GRAINS RESEARCH UPDATE

BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

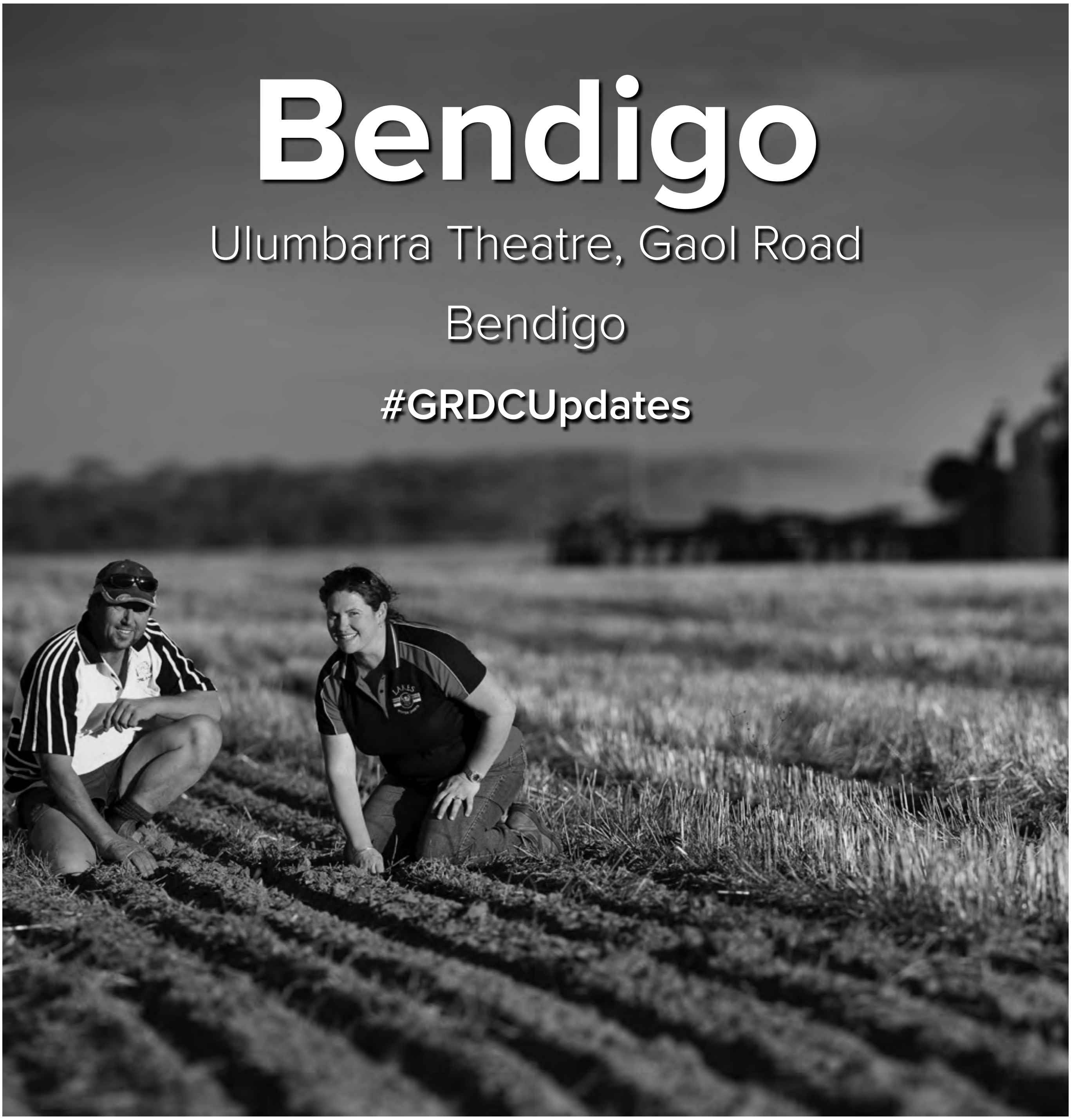
GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Bendigo

Ulumbarra Theatre, Gaol Road

Bendigo

#GRDCUpdates



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GRDC Welcome

Welcome to the 2019 GRDC Grains Research Updates

On behalf of the Grains Research and Development Corporation (GRDC), I have great pleasure in welcoming you to the 2019 Adelaide Grains Research Update.

As South Australia's premier grains research, development and extension (RD&E) forum, the annual Adelaide Update plays an important function in providing industry in this State with the latest insights and advice from the GRDC's broad portfolio of investments.

It is critical that growers and advisers are equipped with cutting-edge knowledge and resources to inform their tactical decision-making and guide them through the coming cropping season and beyond.

Very little stands still in this industry of ours. Grain production is an ever-evolving pursuit – constantly challenged by seasonal and market volatility and unpredictability.

The 2018 season was demonstrative of the implementation of R,D&E and evolution of modern grains farming systems that are able to capture yield opportunities and try to mitigate risk/ increase business resilience in a season with limited GSR for many, albeit frost continuing to be a challenge.

The adoption of new germplasm, focus upon time of sowing, implementation of practices which capture and retain soil moisture, and deployment of agronomic practices agile to seasonal yield potential are just a few factors enabling growers to achieve this – although constant innovation is required, especially in light of declining terms of trade.

It is therefore imperative that we never relent in seeking out advances in research and development that have the potential to enable growers to mitigate production risks and effect positive practice change on-farm for improved profitability.

To that end, this year's Adelaide Update program is rich in terms of both the relevant and impactful information to be delivered as well as the agronomic and technical experts who will lead these robust discussions.

I encourage all of you attending this event to use this opportunity get involved in the discussions, to explore the topics further and to go back to your farms, offices and workplaces armed with an intent to enact innovation, modification and transformation.

A desire for constant positive change – generating profitable, high-impact outcomes for growers – is also very much at the heart of the GRDC's investment agenda. That agenda is now being underpinned by the GRDC's new five-year RD&E Plan which was launched last year.

The plan is pivotal in GRDC's overall strategy to deliver on its purpose to invest in RD&E to create enduring profitability for Australian grain growers. Growers' long-term success and viability is necessary for a buoyant grains industry, vibrant regional communities and the health of the Australian economy.

The GRDC's priorities for investment in RD&E were determined through extensive consultation with industry as well as responses to the plan's discussion paper, largely from growers and advisers. These investment priorities centre on 30 Key Investment Targets that describe the constraints and opportunities required to be overcome or captured for impact at a grower level. If you would like to know more about the plan, go to https://grdc.com.au/rdeplan

As you may be aware, the GRDC in recent times has undergone significant transformation in terms of its organisational structure and operations.

Much of the focus of this change has been on building the GRDC's presence and capacity in the regions. A pleasing outcome of those endeavours is a GRDC southern office that is now staffed by a team of skilled personnel dedicated to engaging with and servicing the needs of growers, advisers, researchers and other grains industry stakeholders in the south.

I take this opportunity to encourage every person attending this Update to make yourselves known to the GRDC staff in attendance, as well as GRDC Southern Regional Panel and Regional Cropping Solutions Network members. If you have an idea or know of an issue that is not being addressed by way of GRDC investment, please bring it to our attention.

In the meantime, I hope you enjoy this Update program and I wish you every success for the season ahead.

