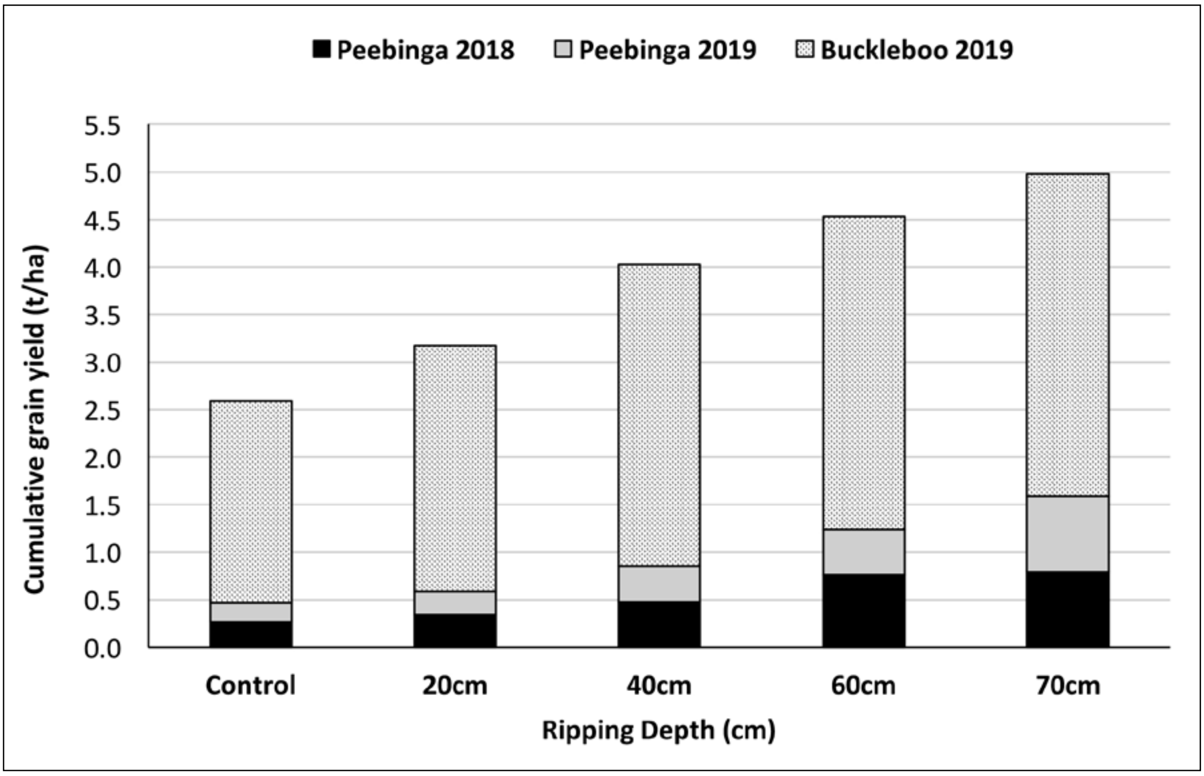

Figure 3. Cumulative cereal grain yield (t/ha) at Peebinga (2018, 2019) and Buckleboo (2019).

Economics of deep ripping

Economics are an important factor when evaluating whether an amelioration strategy should be implemented on farm or not. Soil amelioration is often costly, so it is necessary to have significant and long-term benefits to achieve a good return on investment. Physical interventions like deep ripping have the potential to improve crop productivity in compacted sandy soils, but there is a risk of low returns in low rainfall seasons. Our results from two years of conducting ripping depth x tine spacing trials are showing that better returns are achieved when deep ripping is achieved below 60cm (Table 4). If a narrow tine spacing is being considered, then going deeper than 60cm may not give the best economical return in the first year because the yield gain and extra income may not outweigh the extra cost of ripping further down the soil profile. However, the two years of data from Peebinga showed that by ripping down to 70cm, the marginal benefits in the second year (2019) improved by more than 100%, compared to shallow ripping. There is no evidence from our data of a drop off in yield in the second year after ripping, which implies that the benefits of deep ripping could extend into the third year and beyond, improving the economic returns even more.

Tackling more than just one constraint

Our experiments have focused only on the physical intervention of deep ripping to ameliorate subsoil compaction, however, other research has acknowledged that tackling more than one constraint is better in the long run to improve and sustain crop yields, particularly on sands in medium to low rainfall environments. Trials in the WA wheatbelt have found deep ripping combined with topsoil slotting with inclusion plates can increase yields from sandy soils by more than deep ripping alone. The aim of this topsoil slotting is to improve root growth into the subsoil by providing a nutrient and organic matter rich pathway through infertile subsoil layers, to overcome aluminium toxicity associated with subsoil acidity and to improve the longevity of the ripping benefit. At Meckering WA in 2016, shallow ripping of pale sand over gravel increased wheat grain yield by 11% (320kg/ha), while the addition of topsoil slotting increased the yield by 26% (560kg/ha) over the control (Davies et al. 2017). It is likely that the organic rich topsoil will help prevent re-compaction, and research is continuing to investigate if topsoil slotting will improve the longevity of the benefits of deep ripping.

Ripped soil can be very soft and susceptible trafficking issues for field operations. To maximise the benefits of deep ripping and minimise risks of re-compaction, adopting a controlled traffic farming (CTF) system should be considered. CTF is system built on permanent wheel tracks where the crop zone and traffic lanes for seeding, spraying and harvest are permanently separated. For many deep sandplain soils, deep ripped areas can remain soft for at least four to five years in controlled traffic systems (Davies et al., 2017), and the benefits of deep ripping can be maximised (Wilhelm et al., 2018).

Other research activities are investigating alternative methods to overcome a range of soil constraints including acidity and water repellency to further improve grain yield with cost effective

Table 4. Summary of marginal economic benefits from deep ripping at Peebinga (2018, 2019) and Buckleboo (2019).

		Tine spacing (30cm)				Tine spacing (60cm)			
	Depth (cm)	20	40	60	70	20	40	60	70
	Estimated cost ($/ha)*	40	60	90	100	30	50	70	80
Peebinga 2018	Yield change from control (t/ha)	0.19	0.25	0.56	0.48	-0.04	0.16	0.42	0.57
	Value of extra yield ($/ha)	42	55	123	106	-9	35	92	125
	Marginal benefit ($/ha)	**2**	**-5**	**33**	**6**	**-39**	**-15**	**22**	**45**
Peebinga 2019**	Yield change from control (t/ha)	0	0.27	0.3	0.62	0.08	0.09	0.26	0.57
	Value of extra yield ($/ha)	0	78	87	180	23	26	75	165
	Marginal benefit ($/ha)	**0**	**78**	**87**	**180**	**23**	**26**	**75**	**165**
Buckleboo 2019	Yield change from control (t/ha)	0.58	0.67	1.34	0.94	0.17	1.25	0.82	1.42
	Value of extra yield ($/ha)	145	168	335	235	43	313	205	355
	Marginal benefit ($/ha)	**105**	**108**	**245**	**135**	**13**	**263**	**135**	**275**

**Estimated cost of deep ripping extrapolated from Davies et al., 2017.*

***Cost of deep ripping has only been factored in once in 2018, and therefore, the value of extra yield in 2019 is the same as the marginal benefit in 2019 because there is no cost associated with ripping.*

Assumptions. Price of wheat @ $250/t (2018), $290/t (2019), and barley @ $220/t (2018), $250/t (2019)

(Source: http://image.info.cargill.com/lib/fe911574736c0c7e75/m/1/Wheat_SA_Mallee_UpperSE.pdf http://image.info.cargill.com/lib/fe911574736c0c7e75/m/1/Barley_Feed_SA.pdf)

soil modification and ameliorants (Masters and Davenport 2015, McBeath et al. 2018). Common modifications and ameliorants being investigated include delving and spading, and incorporating gypsum, lime, clay, fertilisers or organic matter. However, with all of these soil amelioration strategies it is important to take into consider practices to minimise the risk of wind erosion, especially on sandy soils with low amounts of stubble cover.

Conclusions

Slow and restricted crop root growth caused by subsoil compaction can often reduce uptake of water and nutrients and poor growth, yields and profits, while increasing the risk of erosion Soil amelioration using strategic deep ripping is costly and time consuming and multiple constraints may occur variably within a paddock, so careful diagnosis of compaction is critical to targeting the right practice in the right location.

Our trials in the dry 2018 and 2019 seasons have shown that ameliorating compacted sandy soils in low rainfall environments of SA often improves crop biomass and grain yield significantly. Ripping with narrow tine spacing (30cm) or wide tine spacing (60cm) gave similar outcomes in terms of grain yield responses, therefore wider tine spacings of 50-60cm which require less fuel and machinery horsepower should be considered.

Ongoing research is showing that deep ripping alone may not be the ultimate strategy to improving soil productivity and crop performance. Where water repellency, acidity, other constraints occur in conjunction with compaction, other practices could improve the longevity of benefits and overall returns on investment.

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Notes

Quantification of frost damage in grains using remote sensing

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GRDC project code: CSP00198

Keywords

- frost, wheat, remote sensing, multispectral, hyperspectral, thermal, fluorescence.

Take home messages

- Frost damage can be detected through sensing but cultivar, plant component, canopy structure and time after frost affects the spectra. Consequently, there are some approaches that look promising but there is currently no unique index that can consistently detect frost damage.
- Temperature variation within canopies due to canopy architecture, plant components and cultivar type causes spectra of frost damage to vary, making quantifying frost damage challenging.
- It appears likely that frost damage can be detected before the onset of visual symptoms, but it is unclear whether this is a relative measure or whether frost severity can be quantified.
- Quantifying frost damage requires comparison to a reference or control area of a paddock where little to no frost damage has occurred.
- Mapping frost damage for the purposes of cutting hay may be feasible but these techniques require field validation.