Craig Ruchs

Senior Regional Manager South

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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

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Ulumbarra Theatre

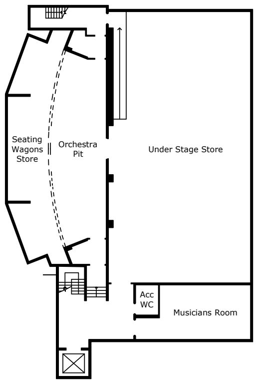
1 Entrance
2 Entrance Hall
3 Cloak Room
4 Box Office
5 Central Hall
6 Ground Floor Foyer
7 Bar
8 Female Toilet
9 Male Toilet
10 Accessible Toilet
11 Vestibule
12 Stalls Seating

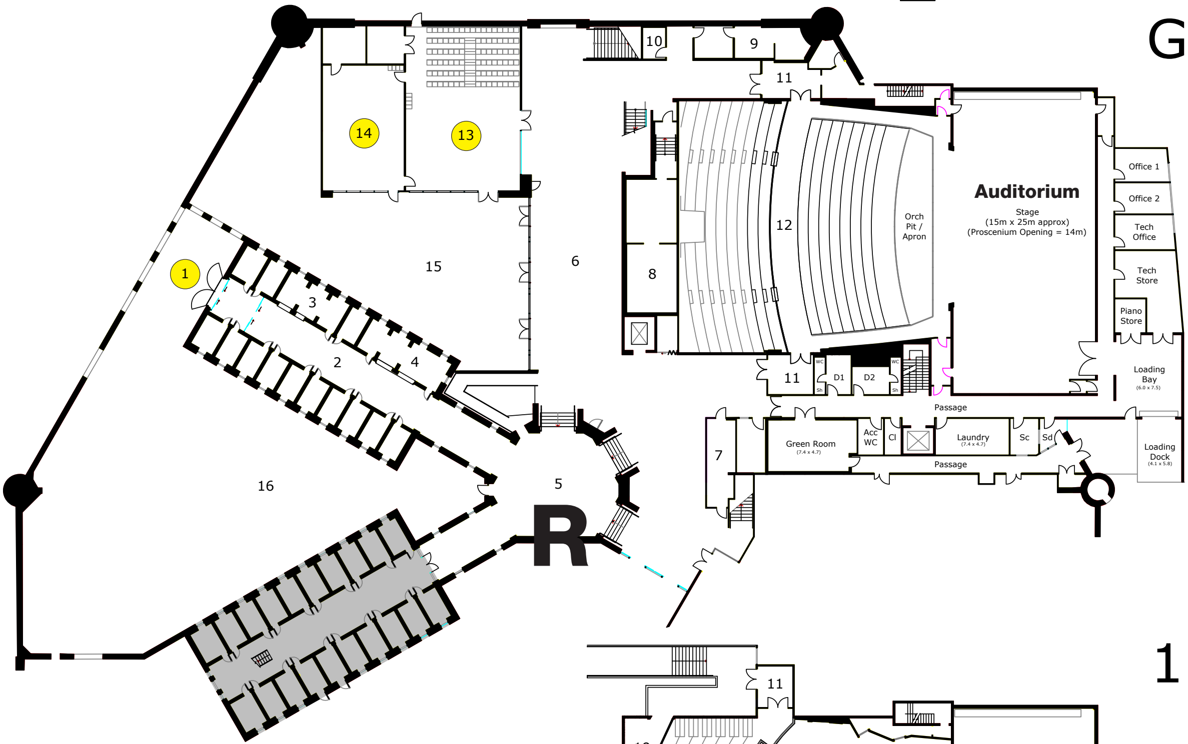
The GRDC Grains Research Update is being hosted in the Bendigo Ulumbarra Theatre this year.

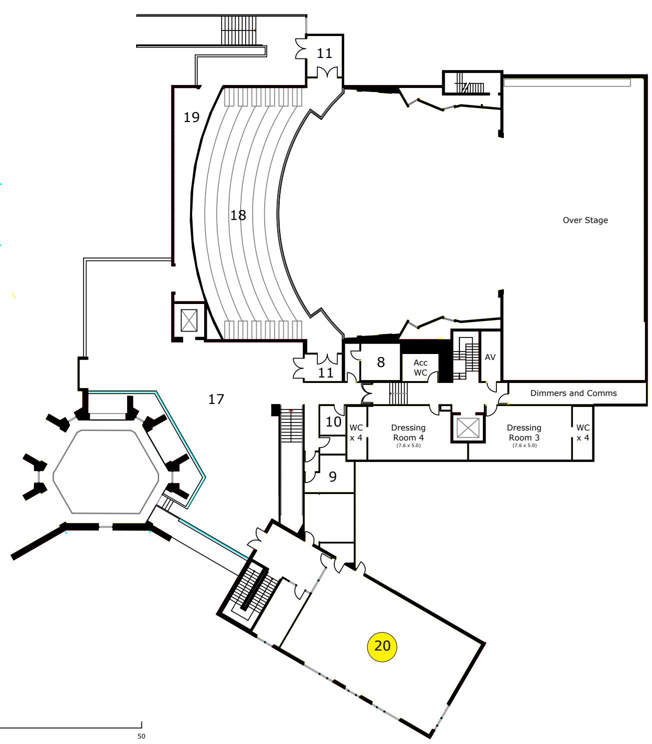
Please enter then venue at **Point 1** on the map.

Please walk down the hall until you reach the registration desk at Point **R**.

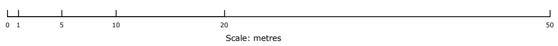
Presentations are in the **Auditorium**, **Room 13**, **14** and **20**. Trade & catering are at **Point 6** and **15**.







13 Strategem studio
14 Dance Studio
15 Performance Courtyard
16 Sculpture Courtyard
17 First Floor Foyer
18 Balcony Seating
19 Passage
20 Multipurpose Room
☒ Lift
D1 Dressing Room 1
D2 Dressing Room 2
Sh Shower
Cl Cleaners Store
Sc Security
Sd Stage Door



Contents — DAY 1

Contents — DAY 2

CONCURRENT SESSION

FINAL SESSION

FURTHER INFORMATION

EVALUATION

BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

PROGRAM DAY 1 - FEBRUARY 26th

8.55 am	**Announcements**	*ORM*
9.00 am	**Welcome and GRDC update**	*GRDC representative*
9.20 am	**National paddock survey - what is it telling us?** – P13	***Harm van Rees,*** *Cropfacts Pty Ltd*
9.55 am	**In-crop weed search and destroy technology** – P23	***Guillaume Jourdain,*** *Bilberry*
10.30 am	**Morning tea**	

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

	Auditorium	Dance Studio	Strategem Studio	Multipurpose Room
11.05 am	**Nitrogen and soil organic matter decline - what is needed to fix it? (R)** - P35 ***Jeff Baldock,*** *CSIRO*	**Statistics made sexy (R)** - P45 ***Dale Grey,*** *Agriculture Victoria*	**Herbicide residue in soil - what is the scale and significance (R)** - P53 ***Mick Rose,*** *NSW DPI*	**Fixing more N - improving the performance of inoculants in suboptimal conditions (R)** - P61 ***Liz Farquharson,*** *SARDI*
11.45 am	**Pest patrol – RQA under the spotlight (R)** - P69,71 ***Elia Pirtle,*** *cesar*	**Emerging management tips for early sown winter wheats (R)** - P83 ***James Hunt,*** *La Trobe University*	**Cost effective outcomes for ameliorating sandy soils (R)** - P91 ***Lynne Macdonald,*** *CSIRO*	**Canola - optimum management strategies (R)** - P99 ***Cam Taylor,*** *BCG*
12.25 pm	**Cereal and soil borne disease wrap up (R)** - P107 ***Grant Hollaway,*** *Agriculture Victoria*	**Herbicide residue in soil - what is the scale and significance** - P53 ***Mick Rose,*** *NSW DPI*	**Nitrogen and soil organic matter decline - what is needed to fix it?** - P35 ***Jeff Baldock,*** *CSIRO*	**Statistics made sexy** - P45 ***Dale Grey,*** *Agriculture Victoria*

1.00 pm **LUNCH**

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

	Auditorium	Dance Studio	Strategem Studio	Multipurpose Room
2.00 pm	**Sustaining our herbicides options into the future (R)** - P117 ***Chris Preston,*** *The University of Adelaide*	**Providing advice to growers - getting a healthy balance between care and responsibility (R)** - P123 ***Kate Burke,*** *Think Agri Pty Ltd*	**Fixing more N - improving the performance of inoculants in suboptimal conditions** - P61 ***Liz Farquharson,*** *SARDI*	**Pest patrol – RQA under the spotlight** - P69, 71 ***Elia Pirtle,*** *cesar*
2.40 pm	**Cereal and soil borne disease wrap up** - P107 ***Grant Hollaway,*** *Agriculture Victoria*	**Cost effective outcomes for ameliorating sandy soils** - P91 ***Lynne Macdonald,*** *CSIRO*	**Canola - optimum management strategies** - P99 ***Cam Taylor,*** *BCG*	**High rainfall zone research forum** **Hyper-yielding cereal project results, latest research from SFS trials and affect of waterlogging on N and water use by wheat** - P129, 135 & 137 ***Nick Poole,*** *FAR Australia;* ***Jon Midwood,*** *SFS;* ***Fiona Robertson,*** *Agriculture Victoria*
3.20 pm	**Providing advice to growers - getting a healthy balance between care and responsibility** - P123 ***Kate Burke,*** *Think Agri Pty Ltd*	**Sustaining our herbicides options into the future** - P117 ***Chris Preston,*** *The University of Adelaide*	**Emerging management tips for early sown winter wheats** - P83 ***James Hunt,*** *La Trobe University*	

3.55 pm **AFTERNOON TEA**

4.25 pm **Disentangling the soil amelioration and plant nutrition effects of subsoil manuring on crop yield** – P149 — ***Corinne Celestina,*** *PhD recipient*

4.35 pm **Potential value of damaged lentil seeds as a flour additive in baked products** – P155 — ***Drew Portman,*** *PhD candidate*

4.45 pm **Evidence and emotion - finding a new way forward for the grains industry** – P161 — ***Richard Heath,*** *Australian Farm Institute*

5.25 pm **COMPLIMENTARY DRINKS IN TRADE DISPLAY AREA**

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BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

PROGRAM DAY 2 - FEBRUARY 27th

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

	Auditorium	Dance Studio	Strategem Studio	Multipurpose Room
9.00 am	**Fungicides strategies in canola - achieving yield responses to foliar application (R)** - P173 ***Steve Marcroft,*** *Marcroft Grains Pathology*	**Mice - status, baiting and forecast threat (R)** - P181 ***Steve Henry,*** *CSIRO*	**Liming and limes - managing soil acidity (R)** - P187 ***Lisa Miller,*** *SFS*	**Sowing into stubble - impact on crop development (R)** - P199 ***Michael Straight,*** *FAR Australia*
9.40 am	**Insects – tools for forecasting risks to enable proactive management (R)** - P205 ***James Maino,*** *cesar*	**Relative importance of different factors on WUE of wheat in western Victoria (R)** - P213 ***Roger Armstrong,*** *Agriculture Victoria*	**Understanding alphabet resistant annual ryegrass - where to from here (R)** - P223 ***Peter Boutsalis,*** *The University of Adelaide*	**Weed research - chaff lining weed persistance and site specific targeted tillage (R)** - P229 ***Mike Walsh,*** *The University of Sydney*
10.20 am	**MORNING TEA**			
10.50 am	**Nitrogen placement application methods - effects on yield, protein and nitrogen use efficiency (R)** - P239 ***Ash Wallace,*** *Agriculture Victoria*	**Mice - status, baiting and forecast threat** - P181 ***Steve Henry,*** *CSIRO*	**Fungicides strategies in canola - achieving yield responses to foliar application** - P173 ***Steve Marcroft,*** *Marcroft Grains Pathology*	**Sowing into stubble - impact on crop development** - P199 ***Michael Straight,*** *FAR Australia*
11.30 am	**Pulse agronomy forum** **Key learnings from the pulse agronomy project including frost response, IMI-tolerance and pulse disease update** - P245, 259 ***Josh Fanning, Jason Brand and Audrey Delahunty,*** *Agriculture Victoria*	**Insects – tools for forecasting risks to enable proactive management** - P205 ***James Maino,*** *cesar*	**Liming and limes - managing soil acidity** - P187 ***Lisa Miller,*** *SFS*	**Understanding alphabet resistant annual ryegrass - where to from here** - P223 ***Peter Boutsalis,*** *The University of Adelaide*

CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

	Auditorium	Dance Studio	Strategem Studio	Multipurpose Room
12.10 pm	**Pulse agronomy forum** **Key learnings from the pulse agronomy project including frost response, IMI-tolerance and pulse disease update** - P245, 259 ***Josh Fanning, Jason Brand and Audrey Delahunty,*** *Agriculture Victoria*	**Weed research - chaff lining weed persistance and site specific targeted tillage** - P229 ***Mike Walsh,*** *The University of Sydney*	**Nitrogen placement application methods - effects on yield, protein and nitrogen use efficiency** - P239 ***Ash Wallace,*** *Agriculture Victoria*	**Relative importance of different factors on WUE of wheat in western Victoria** - P213 ***Roger Armstrong,*** *Agriculture Victoria*

12.50 pm **LUNCH**

1.30 pm **Pesticides and regualtory impacts - the road ahead** – P269 ***Gordon Cumming,*** *GRDC*

2.10 pm **Integrated weed management status - where to from here?** – P277 ***Peter Newman,*** *AHRI & Weedsmart*

2.50 pm **CLOSE AND EVALUATION**

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GROWNOTES

SPRAY APPLICATION GROWNOTES™ MANUAL

SPRAY APPLICATION MANUAL FOR GRAIN GROWERS

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

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

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

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

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

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National Paddock Survey – closing the yield gap and informing decisions

Harm van Rees[1], Kelly Angel[2], Craig Muir[3], Jeremy Whish[4], Elizabeth Meier[4], David Gobbett[4], Roger Lawes[4], Chao Chen[4], Tim McClelland[5], Stephen van Rees[6], Vicki Lane[6], Alan McKay[7], Steven Simpfendorfer[8].

[1]Cropfacts/BCG; [2]BCG; [3]AGRIvision; [4]CSIRO; [5]Model Agronomics/BCG; [6]SquareV; [7]SARDI; [8]NSW DPI.

GRDC project code: BWD00025

Keywords

- potential yield, yield gap, limiting factors, APSIM, WUE.

Take home messages

(from work undertaken on 16 paddocks in north west (NW) Victoria, 2015 to 2018)

- Intensive monitoring of soils and crops over a rotation sequence has identified why crops do not achieve their potential yield.
- Reviewing paddock performance at the end of the season and using paddock records are essential for sustained improvement in agronomic performance. The average yield gap of wheat and barley over four years of monitoring in the southern Mallee and Wimmera was 22%.
- Over the four-year rotation, 32 paddock zones were intensively monitored (128 paddock zone records). Out of these, 56 paddock zones were planted to wheat and barley, and 14 to canola. 2016 and 2017 were generally wet years with above average crop yields. 2015 and 2018 were dry with low yields. Insufficient nitrogen (N) was the main cause for the yield gap in 15 paddock zones, with the majority occurring in 2016. No N deficiencies were recorded in 2018. Diseases, weeds and insects also contributed, but were less severe in impact. Frost and heat shock were also significant causes of the yield gap, particularly in 2017 and 2018.

Background

Yield gap is the term applied to the difference between achieved and potential yield, where potential yield is estimated from simulation models. On average, Australia's wheat growers are currently estimated to be achieving about half their water-limited potential yield (Hochman et al. 2016, Hochman and Horan, 2018). Previous research with individual growers in the Wimmera/Mallee in Victoria determined that the long-term yield gap for those growers was approx. 20% (van Rees et al. 2012). For a national overview of the estimated yield gaps, see www.yieldgapaustralia.com.au

The National Paddock Survey (NPS) is a four-year (2015 to 2018) GRDC supported project designed to quantify the yield gap on 250 paddocks nationally and to determine the underlying causes. Further, its aim is to establish whether management practices can be developed to reduce the yield gap to benefit farm profitability. The project aims to provide growers and their advisers with information and the tools required to close the yield gap.

Method

Nationally, 250 paddocks, 80 in each of Western Australia (WA) and northern New South Wales (NSW)/Queensland, and 90 in southern NSW, Victoria and South Australia (SA), were monitored intensively over a four-year rotation (2015 to 2018). Consultants and Farming Systems groups undertook the monitoring. Two zones in each paddock were monitored at five geo-referenced monitoring points along a permanent 200m to 250m transect. Each monitoring point was visited four times per season (pre-season and post-season soil sampling and in-crop at the equivalent crop growth stages of GS30 and GS65). Yield map data was obtained for each paddock which enabled the yield of each zone to be determined accurately. Table 1 lists the annual monitoring undertaken in each zone.