Background

Recent statistics for frost related damage in Australia estimated agricultural losses at $360 million each year (Rebbeck et al. 2007; March et al. 2015). Frosts that occur in wheat during or after ear-emergence can often result in severe stem and head damage, which can reduce grain yields and quality by up to 80%, depending on location, altitude, soil type and the severity of the frost. Wheat is particularly vulnerable to frost in the period between heading and grain-fill. Other than visually assessing a crop five to ten days after a frost event, there are no tools available to determine if frost damage has occurred or to map its extent across paddocks. Farmers would benefit greatly if they could obtain near real time information about the spatial extent of frost damage in paddocks that are likely to have yield losses. This knowledge would then enable decisions on when and how much of the crop to cut for hay. Maps of frost damaged areas of the paddock would also help farmers at harvest time as frosted areas of the paddock could be selectively harvested or left unharvested if necessary.

As part of the GRDC National Frost Initiative, a Rapid Frost Damage Assessment program was developed to investigate the application of a range of different sensors for the rapid detection of frost damage in wheat. Optical and thermal sensing systems are now being widely developed to measure crop response to abiotic and biotic stresses. These systems, coupled with recent advances in satellite and unmanned aerial vehicle (UAV)/drone technology, means that new opportunities exist for developing techniques to quickly map frost-damage in crops. Remote sensing tools for the rapid spatial quantification of frost damage could help Australian growers (and their advisers) to spatially, understand the impact of frost on yield. Before this research, it was not known whether frost damage in crops could be detected using sensors and/or whether it could be mapped.

The major questions asked in this research were:

- Can frost damage be detected and, if so, can impacts to yield be quantified?
- How soon after a frost event can frost damage be detected?
- What is the potential to map frost damage to provide information for cutting hay?

Methods

Frost exclusion – passive and active methods

Before being able to determine whether frost damage can be quantified either with temperature or a spectral response, it was necessary to develop methods to exclude frost so that an experimental control could be established. Without a control there is no definitive way to determine whether crop damage is due to frost or something else and there is no way to compare data from damaged and non-damaged plants. The two methods developed were: 1) exclusion chambers and 2) active heating.

Several exclusion chamber designs were tested with the final version (1m^2 frame made of 40mm PVC pipe with a double skin consisting of 10 layers of 23µm plastic wrap) shown in Figure 1. By erecting the shelter on a clear afternoon about 90 to 120min before sunset, the chamber was able to maintain internal temperatures above 0°C when ambient canopy temperature dropped to -4.0 to -4.5°C during the night. The multiple layers of plastic wrap provided air spaces that insulated the space in the chamber. It was noted that after five to seven days of plants being protected by the chamber there was a chamber-induced effect on plant growth, even when the chambers were removed during the day. Consequently, the use of passive chambers is limited.

Figure 1. Frost exclusion chamber (photo by Mick Faulkner).

The second method used to exclude frost was through active heating at night during frost events to maintain temperatures just above freezing using a generator and a diesel caravan air heater with air piped through a PVC manifold (Figure 2). The automated system that was developed could be deployed at multiple locations within a research or paddock setting to provide a control area so that frosted areas could be compared with control

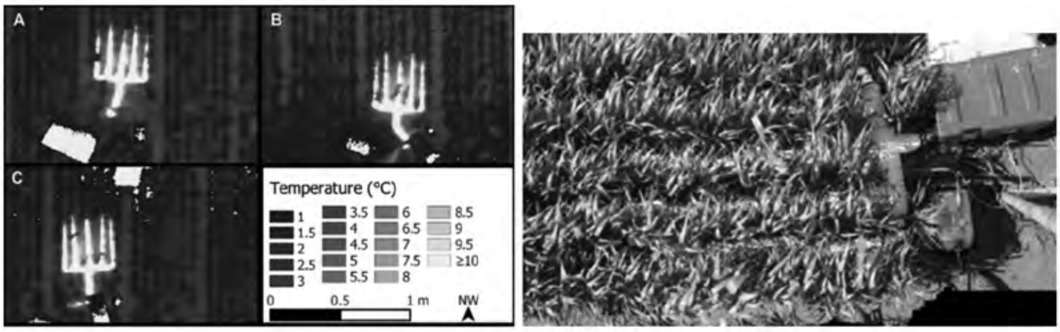

Figure 2. (left) Thermal image of the plot heater effect acquired from a UAV and (right) Close-up picture of diesel plot heater (Stutsel et al., 2019b).

areas and damage accurately assessed. This also alleviated the tedious task of placing chambers at night before an expected frost event.

Frost-imposition chambers were also developed to allow control of the timing and severity of frost for research and this is described in the companion paper in these proceedings (Nuttall et al., 2020).

Quantifying Frost Exposure

Measuring canopy temperatures

Low temperatures from a standard weather station are typically used to assess when a frost event might occur. It has been noted however, that temperatures within a canopy can be colder than those recorded at the 1.2m standard height of a weather station. Temperatures in this study were recorded at canopy height (upper most flag leaf) and these were used to calculate cold sums (Nuttall et al., 2020) to develop relationships to yield. Tiny tags were placed in the different experiments to record temperature at canopy/head height.

Spatial distribution of temperature

A fibre optic Distributed Temperature Sensing (DTS) was used to measure temperatures at the field scale, rather than the traditional point scale to determine the vertical and horizontal temperature distribution in the canopy (Stutsel et al., 2019a; Figure 3). The aim of using this technology was to identify where and when minimum temperatures developed within the crop.

Non-destructive frost detection – temperature

To understand canopy temperature dynamics, sensors were deployed in the field as infrared thermometers (Figure 4) looking at the crop canopy across the experimental plots. This provided information that could be used to validate aerial temperature data and basic crop physiological measurement of damage to transpiration due to frost.

Non-destructive frost detection – spectral reflectance

Multispectral images were acquired from UAVs and proximal hyperspectral sensor measurements (350 - 2500nm, FieldSpec FR, Analytical Spectral Devices, Boulder, CO, USA) were also collected at ground level to assess spectral response to frost. Spectral data included sensor and imagery from the control chambers (removed from the crop) and frost-affected areas of plots or transects within paddock, depending on location, year and experiment. In addition, spectral data were collected in a laboratory experiment using an imaging spectrometer on frosted (Fr) and non-frosted (NFr) wheat heads and leaves (Murphy et al., submitted) and regions of significant differences were determined between 392-889nm.

Handheld spectral measurements were collected using a Polypen™ (Photon Systems Instruments, Drasov Czech Republic, 324-792nm) on leaves, heads and grains to determine its utility for use in frost detection. This is a relatively new tool that could be used by farmers or agronomists for assessment of abiotic stress damage to plant components.

Spectral mixture analysis

One of the main difficulties of using spectral information for detection of frost (and other stresses) is that the spectral signal is ‘mixed’ with other spectra from the canopy; such as heads, green leaves, senescent leaves, soil background and even shade. Thus a ‘spectral mixture analysis’ was used to ‘unmix’ the spectra using spectral libraries composed of other canopy spectra (Fitzgerald et al.,

Figure 3. Distributed Temperature Sensing (DTS) fence. (left) Fence support pole. (right) DTS fence at the trial site (cables).

Figure 4. Infrared thermometers (Arducrop) that were used to measure canopy temperatures.

2019). The technique compares the mixed spectra to the library and estimates the fraction of the target signal (frost, in this case) in the mixed signal. When the frost fraction is compared to yield, a relationship can be developed to estimate severity of frost to yield loss.

Fluorometer

An active fluorometer (Multiplex 3.6, Force A, Orsay Cedex, France) (Figure 5) was used on wheat canopies and individual plant components (heads and leaves) to assess subtle difference in fluorescence emissions that could be related to frost exposure.

Figure 5. Multiplex fluorometer collecting measurements in wheat.

Results and discussion

Determining whether frost can be detected with sensors

Temperature and thermal imagery

Research in this program demonstrated the first application of DTS within an active trial environment, providing a new method to measure and understand temperature dynamics across trial sites. Results showed that even in mild frost events vertical temperature gradients of 0.24°C per 100mm height develop within wheat crops, with the coldest temperatures developing ~100 to 200 mm below the top of the ear. We also showed that there was a varietal influence on cold temperature development that was most likely driven by differences in height, canopy density and closure. Finally, there was greater variation in temperature within a sowing block than between blocks and that trial design and subsequent variety randomisation may impact the development of cold temperature more than topographic or soil differences. This information should lead to more confidence in results from frost trials and reduce instances of falsely identifying plants as being more frost-resistant when they may merely experience less severe cold.

Lightweight thermal cameras on UAVs are not stabilised to a constant temperature, resulting in poor accuracy. Weather data is also needed to normalise and compare across flights, likely making it an impractical method for commercial growers to detect frost in the near future. Infrared sensors (Fig. 5) provide good ground-level data to calibrate aerial imagery in a research context but they may not be practical to deploy in a paddock as many would be required to cover a paddock or farm.

Spectral measurements

Abiotic stresses, such as frost, can be detected with sensors and imagers but using spectral information to detect frost damage in crops had not been an active area of research before this research program. Once a frost event occurs, there are physiological changes to plants, including damage to photosynthetic processes and physical damage to tissues which can potentially manifest as changes in plant colour detected using spectral sensors.