All paddocks were simulated with the Agricultural Production Systems sIMulator (APSIM) (Holzworth et al. 2014) and, during the season, Yield Prophet® was available to all consultants and growers.

The whole data set (four years x 500 paddock zones) is being analysed by Roger Lawes, CSIRO, for factors primarily responsible for the yield gap in each of the three GRDC regions (Lawes et al. 2018).

This paper outlines the results of sixteen paddocks monitored by two consultants, Kelly Angel from the Birchip Cropping Group (BCG) and Craig Muir from AGRIvision working in the southern Mallee and Wimmera, Victoria. The results are discussed as a paddock specific yield gap analysis over four seasons focused on outcomes for the grower and the consultant.

Results are presented as the modelled APSIM simulations in which:

- Ya = Actual yield (as determined for each zone from yield map data).
- Ysim = Simulated yield (for the same conditions as those in which the crop was grown).
- Yw= Simulated water limited, N unlimited yield (for the same conditions as those in which the crop was grown, but with N supply unlimited). Yw is considered the potential yield for the crop.

Note: *APSIM currently accurately simulates wheat, barley and canola. We have not attempted to simulate the other crop types grown (lupins, lentils, faba beans, chickpeas, vetch, field peas).*

The yield gap is calculated as the % difference between Yw and Ya using the equation ((Yw-Ya)/Yw).

Data was entered via the NPS website and stored in a purpose-built SQL Server database.

Results and discussion

Annual individual paddock results

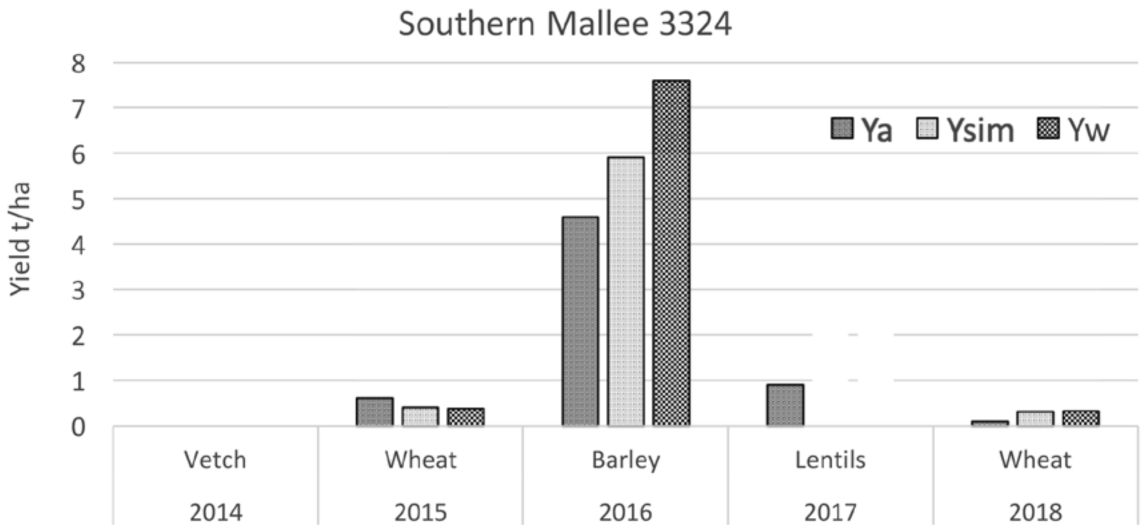
Data from four paddocks in the Victorian southern Mallee and Wimmera are presented as examples of outputs as informed by the paddock monitoring.

Table 1. Overview of monitoring and data collected per zone for each NPS paddock.

Monitoring	Timing	Monitoring	Timing
Deep soil test 4 depths (0-100cm)	Pre-sow	Paddock yield and yield map data	Post-harv
PREDICTA® B (0-10cm)	Pre-sow	Crop density, weeds, foliar diseases, insects (/m^2)	GS30
Deep soil test 4 depths (0-100cm)	Post-harv	Cereal root sample to CSIRO	GS30
Crop and variety		Weeds, foliar diseases, insects/m^2)	GS65
Sowing date and rate		Cereal stubble/crown for Fusarium	Post harv
Fertiliser, herbicide type, rate, date		General observations	
Temp buttons (1 per paddock)	GS60-79		

Example 1. Rotation southern Mallee: Vetch (2014), followed by wheat, barley, lentils, wheat.

Paddock southern Mallee. NPS 3324 Zone A: sandy clay loam
Ya=Actual yield; Ysim=Simulated yield; Yw=Water limited N unlimited yield (potential yield).



Paddock and crop information over the rotation. (Note - nd is 'not detected')
N available* 2015 (following vetch): 68kg/ha N available 2016 (following wheat): 124kg/ha
N available 2017 (following barley): 60kg/ha N available 2018 (following lentils): 56kg/ha
Water available# 2015: 16mm Water available 2016: 143mm
Water available 2017: 102mm Water available 2018: 16mm

*Note: * N available = pre-sowing # Water available = water pre-sowing*

Disease
PREDICTA® B: 2015 Fusarium & YLS Mod
2016 TakeAll & YLS Mod
Root health GS30: 2016 Mod disease level
Fusarium stubble: 2015 not observed
2016 v low
In-crop GS65: not detected
Weeds In-crop GS65: not detected
Insects: not detected

Days of heat and frost during GS60-79

Heat	> 34°C	Frost 0 to -2°C	-2 to -4°C
2015	2	0	0
2016	0	1	0
2017	0	1	0
2018	1	0	0

(note: temperature records from nearest BoM)

Interpretation

Crop 2014: Vetch

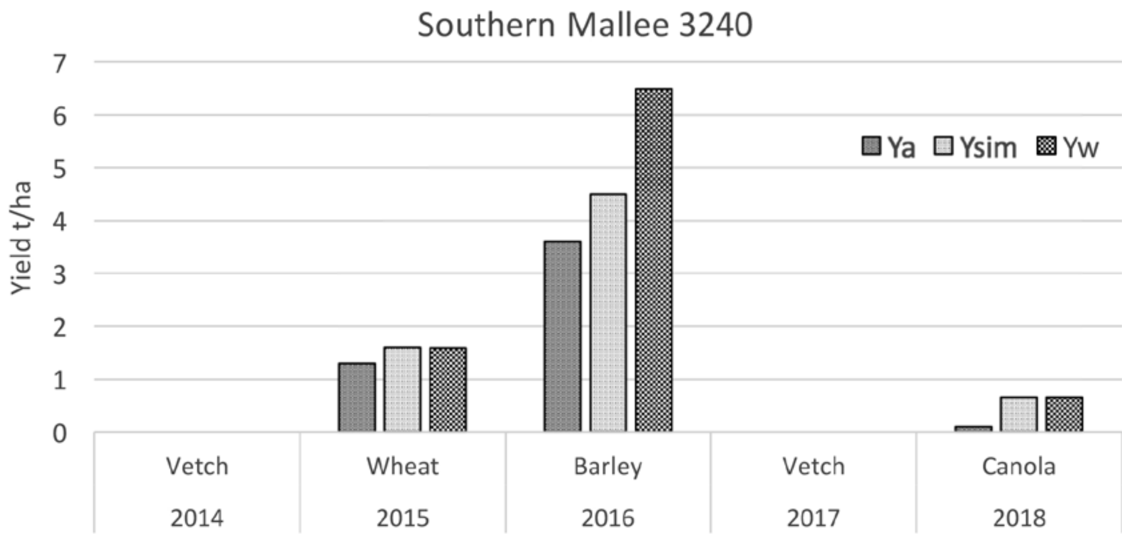
Wheat 2015: Very low yield, in-crop rain 148mm (Decile 1 season).

Barley 2016: Ya<Ysim<Yw. N unlimited yield (Yw) was 1.5t/ha higher than the simulated yield (Ysim), indicating the crop was N deficient. Ya<Ysim indicates that factors other than N had an impact on the crop, possibly moderate levels of disease, and one frost event during flowering/grain filling.

Wheat 2018: Very low yield, in-crop rainfall 131mm (Decile 1 season).

Example 2. Rotation southern Mallee: Vetch (2014), followed by wheat, barley, vetch, canola.

Paddock southern Mallee. NPS 3240 Zone A: sandy clay loam
Ya=Actual yield; Ysim=Simulated yield; Yw=Water limited N unlimited yield (potential yield).



Paddock and crop information over the rotation. (Note - nd is 'not detected')
N available* 2015 (following vetch): 103kg/ha. N available 2016 (following wheat): 61kg/ha
N available 2018 (following vetch) : 115kg/ha
Water available# 2015: 32mm Water available 2016: 53mm Water available 2018: 11mm

*Note: ** N available = soil N pre-sowing   # Water available = soil water pre-sowing*

Disease
PREDICTA® B: 2015 Rhizo, Bipolaris, YLS Mod
2016 Rhizo, Bipolaris High
YLS, Prats Mod
2018 Rhizo, YLS High
Bipolaris, Prats Mod
Root health GS30:
2015 Mod; Rhizo Low, Prats Mod
2016 High; other High
Fusarium stubble:
2015 low to mod
2016 mod (Fusarium 40% stems)
Disease in-crop GS65: 2016 Fusarium low
Weeds in-crop GS65:
2015 Rye 2, Brome 32/m^2
2016 Rye 9, Wheat 22, Brome 21/m^2
2018 nd
Insects: nd

Days of heat and frost during GS60-79

Heat	> 34°C	Frost 0 to -2°C	-2 to -4°C
2015	0	0	0
2016	1	2	0
2018	0	0	0

(note: temperature records in paddock)

Consultant observations:
2015: brome grass throughout
2016: head loss 380kg/ha
2017: heavy grazing
2018: stand thin and drought stressed

Interpretation

Crop 2014: vetch

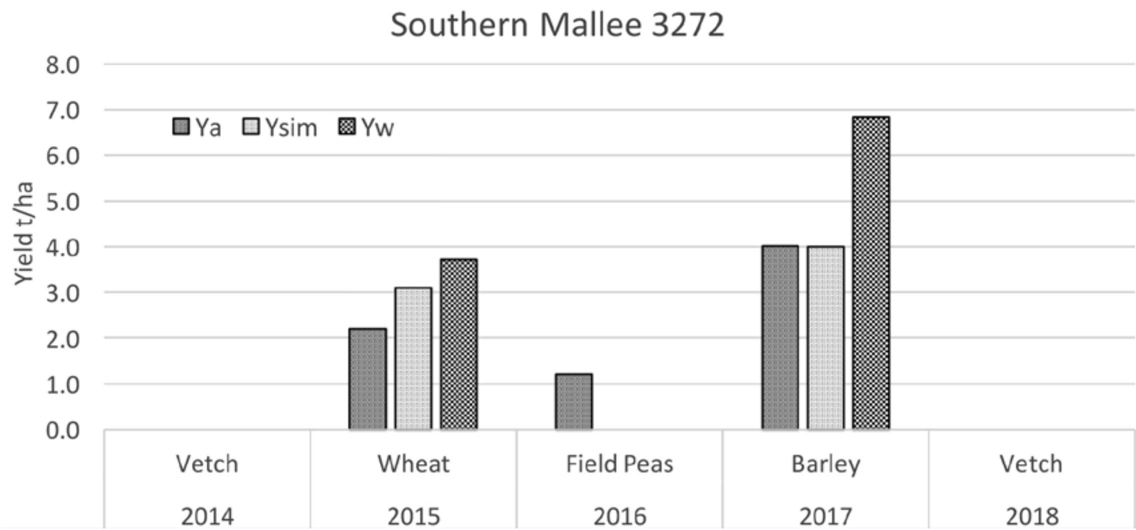
Wheat 2015: Ya=Ysim=Yw. Crop not limited by biotic stress. Dry season: 135mm in-crop rainfall (Decile 1).

Barley 2016: Ya<Ysim<Yw. N was limiting (Ysim<Yw). Fusarium was at moderate levels (stubble assessment), some weed pressure and frost were recorded during flowering. Head loss was noted by the consultant.

Canola in 2018: Ya<Ysim=Yw very poor crop in drought year (108mm in-crop rainfall, Decile 1).

Example 3. Rotation vetch brown manure (2014), followed by wheat, field peas, barley, vetch.

Paddock Southern Mallee, Victoria. NPS 3272 Zone A: sandy loam
Ya=Actual yield; Ysim=Simulated yield; Yw=Water limited N unlimited yield (potential yield).



Paddock and crop information over the rotation. (Note - nd is 'not detected')
N available* 2015 (following vetch): 152kg/ha.   N available 2016 (following wheat): 112kg/ha
N available 2017 (following field peas): 126kg/ha
Water available# 2015: 59mm   Water available 2016: 1mm Water available 2017: 116mm
*Note: * N available = soil N pre-sowing   # Water available = water pre-sowing*

Disease
PREDICTA® B: 2015 Rhizoc, YLS, Pyth. mod
2016 Rhizoc, YLS high, Pyth mod
2017 Rhizoc, YLS, Pyth mod
Root health GS30: 2015, 2017 Low to Mod
2017 Rhizoc Mod
Fusarium stubble: nd
Disease in-crop GS65: 2015 YLS low
2016 Ascoch. mod; 2017 SFNB low
Weeds
in-crop GS65: 2015 Brome 5/m^2
2016 Brome 2, Must. 2/m^2
2017 nd
Insects GS65: 2015 oat aphid 80
2016 oat aphid 38

Days of heat and frost during GS60-79

Heat	> 34°C	Frost 0 to -2°C	-2 to -4°C
2015	3	2	0
2016	0	4	0
2017	0	4	0

(note: temperature records in the paddock and BoM)

* Pythium root rot: all crops/pastures
Canola/pulses susceptible. Cereals less so.

Interpretation

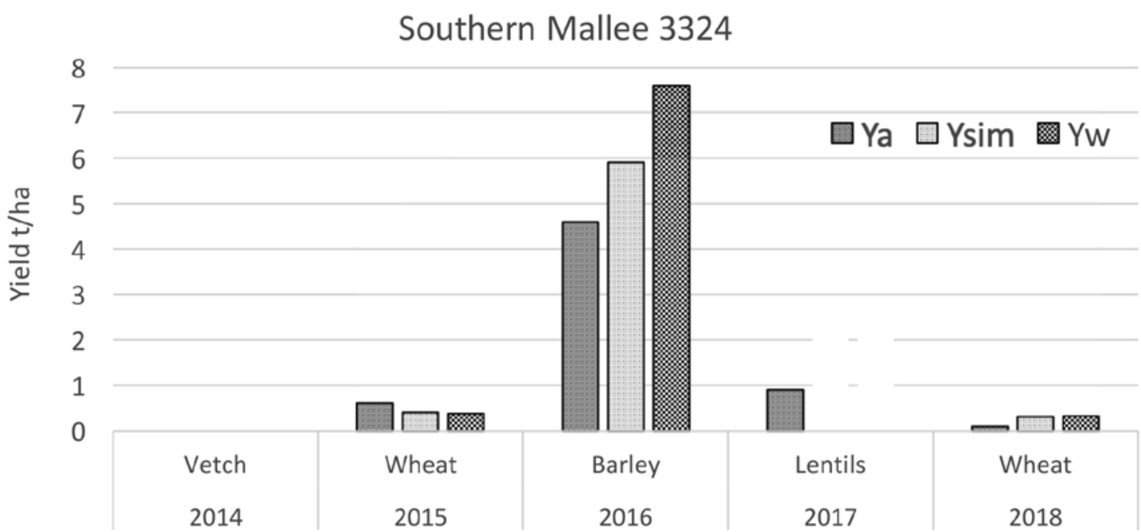
Crop 2014: vetch

Wheat 2015: Ya<Ysim<Yw crop was N limited (indicated by Ysim<Yw). Ya<Ysim may have resulted from the presence of moderate soil disease levels and some brome grass, two frost events occurred during flowering and grain filling.

Barley 2017: Ya<Ysim=Yw crop is N limited. Other factors did not contribute to a yield penalty (even though frost occurred during flowering in 2017).

Example 4. Rotation wheat (2014), followed by barley, vetch hay, canola, barley.