To identify spectral regions that could indicate frost damage in wheat, spectra were collected from positively-identified Fr and Nfr wheat canopies in two seasons; 2006 and 2015. To clarify the differences, a normalisation of the data was performed, which helped identify eight spectral absorption regions (noted as 'dips' in the spectra, Figure 6a, shaded areas (1-8)). Taking the difference between the normalised NFr and Fr spectra from each data set (Figure 6b) determined where there were similarities and differences between the two years within each of the absorption regions identified in Figure 6a. Maximum differences are noted as higher values along the horizontal x-axis; and areas where there are peaks denote where the relationship changes. Maximum values, peaks and where there are similarities between the two years, show potential spectral regions for detecting frost damage (shaded areas, Figure 6b).

In a laboratory experiment where wheat heads and leaves were imaged using a hyperspectral imager (Murphy et al., submitted) it was shown that spectral responses differed between frost damaged heads and leaves, but there were spectral regions in common. From both laboratory and field studies, the regions in common for detection of frost damage across canopy, leaves and heads were 419-494nm and 670-675nm. Areas outside the range of the laboratory analysis include those identified in Figure 6b (shaded region). Those areas where data from multiple years overlap show potential to detect frost across a range of conditions. Wide regions showing similarity between the sites may indicate relatively stable regions in the infrared (for example

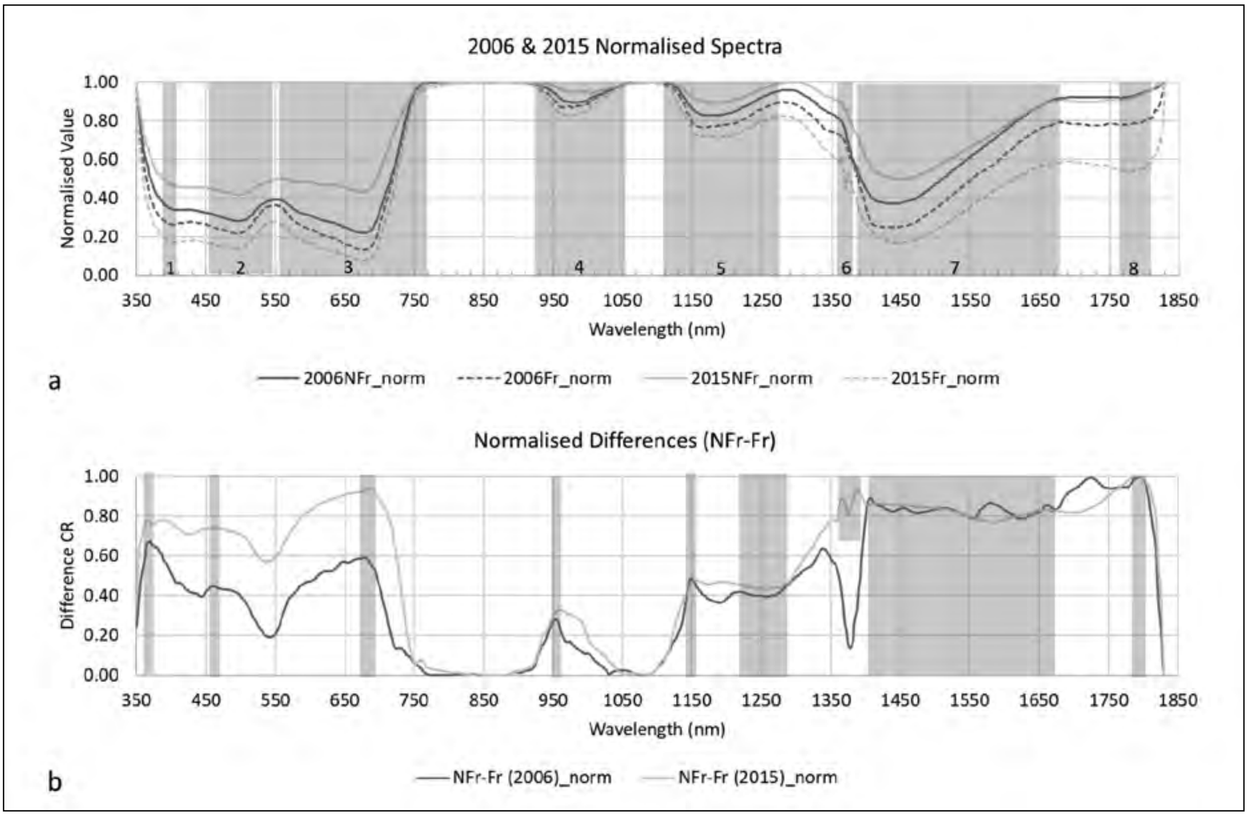

Figure 6. Spectra of wheat canopy in visible to near infrared portion of the spectrum. Two years and locations (2006, Horsham; 2015, Kewell, Victoria). (a) Spectra normalised and identification of spectral absorption regions (1-8, shaded) with differences between Fr and NFr. (b) Difference of normalised spectra (NFr - Fr) showing regions (shaded area) with potential to identify frost damage in wheat.

approximately 1220-1270nm and approximately 1400-1670nm) while reflectance values near 1800nm (Figure 6b) showed the highest difference between Fr and NFr across both years. The visible portion of the spectrum (400-700nm), although indicating similar spectral shapes between the two years, show distinct differences between the plotted lines (Figure 6b). Because photosynthesis is affected by frost (noted by the differences in Figure 6b near 450 and 670nm, where chlorophyll absorbs energy) and this changes due to many factors, it is possible that the near infrared is a more stable region of the spectrum and is more suited for frost damage detection across environmental conditions and varieties.

Spectral measurements of wheat heads

Hyperspectral measurements were taken on wheat heads subjected to frost under controlled conditions using a handheld Polypen™ (Figure 7). Results showed that there were spectral changes in

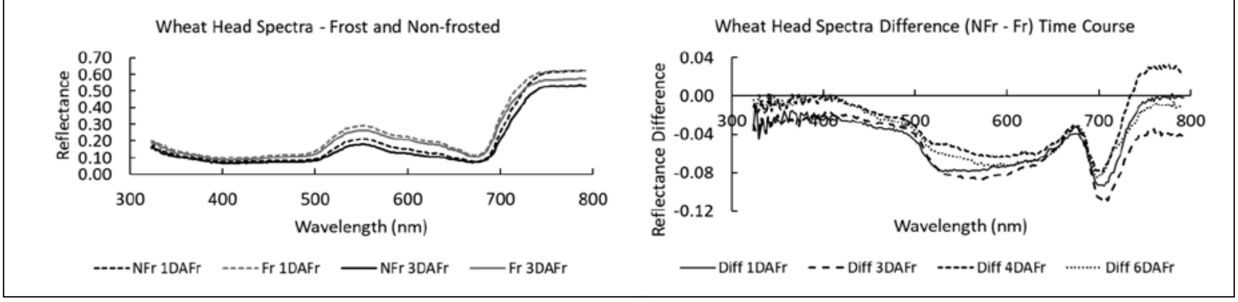

Figure 7. Spectra of wheat heads, cv Wyalkatchem⊕ collected with a Polypen™. (a) One and three days after frost (DAFr) for non-frost (NFr) and frost-damaged (Fr) heads. (b) Difference between NFr and Fr heads one, three, four and six DAFr. This shows that spectra change depending on time after the frost event.

frost-affected heads even one day after a frost event (Figure 7a) but the difference in spectra (NFr - Fr) at one, three, four and six days (Figure 7b) after frost showed that the spectra changed depending when measurements were made. Although this indicates potential for a handheld device to measure frost damage in wheat heads before visual symptoms appear, this assessment may be limited to a qualitative assessment of frost damage because of spectral changes over time. The spectral differences appear to be due to changes in plant physiology after a frost.

Quantifying frost damage

As noted previously, it may be challenging to quantify the effects of frost on yield due to spectral changes after a frost, differences between varieties and varying temperature impacts to the canopy. However, if a method could be developed to measure the severity of frost damage and its impact on yield then spectral information could be used to quantitatively map frost after a frost event, allowing farmers to make decisions to cut for hay based on yield loss information. One approach that could be useful is the use of the information in the spectra to quantify yield impacts.

One full-spectrum analysis method is ‘spectral mixture analysis’. This method was used to estimate yield measured from the sampled areas (Figure 8). By comparing the measured spectrum of points where yield was collected to a library of spectral components (Figures 8a, b), the measured spectrum can be ‘unmixed’, resulting in a measure of the proportion of frost damage represented by a fraction of frost damage (Fr fraction). Here, yield was plotted against the Fr fraction (measure of frost severity) for three data sets (Figure 8c) collected at or near anthesis. Results showed that there is a frost spectral signature that can estimate yield (R^2 values from 0.58 to 0.75) within an acceptable degree of accuracy (Root mean square error (RMSE) ranged from 0.11 to 0.46t/ha) but the relationships for each data set were different. As noted previously, this could be due to differences between time after frost, cultivar or other factors. Thus, there is still more research needed to understand and measure the factors that cause frost damage and to robustly estimate yield loss.

Discussion of a multispectral approach is presented in the companion paper in these proceedings, (Nuttall et al., 2020).