Paddock Wimmera, Victoria. NPS 3271 Zone B: self-mulching black clay
Ya=Actual yield; Ysim=Simulated yield; Yw=Water limited N unlimited yield (potential yield).



Paddock and crop information over the rotation. (Note - nd is 'not detected')
N available* 2015 (following wheat): 73kg/ha. N available 2017 (following vetch): 177kg/ha
N available 2018 (following canola) : 95kg/ha
Water available# 2015: 38mm Water available 2017: 146mm Water available 2018: 17mm

*Note: * N available = soil N pre-sowing # Water available = water pre-sowing*

Disease
PREDICTA® B: 2015,16,17 Fusarium High,
Take-all Mod, Pythium Mod
Root health GS30: 2016, 2017 Low to Mod
2017 Fusarium Mod
Fusarium stubble: 2015 low
Disease in-crop GS65: nd
Weeds
in-crop GS65: 2015 Ryegr. 3/m^2,
2016 Sow thistle 6/m^2
Insects GS65: nd

Days of heat and frost during GS60-79

Heat	> 34°C	Frost 0 to -2°C	-2 to -4°C
2015	0	3	0
2017	0	3	0
2018	0	2	0

(note: temperature records from nearest BoM)

* Pythium root rot: all crops/pastures
Canola/pulses susceptible. Cereals less so.

Interpretation

Crop 2014: wheat

Barley 2015: Ya<Ysim<Yw crop was N limited (indicated by Ysim<Yw). Ya<Ysim may have resulted from the presence of Fusarium (detected on the stubble) and three frost events during flowering and grain filling.

Canola 2017: Ya<Ysim=Yw crop is not N limited. The root disease Pythium was at moderate levels in the soil and three frost events occurred during flowering and grain filling.

Barley 2018: Ya=Ysim=Yw indicating the crop grew to potential.

Assessing crop performance: Water use efficiency versus modelling

The first paper on water use efficiency (WUE) was published by French and Schultz in 1984. It was a breakthrough at the time, enabling growers and agronomists to benchmark crop performance against a target and compare performance against other wheat crops. The French and Schultz WUE equation has since been updated by Sadras and Angus, 2006, and Hunt and Kirkegaard, 2012

Hunt and Kirkegaard, 2012, calculate crop water use as: Soil water pre-sowing – soil water post-harvest + rainfall during the same period. WUE is then calculated as yield (kg/ha) / (crop water use - 60). Potential yield is calculated as 22 x (crop water use – 60).

The 2015 to 2017 Southern Mallee and Wimmera NPS cereal yields are plotted against crop water use in Figure 1. The graph reveals a general tendency for Ya to increase with crop water use with an upper boundary of yield. The upper boundary is reasonably interpreted as Yw for well-managed crops as crop water use increases. The two lines included on the diagram are the Yw lines proposed by French and Schultz, 1984, and Sadras and Angus, 2006, to describe the most efficient use of water. This establishes a common maximum WUE of 22kg/mm/ha.

How useful is WUE compared with computer modelled assessments of potential yield, and what will the future hold?

Figure 1 and other data analysed by French and Schultz (1984) and Sadras and Angus (2016) demonstrate a considerable variation in Ya relative to Yw, i.e. a considerable yield gap in many crops. Key questions for growers and agronomists are what is the cause of the yield gap in each individual case and how can it be alleviated?

There are many possible causes that cannot be identified without careful paddock monitoring of abiotic and biotic factors, as attempted in the present project.

We must remember that using WUE to assess yield potential is a bucket approach to a complex problem in a system with many interactions. WUE will not explain the causes of a yield gap, nor can it inform on reasons for favourable outcomes. It may identify the presence of a yield gap, but not the underlying cause(s).

Causes of yield gaps

Abiotic factors

Variability is a feature of farming in Australia and there are several reasons why crop roots cannot access soil water and nutrition such as

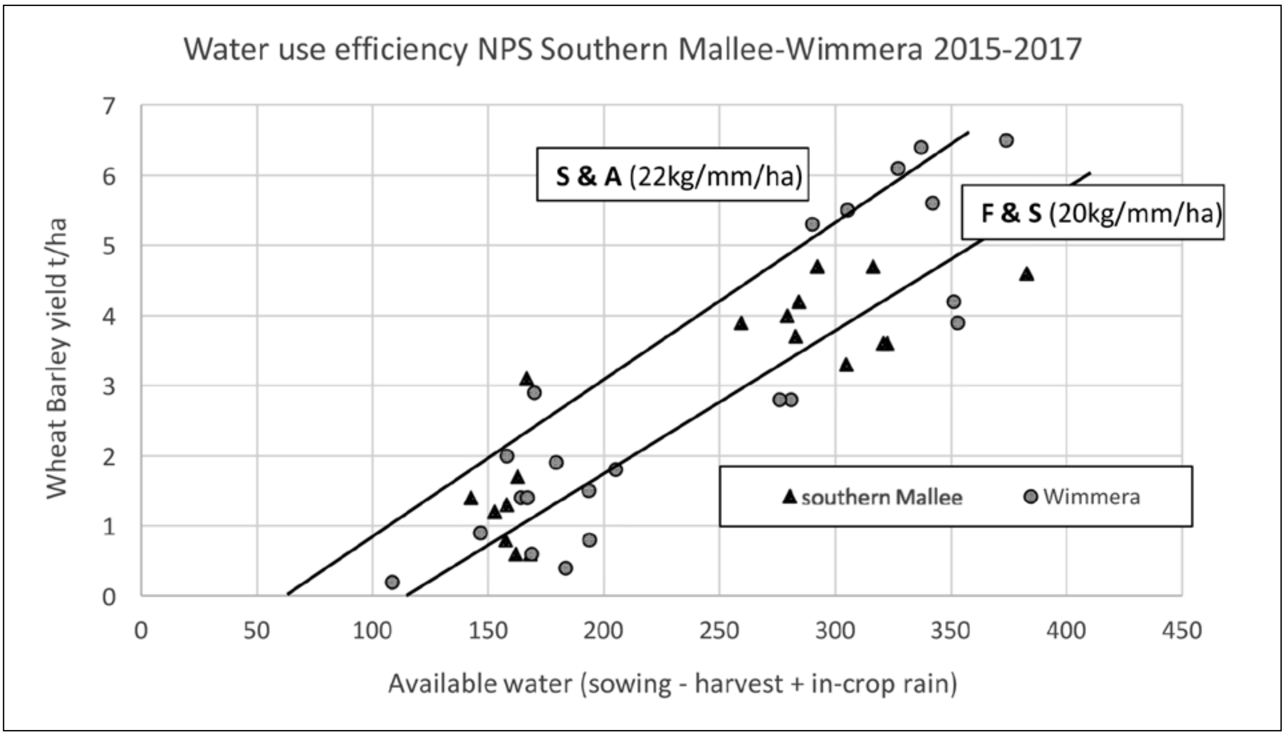


Figure 1. NPS – Southern Mallee - Wimmera cereal yields (Ya) plotted against water use (2015 to 2017).

soil type (texture) and physical and chemical limitations. Chemical and physical constraints to root development can have a large impact on potential yield such as high soil chloride levels in the southern Mallee. Frost and heat shock are two other abiotic factors which can have a large impact on crop yield.

Interactions between soil type, available soil water and the amount of water extracted by the growing crop are influenced by crop growth and the distribution and amount of rainfall. If these factors are ignored, there is limited predictive capability of yield.

Crop nutrition appropriate to achieving potential yield (Yw) is relatively well understood and in the case of N, with many examples of successful tactical responses to fertilisation. But this is not matched for other nutrients such as phosphorus (P) and potassium (K), and micronutrients such as zinc (Zn).

Biotic factors

Major infestations of weeds, pests and diseases can cause yield loss and less serious infestations may cause greater losses than is commonly appreciated and remain unknown without careful paddock monitoring.

The nature of these biotic causes of yield loss varies greatly from site to site, paddock to paddock and also within paddock.