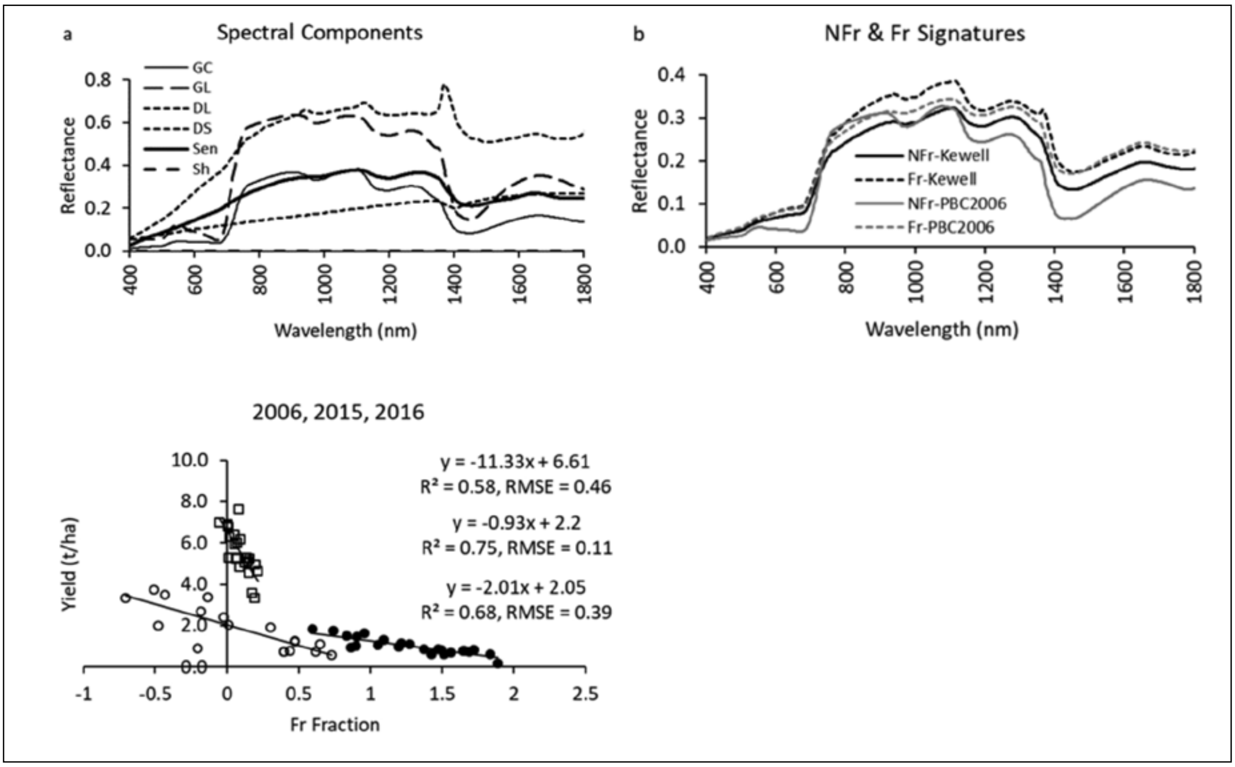

Figure 8. (a) Spectral signatures for canopy components, and (b) frost (Fr) and non-frost (NFr) canopies. (c) Frost (Fr) fraction values vs yield for three data sets using a spectral mixture analysis approach to determining frost severity and impacts to yield.

Fluorescence

Good correlations were found between some of the fluorescence indices tested and yield (Figure 9; Perry et al. 2017) or cold sums (Nuttall et al. 2018) across different experiments. The fluorescence values tracked yield across a transect in one experiment (Figure 9) and had high correlation to cold sums (r = -0.83) in another when measured on both flag leaves and heads. Advantages of this technology is that with its active light source, it can make measurements independently of sky conditions. However, the instrument is only effective when in direct contact with the plant component (leaves, heads), limiting its use to handheld measurements. Future applications may be use of fluorescence as a frost damage validation tool for crop heads or leaves.

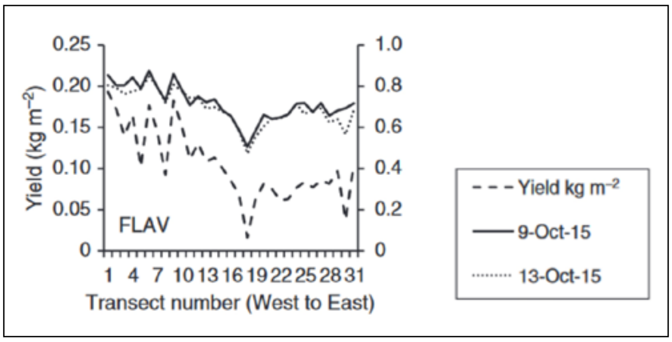

Figure 9. Corresponding grain yield and fluorometer measurements from a paddock near Kewell, Victoria in 2015 following the first observation of frost. The measurements were made along a transect of 31 rows on two dates, 9 October 2015 and 13 October 2015 (growth stages; Z61–69, Z71–75). Correlation coefficients were 0.91 and 0.90 for the two dates (Source: Figure revised from Perry et al. 2017).

Conclusions

Frost damage can be detected through sensing but cultivar, plant component, canopy structure and time after frost affect the spectral indices so that there are some approaches that look promising but currently no unique index that can consistently detect frost damage.

It appears likely that frost can be detected before onset of visual symptoms but whether this is a qualitative or quantitative assessment is still unclear.

Fluorescence seems a promising technology for frost detection but it requires direct contact with the canopy.

The most stable parts of the spectrum for a frost damage signal may be in spectral regions that cannot be currently detected by most commercially available sensors.

Non-frost damaged controls are required for research experiments.

Temperatures with frost research experiments may be more variable within experimental units than between, suggesting careful design of frost experiments is needed.

Currently there are too many technical challenges for accurate measures of crop temperature, and therefore, measuring frost damage with thermal imaging from UAVs is currently not feasible.

Mapping frost damage for the purpose of cutting hay may be feasible but these techniques still require field validation.

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Notes

Rapid detection of frost damage in wheat using remote sensing

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Keywords

- low temperature, proximal sensors, multispectral reflectance, climate change.

Take home messages

- Applying a single frost to wheat at flowering reduced yield by 7% for every degree below zero (up to -4°C), however, this increased to a reduction by 12% for every degree below zero when applied over two consecutive nights (up to -3°C).
- Remote sensing spectral indices including normalised difference vegetation index (NDVI), normalised difference red edge (NDRE) and photochemical response index (PRI) showed significant relationships with cold load applied to wheat, however, to date no universal index for frost damage using remote sensing has been identified.
- Similar utility of these three spectral indices were observed for a survey of six commercial wheat paddocks in 2018 near Murtoa, Victoria, suggesting an opportunity for spatial management of crops when considering hay versus grain production.

Background

Frost can significantly reduce production of field crops grown in Mediterranean-type environments, where economic losses for Australian wheat is estimated at up to $360 million per year in Australia (Rebbeck et al. 2007; Watt 2013; March et al. 2015). Frost risk is predominantly managed through avoidance measures, by manipulating flowering time to avoid periods of high frost risk. However, such tactics must be assessed against the potential for heat stress and drought associated with later flowering dates. If non-destructive proximal or remote sensing technologies could make rapid, spatial assessment of frost damage (Perry et al. 2017) this could limit economic losses through timely management decisions such as zoning for crops to be cut for hay, prioritising further crop inputs, altered grain marketing strategies and improved planning of harvest logistics. While the companion paper in these proceedings (Fitzgerald et al., 2020) presents methods for frost exclusion and fundamental spectral response to frost, this paper reports on: i) the response of wheat to imposed artificial frost treatments using purpose built mobile chambers, ii) the identification of remote sensing indices linked with frost affected wheat, and iii) the utility of these proposed indices for spatial mapping of frost damage in wheat at paddock scale. Overall, the objective of this work was to investigate the ability to utilise remote sensing technologies to manage in-season frost damage in wheat.

Method

i) Wheat response to frost

Mobile frost chambers were used to examine the impact of simulated frost applied at night on wheat yield, a detailed methodology is outlined in Nuttall et al. 2018. Briefly, temperatures below 0°C were applied to wheat at head emergence and flowering in a field experiment at Horsham, Victoria during 2016. Dry ice was applied to cool the chamber in a similar pattern to a natural frost with temperature monitored at canopy level in each chamber. For the treatments at flowering, minimum temperature ranged from 1 to -3°C with frost applied either as a single night or on two consecutive nights. For the head emergence treatments, these were more severe, with temperatures down to 9°C and were applied as either single, double or triple night series. Severity of frost was calculated based on a combination of both the temperature below 0°C and the time spent below 0°C, also known as 'cold load' and measured in 'degree hours below zero'.

ii) Identifying remote sensing indices for frost damage

A range of electronic sensors were tested for their ability to identify frost affected wheat by capturing images of the crop on the day after and eight to ten days after frost application. The sensors work by measuring the light reflected off the crop canopy including; visible light (wavelengths from 400 to 700nm) as well as ultra-violet and infra-red wavelengths that are not visible to the human eye. Images were captured at various heights above the canopy and in some cases focussed on different parts of the canopy (heads, leaves, etc.). The imagery was then used to calculate a range of 'indices' which compare the light reflected at different wavelengths to give an indication of various physical and chemical characteristics of the crop. Examples include the NDVI, as well as others such as the canopy chlorophyll concentration index (CCCI), cellulose absorption index (CAI), chlorophyll index red-edge (CI), enhanced vegetation index (EVI), modified chlorophyll absorption reflectance index (MCARI), NDRE, PRI, plant senescence reflectance index (PSRI), structure insensitive pigment index (SIPI), triangular greenness index and water index (WI). The aim was to test a wide range of indices and their correlation with canopy cold load and frost damage in wheat.

iii) Paddock application of remote sensing to detect frost damage in wheat

Commercial wheat paddocks situated in a frost prone region near Murtoa, Victoria (36.620°S, 142.471°E, 139m above sea level) were monitored for frost damage in 2018. Six survey points were established in each paddock at 150m intervals along a linear transect running through the centre of the paddock, picking up the maximum variation in intra-paddock relief and likely frost severity. For monitoring crop canopy temperature, thermistors were installed at canopy (crop head) height throughout the season with sensor height adjusted as the canopy grew taller. At each site, a Stevenson screen containing a temperature logger was also installed 1.2m above the ground level, consistent with the protocol used by the Australian Bureau of Meteorology for measuring air temperature.