Going forward with crop simulation models

Crop models, such as APSIM used in this study, are focused on abiotic factors, but include biotic factors such as N nutrition. Their objective is to simulate yield (Ysim) in the absence of biotic factors such as weeds, diseases and pests and to estimate Yw by removing the effect of N shortage. For this, APSIM grows the crop on a daily time step and takes into account daily solar radiation, rainfall and availability of N. It uses soil-specific information for crop lower limit (CLL) (wilting point) of the soil, defined as the soil water content below which water is not accessible to the crop. CLL is influenced by soil texture (sand, silt, clay content) and subsoil limitations (such as high chloride levels). APSIM also explains the importance of rainfall distribution in terms of growth reductions due to transient water stress. Extreme events of temperature (hot and cold), which may be important at less-than daily time scales, need to be further addressed.

Over the past decade, the industry has made huge advances in engineering, with precision agriculture enabling mapping of soil types across paddocks, understanding what affects the ability of crops to extract water and most importantly empowering growers to adopt precision seeding and to apply nutrients as required.

To fully utilise the power of crop models, on-the-go modelled outputs need to be incorporated into field operations such as seeding and nutrient applications. This could well be the next frontier in crop management. Biotic stresses such as weeds, diseases and pests can be included if the appropriate in-field observations are made.

The NPS project has demonstrated that, as crop management becomes more sophisticated, it is essential to understand the reasons why crops fail to perform at their potential. When we understand the reasons why crops do not reach their potential yield, we can better advise the growers we are working with.

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Green on green camera spraying - a game changer on our doorstep?

Guillaume Jourdain.

Bilberry.

Keywords

- green on green, camera spraying, spot spraying, technology

Take home messages

- Green on green camera technologies is now used on farms. This will lead to important financial benefits for growers but will also have impacts on farm management.
- Growers need to understand the benefits but also the limitations of these new technologies. This is the only way it will bring real benefits.

Overview of vision systems for spraying and identifying weeds

In this paper, we will only focus on systems embedded on sprayers or spraying equipment, and thus we will not talk about drones. Drones are a very interesting technology, however there are current limitations on their convenience of use such as regulation, the need for a pilot, necessity of good weather conditions (no wind or rain), and ground resolution is often not as high as with embedded sensors.

Systems on the market and their limitations

Two optical camera systems to spray weeds have been on the market for several years, WEEDit and WeedSeeker. These systems are now commonly used in Australia for green on brown applications. Previous analysis of these can be found in a GRDC Update paper:

https://grdc.com.au/__data/assets/pdf_file/0015/117231/pa-in-practice-ii-incrop.pdf.pdf

and here is a link to a factsheet from the Australian Society of Precision Agriculture, SPAA:

https://spaa.com.au/pdf/456_9056_SPAA_fact_sheet_(Weed_Sensing)_A4.pdf

Summary of key facts for these sensors

- Active sensors – chlorophyll sensing
- High number of sensors (one per meter for WEEDit and one per nozzle for WeedSeeker)
- Significant reduction in chemical usage
- High cost ($4000 / meter)
- Day and night usage
- Limited speed (15 km/h for WeedSeeker and 20 km/h for WEEDit)
- Boom stability is important, so wheels are usually added on the booms
- Calibration is needed on the WeedSeeker, while the WEEDit has an autocalibration mode
- Both technologies cannot work on green on green applications.

Systems under development

Many companies, both start-ups, large corporations and universities are now developing systems with green on green capability. The technology used is similar: artificial intelligence with cameras (sometimes RGB/colour cameras, sometimes hyperspectral cameras).

Examples of companies working on green on green technologies:

- Bilberry, a French AI based start-up that specialises in cameras for recognising weeds (more below)
- Blue River Technology, acquired by John Deere in September 2017 for more than $300M, developing a See and Spray technology - a spraying tool with smart cameras, trailed by a tractor, that can spray weeds very accurately at about 10 km/h
- Ecorobotix, a Swiss based start-up developing an autonomous solar robot that kills weeds. They are also developing the camera technology
- AgroIntelli, a Danish company developing an autonomous robot to replace tractors, that will also include spraying capacity. They are also developing the camera technology
- Bosch, the German company, that is more and more involved in agriculture has launched a project call Bonirob a couple of years ago, a robot that includes smart cameras to kill weeds in a more efficient way

Artificial intelligence to detect weeds

Past research

Recognising weeds within crops is a topic that has been interesting companies and researchers for a very long time. First patents on this topic are from the 1990s. The main approach was to differentiate weeds from crops thanks to their colour and shape. Through mathematical formulas, a range of colours and a range of shapes for each weed (we can call these algorithms conventional algorithms) would be created.

To give a very simplistic example, one could define, through experimentation, that radish colour would be within a specific green range, as shown on Figure 2.

This way of working gave good results in the lab, because they have excellent conditions, that can be replicated easily: the light is constant and homogeneous, there is no wind, all crops and weeds are from the same variety and are not stressed etc. Since all these conditions are very controlled, it is often true that you can differentiate two types of weeds / crops thanks to colour and shape.

Figure 1. From top left to bottom right: Agrointelli robot, Blue River Technology tool, Bosch robot and Ecorobotix robot.

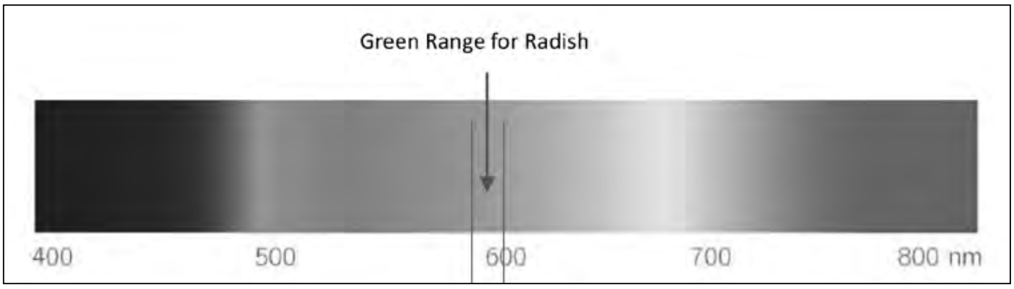

Figure 2. Simplistic example of conventional algorithms mechanism.

However, paddock conditions are completely different. Indeed, the sun can be high or low, in your back or in your eyes, there can be clouds, there can be shadows from the tractor/sprayer cabin or from the spraying boom, crops can be wet in the morning (which would create sun reflection), soils always have different colours ...

It became clear that conventional algorithms could not work in field conditions.

Artificial intelligence as a game changer

Artificial intelligence and especially deep learning is another way of working on images to recognise different objects. It is now the most widely used technology for computer vision when it comes to complex images (recognising weeds within crops, or on bare soil, is definitely a complex image). Complex images could be defined as images that show high variability between the same category of object (an object being a cat, a dog, a human, or a weed).

Deep learning is part of the family of machine learning and is inspired by the way the human brain works (deep learning often uses deep neural networks architecture). The learning part can be either supervised or unsupervised. We will discuss supervised learning and how to apply it to weed recognition more in depth below.

Below is an example of different kind of deep learning architectures applied to computer vision.

Deep learning is now possible on embedded systems

Research on deep learning also started in the 90s, however it only became widely used in the 2010s. There are 3 key components needed to develop deep learning applications, and these 3 key components have only been available for very few years. These are:

1. Plenty of data
2. High computing power
3. Powerful algorithms

Data generation has grown at an incredible speed since the early 2000s and the fast development of internet. We now have access to data about almost everything, in very large quantity.

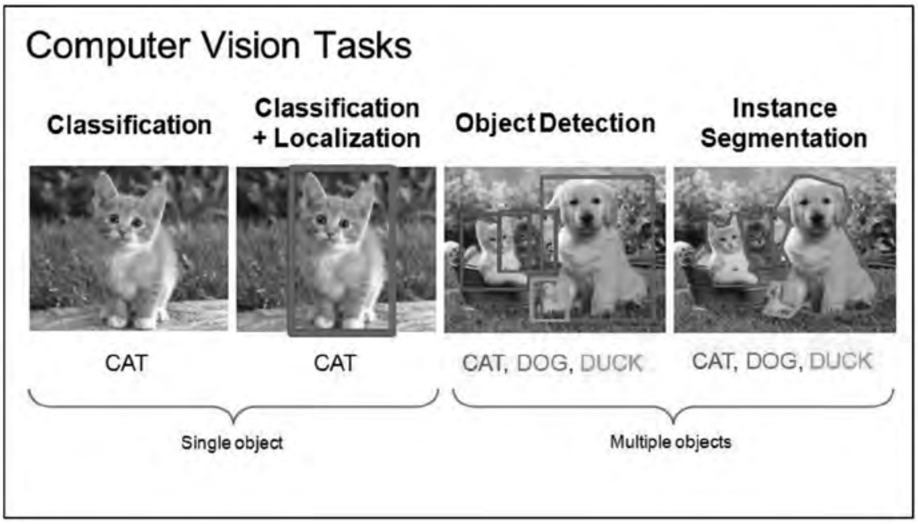

Figure 3. Different deep learning architectures.