A six-band multispectral camera (Airphen®, Hiphen, Avignon, France) capturing light at 450, 530, 675, 730 and 850nm wavelengths, was flown over the six survey paddocks on 1 Oct 2018 using a manned, fixed wing aircraft. The imagery was acquired at approximately 9000 feet above ground level (AGL) in order to capture each paddock entirely within a single image, resulting in a spatial resolution of approximately 1m. The light reflectance spectrum (six bands) for each of the survey points were extracted from the spatial paddock images. These reflectance values were then used to compute the

Figure 1. Frost chambers a) Performance testing using visual infrared thermometer, Fluke VT02 (temperature at 32.7°F (0°C)) and b) Simulated frost being applied to wheat to determine impact on yield and ultimately the link between frost induced sterility and proximal sensor response.

subset of vegetation indices; NDRE, NDVI and PRI. At each survey point, biomass cuts (25m^2 per point) were taken at harvest for yield and quality analysis. Collectively, vegetation indices were compared with measured crop canopy load and yield across the six intra-paddock survey points for the six paddocks.

Results and discussion

i) Wheat response to frost

Simulated frost treatments

The frost chambers effectively reduced canopy temperature of wheat to below zero degrees. The simulated frosts were characterised by a rate of cooling of 2°C per hour with a duration below zero degrees of around eight hours applied during the night. For flowering frost treatments, average minimum temperatures ranged from -2.2 to -3.4°C (when applied as a single frost at each growth stage) resulting in a cold sum of 8.6 to 11.8°C.hr (< 0°C). For the treatments where frost was applied over two consecutive nights, average minimum treatment temperatures ranged from -1.4 to -2.6°C the first night and from -1.0 to -1.6°C the second night. The corresponding range in cold sum, totals over the two nights was 5.0 to 12.9°C.hr (< 0°C). For the head emergence treatments, cold loads applied over three nights were up to 161°C.hr (< 0°C) and were severe enough to cause 100% yield loss.

Cold load and crop response

For wheat grown under open ambient temperature, in the absence of naturally occurring frost (or heat wave) events during the growing season, grain-set and yield was 15890 grains per m^2 and 6.8t/ha respectively (Figure 2). Applying frost over a single night resulted in an 8.8 and 7.2% reduction in grain number and yield respectively, per degree Celsius below zero up to -4°C (Figure 2a). For those frost treatments applied over two nights, the reduction in grain number and yield increased to 15.7 and 11.8% respectively, per degree Celsius below zero up to -3°C, indicating a cumulative effect of multiple frosts. To account for both frost duration and severity, cold load was compared with yield. The response of wheat was a 2.2% reduction in grain number per °C.hr (below 0°C), which translated to a yield reduction of 1.9% per °C.hr (Figure 2b).

ii) Identifying remote sensing indices for frost damage

For the 11 indices derived from reflectance of wheat (flag leaf, head and canopy), PRI, NDVI and NDRE demonstrated significant linear relationships with frost intensity for treatments (head emergence) that were in excess of 20°C.hr <0°C (or minimum temperatures of -6.6 to -9.6°C), although the relationship was poor following frosts treatments at flowering with intensities less than 20°C.hr (Nuttall et al. 2018). This was possibly related to the limited range in cold load for the flowering treatments and any subtle impacts to crops not being detectable. Importantly, PRI showed greatest utility in its consistent relationship across both the head emergence and flowering frost treatments (Figure 3). For NDVI, although a high correlation existed for frost applied at head emergence, the anthesis response fell below the regression line compared with the earlier heading measurements, highlighting the confounding effect of senescence associated with advancing crop growth stage, on NDVI.

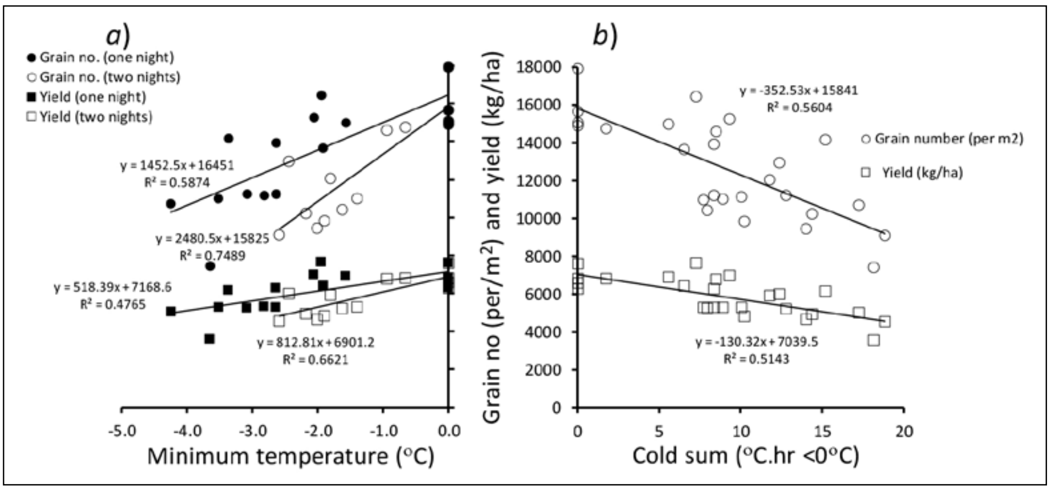

Figure 2. Relationship between wheat yield components and a) minimum temperature and b) cold sum (°C.hr < 0°C) for frost treatments.

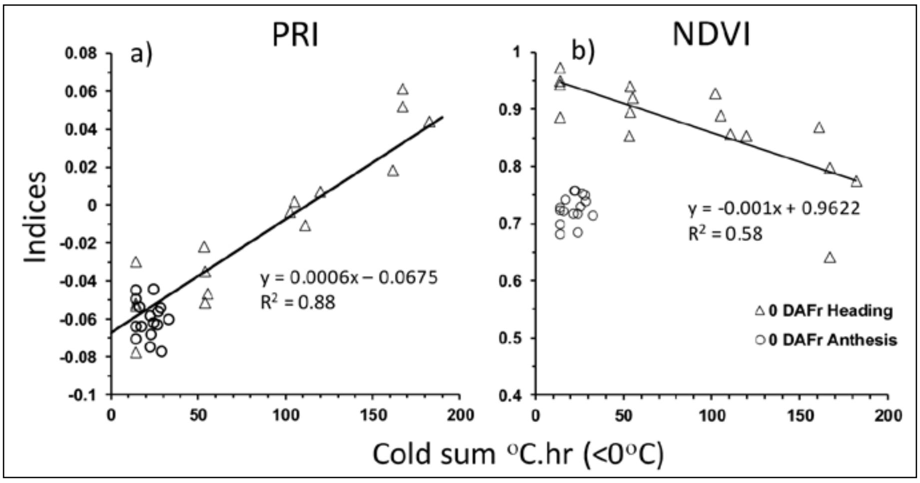

Figure 3. Reflectance derived spectral indices photochemical response index (PRI) and normalised difference vegetation index (NDVI) from wheat heads the day after frost (DAFr) treatments, applied at varying intensities and expressed as cold sums. Frost treatments were applied at the crop stages; head emergence and flowering.

iii) Paddock application of remote sensing to detect frost damage in wheat

For the six wheat paddocks surveyed in 2018, which was a decile 2 growing season, paddock averages for yield ranged from 0.4 to 1.6t/ha and ranged up to 0.2 to 2.6t/ha within any single paddock (Table 1). For the period between 15 August and 30 September there were approximately 30 nights where canopy temperatures were below 0°C, this period typically coinciding with growth stages of early stem elongation to flowering. These rolling frost events culminated in total cold load (paddock average) for this period ranging from 283 to 739 °C.hr < 0°C. Within each paddock, cold load varied substantially; in some cases, varying from 189 to 452°C.hr < 0°C across the six survey points.

Good agreement existed between intra-paddock cold load and yield, for four of the six paddocks surveyed, where there was a negative relationship for paddocks 2, 3, 4 and 5 (Figure 4). For paddock 2, the large yield range and strong negative correlation with cold load is likely linked with the substantial variation in topography across this paddock. In this case, changes in topography were associated with substantial changes in soil type; resulting in co-location of high cold loads with heavy soil types causing greater water stress in a year when growing season rainfall was decile 3. This co-location made it difficult to separate water stress from frost effects. Irrespective of this observation, a good agreement between yield and cold load was demonstrated in paddock 5, where the terrain was flat. For paddocks where there was no apparent link between yield

Table 1. Wheat yield (t/ha), minimum temperature (°C) (screen at 1.2m and crop canopy) and cold load (°C.hr < 0°C) for six commercial paddocks in 2018, Murtoa, Victoria. Intra-paddock range in values is defined in italics, which represent six points along a 750 metre transect. Minimum temperature and cold load are for the period between 15 August and 30 September.

Variable	Paddock					
	1	2	3	4	5	6
Yield	1.1	1.6	0.4	1.3	1.1	0.9
	0.8/1.3	*0.2/2.6*	*0.1/0.9*	*0.8/2.2*	*0.5/1.7*	*0.7/1.3*
Harvest index	0.21	0.27	0.11	0.19	0.26	0.22
	0.19/0.23	*0.05/0.42*	*0.04/0.18*	*0.10/0.29*	*0.17/0.38*	*0.16/0.31*
Screen min temp	-2.3	-3.7	-4.5	-3.4	-3.4	-5.2
Canopy min temp	-6.2	-5.1	-7.1	-6.3	-8.0	-9.4
	-5.2/-7.4	*-4.1/-7.3*	*-6.1/-7.8*	*-5.1/-7.7*	*-6.9/-9.1*	*-8.2/-10*
Cold load	413	283	436	423	617	739
	295/527	*189/452*	*357/496*	*310/522*	*473/745*	593/816

and cold load, it would be expected that factors other than canopy temperature (and/or soil type variation associated with topography) are having an overriding effect on yield e.g. pest and disease.

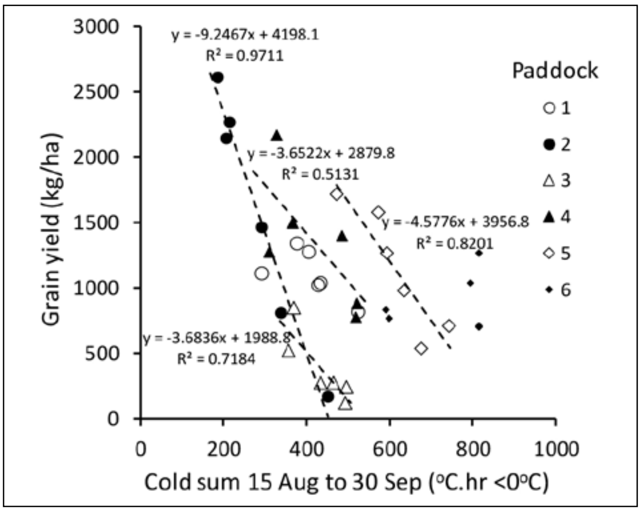

Figure 4. Intra-paddock relationship between wheat yield (kg/ha) and cold load (°C.hr <0°C) for six commercial paddocks in 2018, Murtoa, Victoria. Regression models describing intra-paddock fit between yield and cold load are for paddocks 2, 3, 4 and 5.

For paddocks 2, 3, 4 and 5, where yield and canopy cold load were correlated, there was also reasonable agreement with the reflectance indices NDRE, NDVI and PRI, these being correlated with both canopy cold load and crop yield (Table 2). For these paddocks, NDRE and NDVI were consistently negatively correlated with cold load and generally positively correlated with yield. For PRI, this relationship was less stable across paddocks when comparing cold load and yield. PRI has previously been shown to be positively correlated with cold load and negatively related to yield (Nuttall et al. 2018). The reverse pattern of PRI for paddock 5 may be due to artefact effects of previous seasons; canola stubble confounding reflectance in wave bands associated with PRI calculation, highlighting the need for ground truthing remotely sensed spatial information.

Using paddock 2 as a more detailed case study, since in this paddock there was the most consistent agreement between crop growth, cold load and indices. For this paddock, wheat yield was strongly correlated with NDRE (Figure 5a) and NDVI (Figure 5b) and negatively correlated with PRI (Figure 5c), which is consistent with the trend direction observed within controlled environment studies (Nuttall et al. 2018).

The spatial variation in PRI (or NDRE and NDVI) across paddock 2 can be used as a relative-surrogate to represent frost affected regions of crop and an opportunity for spatial management of crops for hay versus grain production (Figure 6). For 2018, the multiple heavy frosts up to crop flowering meant that this abiotic constraint is likely to have driven variation in yield across the landscape, where a single capture of remotely sensed data at flowering had utility for defining frost affected crops in four out of the six paddocks surveyed. For paddocks/regions/years where mild or discrete frost effects on crops are assessed with remote sensing tools, multiple sensor acquisitions may be required to isolate the change in crop reflectance signature associated with these short-term events. Common indices such as NDVI should also be used with caution, as their utility appears inconsistent across a range of frost related studies (Perry et al. 2017; Fitzgerald et al. 2019). This variable response may reflect the confounding effects of factors such as crop development and natural senescence, weeds and/or other constraints. The confluence of multiple indices (for example NDRE, NDVI and PRI) indicating

Table 2. Cold load, crop yield and crop spectral reflectance. Correlation (r) for reflectance-derived spectral indices taken from wheat canopies at around flowering and total cold load (°C.hr < 0°C) measured at the crop canopy between 15 August and 30 September, and wheat yield. Reflectance readings were taken on the 1 October using an Airphen® multispectral camera.

Spectral	Paddock					
	1	2	3	4	5	6
	Cold load (°C.hr < 0°C)					
NDRE	0.08	-0.98	-0.46	-0.20	-0.71	0.70
NDVI	-0.40	-0.97	-0.79	-0.23	-0.09	0.13
PRI	0.19	0.85	0.66	-0.43	-0.89	-0.54
	Wheat yield (kg/ha)					
NDRE	-0.19	0.96	0.36	0.72	0.61	0.38
NDVI	0.90	0.92	0.89	0.74	-0.06	0.50
PRI	-0.79	-0.90	-0.65	0.18	0.86	-0.19

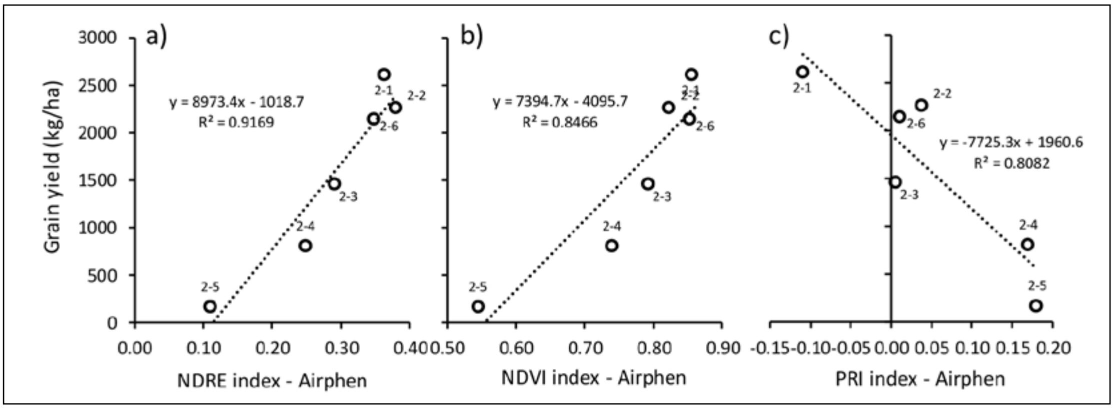

Figure 5. Relationship between wheat yield and Airphen® derived indices for a paddock (2) monitored near Murtoa, Victoria in 2018. Indices include a) normalised difference vegetation index (NDVI), b) normalised difference red edge (NDRE) and c) photochemical response index (PRI) derived from an Airphen® multispectral camera.

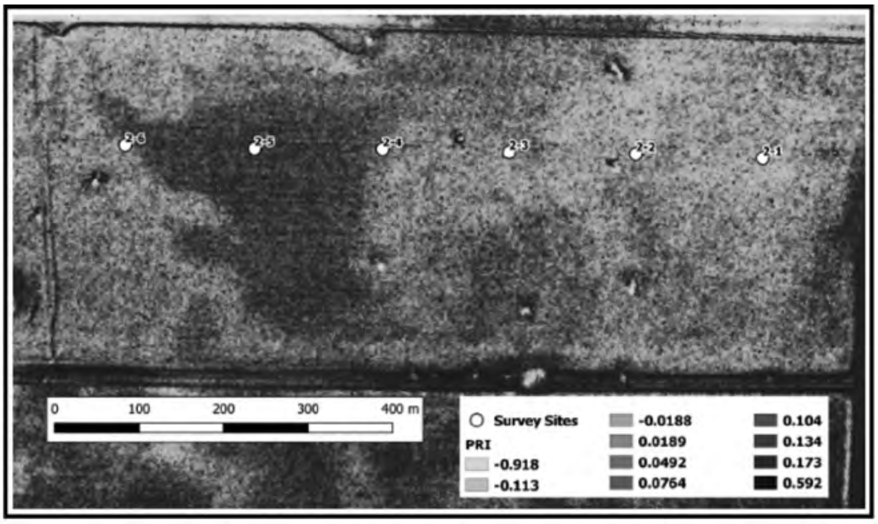

Figure 6. Spatial variation in the photochemical response index (PRI) across a wheat paddock (paddock 2) linked with crop frost damage. This represents an opportunity for spatial management of crops for hay versus grain production. Dark grey areas indicate low yielding zones and light grey areas are high yielding zones.

frost affected crops, may provide one multispectral method of estimating frost damage more reliably, or alternatively using a spectral mixture analysis approach to define new indices specifically targeted to frost response (Fitzgerald et al. 2019).

For remote sensing tools to have a practical application to industry, imagery needs to be captured at the paddock scale. For example, assessment of frost damage across whole-paddocks may be possible if several growers contract an aircraft equipped with a multi-spectral camera (e.g. Airphen®) to fly over multiple farms, making the process fast and affordable. Alternatively, spatial assessment using satellite (e.g. Sentinel 2) sensors may offer another approach, to support research and commercial opportunities (e.g. Flurosat Pty Ltd), although satellite obtained data may be limited by wave band and available indices. In both of these cases, the high-altitude platforms and large field-of-view takes away the complexity and error associated with 'stitching' overlapping images, which is required for sensors mounted on unmanned aerial vehicles (UAV) platforms. Ultimately, remote sensing tools may offer the opportunity to spatially manage frost affected crops. The next steps are to validate the proposed indices, identify other alternative indices (and determine their stability across different paddocks and seasons), quantify the economic benefit to growers and identify a commercial model that the industry may find attractive.

Conclusion

For wheat, where frost treatments were applied at flowering, grain number and yield were reduced by 8.8 and 7.2%, respectively, for every degree Celsius below zero (down to -4°C). This effect was additive over two consecutive nights. In terms of cold load, there was a 2.2 and 1.9% reduction in grain number and yield, respectively per °C.hr (below 0°C). The remote sensing spectral indices; PRI, NDVI and NDRE showed significant relationships with cold load and wheat yield over four of the six paddocks surveyed and represent an opportunity for spatial management of crops when considering hay versus grain production. Further investigation over multiple years, sites and crop growth stages is required to verify the stability and utility of these indices. Finally, the need for ground scouting to validate sensor derived information ahead of making a tactical management decision remains essential.

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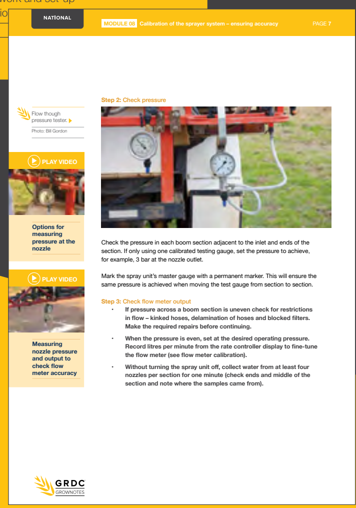

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Sustaining our herbicide options into the future

Christopher Preston.

School of Agriculture, Food & Wine, University of Adelaide.

GRDC project codes: UCS00024, UA00158

Keywords

- pre-emergent herbicide, annual ryegrass, broadleaf weeds.

Take home messages

- Resistance to pre-emergent herbicides is increasing across southern Australia.
- New pre-emergent herbicides are becoming available; however, it is vital that these are used appropriately to get the best results.
- Rotating pre-emergent herbicide modes of action and using other weed management practices will be essential to managing resistance to these new herbicides.

Resistance to pre-emergent herbicides in south-eastern Australia

Pre-emergent herbicides have become more important for the control of grass weeds, particularly annual ryegrass, in the past decade as resistance to post-emergent herbicides has increased. However, resistance to trifluralin is now common across many cropping regions of South Australia (SA) and Victoria (Vic) (Table 1). Worryingly, resistance to the Group J and K pre-emergent herbicides has also been detected in random weed surveys. In some parts of SA, resistance to triallate is also becoming common. This means that it will become more difficult to control annual ryegrass with the current suite of herbicides available.

New pre-emergent herbicides

There are several new pre-emergent herbicides coming to market in the next few years. As with previous recent introductions of pre-emergent herbicides, it is important to understand their best use in different environments and farming systems. Some of these products will be new modes of action, which will provide an opportunity to manage weeds with resistance to existing herbicides. However, it will be important to rotate these new herbicide modes of action to delay resistance.

Table 1. Resistance to pre-emergent herbicides in annual ryegrass populations from random surveys in South Australia and Victoria. Samples were considered resistant to a herbicide if more than 20% of individuals survived the herbicide application.

Herbicide	Trade name	South Australia				Victoria		
		Mid North	Mallee	Eyre Peninsula	South East	Wimmera/ Mallee	North East	Southern
		Samples resistant (%)						
Trifluralin	TriflurX®	62	39	34	41	31	0	2
Triallate	Avadex® Xtra	26	2	2	23	3	2	10
Prosulfocarb + S-metolachlor	Boxer Gold®	2	0	1	5	0	0	0
Prosulfocarb	Arcade®	2	0	1	5	-	1	0
Pyroxasulfone	Sakura®	0	1	0	5	0	0	0
Propyzamide	Edge®	0	0	0	0	0	0	0

Grass herbicides

Luximax

Luximax® from BASF is a new mode of action herbicide (currently Group Z), containing cinmethylin that is available from 2020. Luximax will be a pre-emergent herbicide for annual ryegrass control in wheat, but not durum. It will provide some suppression of brome grass and wild oats. In our trials, control of ryegrass is as good as Sakura®.

Cinmethylin has high water solubility and moderate binding to organic matter in soils. Cinmethylin will move readily into the soil with rainfall events but will be held up in soils with high organic matter. Less rainfall will be required to activate the herbicide similar to Boxer Gold® (prosulfocarb + S-metolachlor). Persistence of Luximax is generally good, but it degrades sufficiently quickly so that plant backs in subsequent years are not likely to be a problem.

Wheat is not inherently tolerant of cinmethylin, so positional selectivity (keeping the herbicide and the crop seed separate) is important. Knife-points and press-wheels are the only safe seeding system and the crop seed needs to be sown 3cm or deeper. Obtaining crop safety with Luximax will be challenging on light soils with low organic matter. Heavy rainfall after application can also see the herbicide move into the crop row and cause crop damage. Due to its behaviour, Luximax is not generally suitable for dry seeding conditions. Mixtures with trifluralin, triallate and prosulfocarb are good and can provide some additional ryegrass control; however, mixtures with Sakura, Boxer Gold or Dual Gold® are likely to cause crop damage and need to be avoided.

Overwatch™

Overwatch, active ingredient bixlozone, from FMC is a Group Q herbicide that will be available for 2021. Overwatch controls annual ryegrass and some broadleaf weeds and will be registered in wheat, barley and canola. Suppression of barley grass, brome grass and wild oats can occur.

Wheat is most tolerant to bixlozone, followed by barley and then canola. The safest use pattern will be incorporated by sowing (IBS) with knife-points and press wheels to maximise positional selectivity, particularly with canola. Some bleaching of the emerging crop occurs often, but in our trials, this has never resulted in yield loss. In situations where the crop grows poorly, for example, water logging, high root disease, etc., the crop may have more difficulty growing away from the initial bleaching effect.

The behaviour of Overwatch in the soil appears to be similar to Sakura. It needs moisture to activate and has low to moderate water solubility. The level of ryegrass control in our trials has been just behind Sakura. Mixtures with other herbicides can increase control levels and in our trials in the high rainfall zones, the mixture of Overwatch plus Sakura has been very good.

Ultro

Ultro, active ingredient carbetamide, from Adama is a Group E herbicide that will be available from 2021. Ultro will be registered for the control of annual ryegrass, barley grass and brome grass in all pulse crops.

Pulses are all tolerant of Ultro, so crop damage should be rare. Ultro provides the best control of annual ryegrass when used pre-emergent. Ultro has relatively high-water solubility, so is more effective on weeds like brome grass that tend to bury themselves in the soil. Persistence of Ultro is shorter than Sakura.

Persistence in the soil is medium; however, extended use of carbetamide in the pasture seed industry in the 1990s led to enhanced soil breakdown. This is unlikely to be a problem in grain production, as pulse crops are not grown every year. However, these soils also developed enhanced breakdown of propyzamide.

Devrinol-C

Devrinol-C, active ingredient napropamide, is a Group K herbicide from UPL registered in 2019. Devrinol-C is registered for annual grass weed control in canola.

Napropamide is not as water soluble as metazachlor (Butisan®) and has less movement through the soil. Canola has much greater tolerance to napropamide compared to metazachlor making its use much safer under adverse conditions. Devrinol-C offers an alternative pre-emergent herbicide to propyzamide or trifluralin for canola.

BAY167

BAY167 is an experimental product from Bayer. It will be a new mode of action, pre-emergent and early post-emergent herbicide for the control of grass and some broadleaf weeds in wheat and barley. Registration is expected in 2023.

The behaviour of this herbicide in the soil will be more similar to Sakura, compared to Boxer Gold. It will require more rainfall to activate and will have similar persistence to Sakura. It will most likely work best as a pre-emergent IBS herbicide. The timing of the early post-emergent application will be similar to Boxer Gold, at the 1 to 2-leaf stage of annual ryegrass. It will require more rainfall after application than Boxer Gold does, so the post-emergent application will be more suited to higher rainfall regions.

Broadleaf herbicides

Callisto®

Callisto, active ingredient, mesotrione is a pre-emergent Group H herbicide from Syngenta with expected registration in 2020. It will be registered as for IBS, knife-point press wheel use in wheat and barley. It will control a range of broadleaf herbicides including brassicas, legumes, capeweed and thistles.

Wheat is more tolerant than barley, **and in both cases**, positional selectivity is important for crop safety. Mesotrione has high water solubility and medium mobility in soils. High rainfall resulting in furrow wall collapse could result in crop damage. Callisto has moderate persistence with plant backs of only nine months, provided 250mm of rainfall has occurred. Callisto offers an alternative to post-emergent Group H herbicide mixtures, where early weed control is important.

Reflex®

Reflex, active ingredient fomesafen, is a Group G herbicide from Syngenta with expected registration in 2021. It will be registered pre-emergent and post-sowing pre-emergent (PSPE) in pulse crops for control of broadleaf weeds; IBS only in lentils. It will have similar weed spectrum to Terrain®, but will likely provide better control of brassicas, sowthistle and prickly lettuce.

Fomesafen has more water solubility than flumioxazin (Terrain), so will be more mobile in the soil. It does not bind tightly to organic matter. Pulse crop safety is good, except for lentils, which are most sensitive. Care will be needed in lentils on light soils with low organic matter. Fomesafen persistence is good; however, plant backs are expected to be nine months provided 250mm rainfall has occurred.

Voraxor

Voraxor, from BASF, contains the active ingredients trifludimoxazin and saflufenacil, which are both Group G herbicides. Voraxor will provide broadleaf weed control and some annual ryegrass control as a pre-emergent herbicide in cereals. It is expected to be registered in 2021.

Voraxor is a little more mobile in the soil compared to Reflex® and considerably more than Terrain. Voraxor will offer a broader spectrum of broadleaf weed control compared to Terrain and more annual ryegrass control. However, annual ryegrass control will not be as good as with current annual ryegrass pre-emergent standards. This means that it will be best used where broadleaf weeds are the main problem and annual ryegrass populations are very low. Grass pre-emergent herbicides cannot be tank mixed with Voraxor and will have to go out as a separate application.

Managing resistance to the new pre-emergent herbicides

The availability of new modes of action, particularly for annual ryegrass control, is a valuable aid to maintaining no-till in grain production. However, overreliance on any herbicide mode of action can lead to resistance. Some of the annual ryegrass populations with widespread resistance to other herbicides already have low level resistance to napropamide and bixlozone. In addition, there are an increasing number of Group H and Group G herbicides becoming available. Care needs to be taken to rotate herbicide modes of action through the cropping rotation to delay the onset of resistance. Other weed management practices such as crop competition, crop topping and harvest weed seed control should be employed where appropriate.

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

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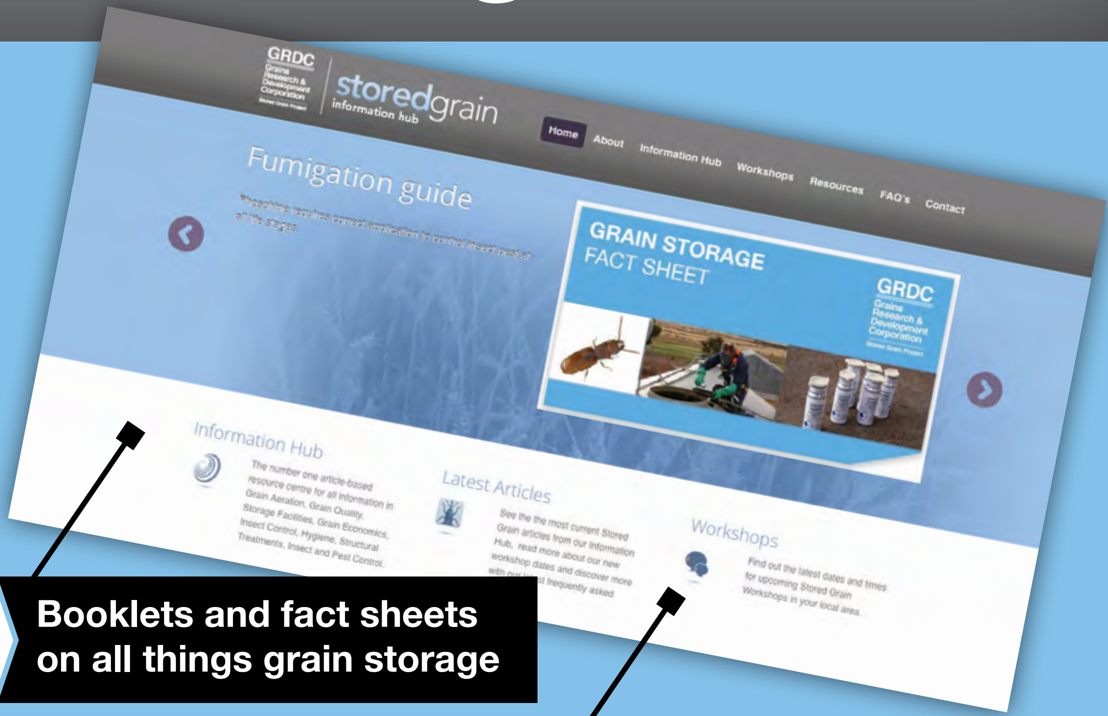

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Based at Lawloit, between Nhill and Kaniva in Victoria's West Wimmera, John, his wife Allison and family run a mixed farming operation across diverse soil types. The farming system is 70 to 80 percent cropping, with cereals, oilseeds, legumes and hay grown. John believes in the science-based research, new technologies and opportunities that the GRDC delivers to graingrowers. 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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Jon has worked in agriculture for the past three decades, both in the UK and in Australia. In 2004 he moved to Geelong, Victoria, and managed Grainsearch, a grower-funded company evaluating European wheat and barley varieties for the high rainfall zone. In 2007, his consultancy managed the commercial contract trials for Southern Farming Systems (SFS). In 2010 he became Chief Executive of SFS, which has five branches covering southern Victoria and Tasmania. In 2012, Jon became a member of the GRDC's HRZ Regional Cropping Solutions Network.

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Richard along with wife Lee-Anne, son Will and staff, grow wheat, canola, lentils and faba beans on some challenging soil types at Warooka on South Australia's Yorke Peninsula. They also operate a self-replacing Murray Grey cattle herd and Merino sheep flock. Sharing knowledge and strategies with the next generation is important to Richard whose passion for agriculture has extended beyond the farm to include involvement in the Agricultural Bureau of SA, Advisory Board of Agriculture SA, Agribusiness Council of Australia SA, the YP Alkaline Soils Group and grain marketing groups.

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Michael runs a collaborative family farming enterprise at Nile in the Northern Midlands of Tasmania (with property also in northern NSW) having transitioned the business from a dryland grazing enterprise to an intensive mixed farming enterprise. He has a broad range of experience from resource management, strategic planning and risk profiling to human resource management and operational logistics, and has served as a member of the the High Rainfall Zone Regional Cropping Solutions Network for the past seven years.

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KATE WILSON

Kate is a partner in a large grain producing operation in Victoria's Southern Mallee region. Kate and husband Grant are fourth generation farmers producing wheat, canola, lentils, lupins and field peas. Kate has been an agronomic consultant for more than 20 years, servicing clients throughout the Mallee and northern Wimmera. Having witnessed and implemented much change in farming practices over the past two decades, Kate is passionate about RD&E to bring about positive practice change to growers.

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Andrew is a forth generation grain grower and is currently the Managing Director and 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 the family farm in the Rutherglen area, a 2,500 ha mixed cropping enterprise and also runs 2000 cross bred ewes. Lilliput AG consists of wheat, canola, lupin, faba bean, triticale and oats and clover for seed, along with hay cropping operations. Andrew has been a member of GRDC's Medium Rainfall Zone Regional Cropping Solutions Network and has a passion for rural communities, sustainable and profitable agriculture and small business resilience.

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SOUTHERN/WESTERN REGION*

PREDICTA® B
KNOW BEFORE YOU SOW

*CENTRAL NSW, SOUTHERN NSW, VICTORIA, TASMANIA, SOUTH AUSTRALIA, WESTERN AUSTRALIA

Cereal root diseases cost grain growers in excess of $200 million annually in lost production. Much of this loss can be prevented.

Using PREDICTA® B soil tests and advice from your local accredited agronomist, these diseases can be detected and managed before losses occur. PREDICTA® B is a DNA-based soil-testing service to assist growers in identifying soil borne diseases that pose a significant risk, before sowing the crop.

Enquire with your local agronomist or visit http://pir.sa.gov.au/research/services/molecular_diagnostics/predicta_b

Potential high-risk paddocks:

- Bare patches, uneven growth, white heads in previous crop
- Paddocks with unexplained poor yield from the previous year
- High frequency of root lesion nematode-susceptible crops, such as chickpeas
- Intolerant cereal varieties grown on stored moisture
- Newly purchased or leased land
- Cereals on cereals
- Cereal following grassy pastures
- Durum crops (crown rot)

There are PREDICTA® B tests for most of the soil-borne diseases of cereals and some pulse crops:

- Crown rot (cereals)
- Rhizoctonia root rot
- Take-all (including oat strain)
- Root lesion nematodes
- Cereal cyst nematode
- Stem nematode
- Blackspot (field peas)
- Yellow leaf spot
- Common root rot
- Pythium clade f
- Charcoal rot
- Ascochyta blight of chickpea
- White grain disorder
- Sclerotinia stem rot

Government of South Australia
Primary Industries and Regions SA

SARDI
South Australian Research and Development Institute

GRDC
Grains Research & Development Corporation

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- The local GRDC Grains Research Update planning committee including both government and private consultants and GRDC representatives.

- Partnering organisation: Hart Field Site Group

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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/Balaklava-GRU

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.

2020 Balaklava 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 main 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**).

3. What's the cost of Harvest Weed Seed Control for you? ***Peter Newman***

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

[ ]

4. Use of chemicals and residues arising: ***Gerard McMullen***

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

[ ]

5. The hows and whys of deep ripping sandy soils: ***Brian Dzoma***

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

[ ]

6. Rapid post-event frost damage assessment - can it be achieved? ***Glenn Fitzgerald and Audrey Delahunty***

Content relevance [ ] /10 Presentation quality [ ] /10

Have you got any comments on the content or quality of the presentation?

[ ]

7. Integrating new chemistries in the field: *Chris Preston*

Content relevance ☐ /10 Presentation quality ☐ /10

Have you got any comments on the content or quality of the presentation?

Your next steps

8. Please describe at least one new strategy you will undertake as a result of attending this Update event

9. 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

10. This Update has increased my awareness and knowledge of the latest in grains research

Strongly agree	Agree	Neither agree nor Disagree	Disagree	Strongly disagree
❑	❑	❑	❑	❑

12. Do you have any comments or suggestions to improve the GRDC Update events?

13. Are there any subjects you would like covered in the next Update?

Thank you for your feedback.