Computing power is needed twice for deep learning: firstly during algorithm training and secondly during the "inference", which is the moment the algorithm is being used. Deep learning is run on GPUs (Graphics Processing Unit), and these GPUs became really powerful with the development of autonomous vehicles.

Since more powerful processing units were available, more powerful algorithms were also developed by engineers.

The 3 conditions above are now met and so deep learning is therefore applicable to many situations and is especially relevant for farming.

Supervised process for deep learning

Here is the classical process to develop a deep learning algorithm with the supervised method:

- Define algorithm usage and objectives
  - Example with weed recognition (WR): Recognize flowering radish in wheat with > 90% accuracy
- Gather data
  - WR: Take pictures in the fields of flowering wild radish in wheat
- Sort and label data
  - WR: On each picture, indicate what is wheat, what is wild radish etc.
  - WR: Also separate all images into 2 sets, training set and testing set. Training set is only used for training, and testing set is only used for testing (images cannot be on both sets)
- Train algorithm
  - WR: Show the training set (thousands of times) to the algorithm so that it can learn patterns
- Test algorithm
  - WR: Show the test set (one time) to the algorithm to compare the results of the algorithm with the reality
  - WR: Once happy with the results of the algorithms, go into the paddock to test (paddock testing is the most crucial part of the process)
    - Note: It NEVER works first time …
- Repeat until you reach your objectives

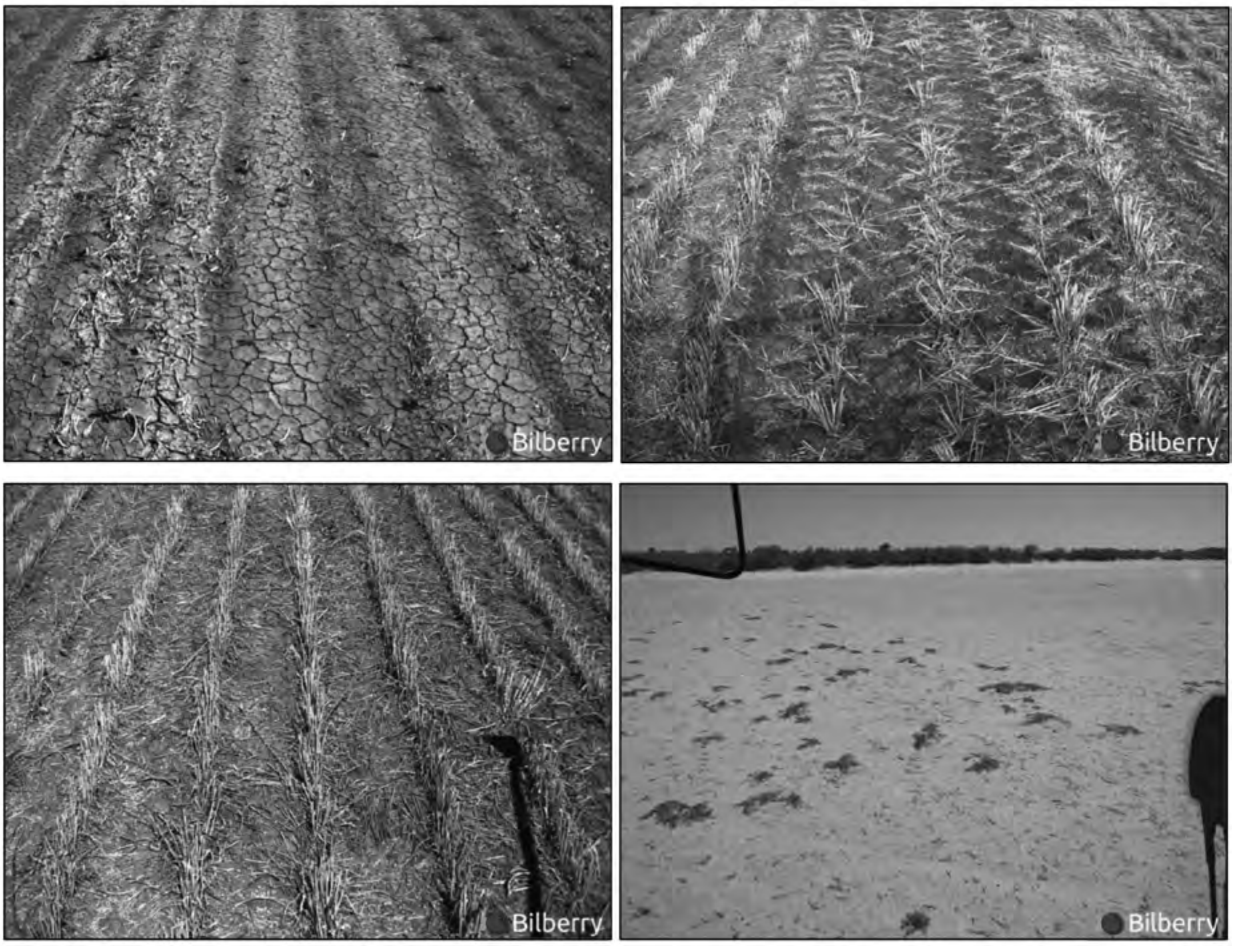

Figure 4. Different situations for summer spraying in Australia (sandy soils, high stubble, no stubble).

Two of the most important steps are data gathering and paddock testing (these 2 steps happen in the field). What is especially complex and important about data gathering is to be able to capture the diversity of situations. Below is an example of different situations, where the aim is to spray any live weed on bare soil.

Research and results at Bilberry

Bilberry presentation

Bilberry was founded in January 2016 by three French engineers, with the idea to use artificial intelligence to help solve problems in agriculture. The main product of Bilberry is now embedded cameras on sprayers. They scan the paddocks to recognise the weeds and then control the spraying in real time to spray only on weeds and not the whole paddock. Bilberry also develops cameras that recognize weeds on rail tracks. The technology is similar, with just a higher speed (60 km/h) and day and night applications.

The biggest focus to develop this product is now Australia, with several sprayers already equipped with Bilberry cameras. One of the reasons of this focus is the huge interest among Australian growers and agronomists towards green on green spot spraying.

On the booms of the sprayer, there is one camera every 3 meters and then computing modules (to process the data) and switches (to distribute power and data to each camera). In the cabin, there is one screen to control the system.

Results achieved until now

Three algorithms are now validated and usable directly by growers in the field (two are more focused on Australian growers):

- Weeds on bare soil detection (using AI, but same application as WEEDit or WeedSeeker)
- Rumex (dock weed) in grasslands
- Wild radish in wheat (especially when they are flowering) (link to a video for wild radish spraying, watch in HQ to see the sprays better: https://drive.google.com/file/d/1vUfCC7hN77VI2Jp2S6XDEFr8CJ_pU7LL/view

It is important to note that large chemical savings are made with the cameras, however it is also a very interesting tool to fight resistant weeds, potentially enabling the use of products that cannot be currently used in crop due to either cost or crop impact.

Figure 6 are some pictures taken by our cameras and what is seen by the algorithm.

Main usage conditions of the Bilberry camera

The cameras are used at up to 25 km/h speed and can be used on wide booms (widest boom used is 49 metres but could be more if needed). This means there is a very high capacity with the sprayer equipped with cameras.

Theoretical camera capacity = 25 km/h * 48 meters = 120 ha/hour

Figure 5. Bilberry cameras on an Agrifac 48 metre self-propelled sprayer.

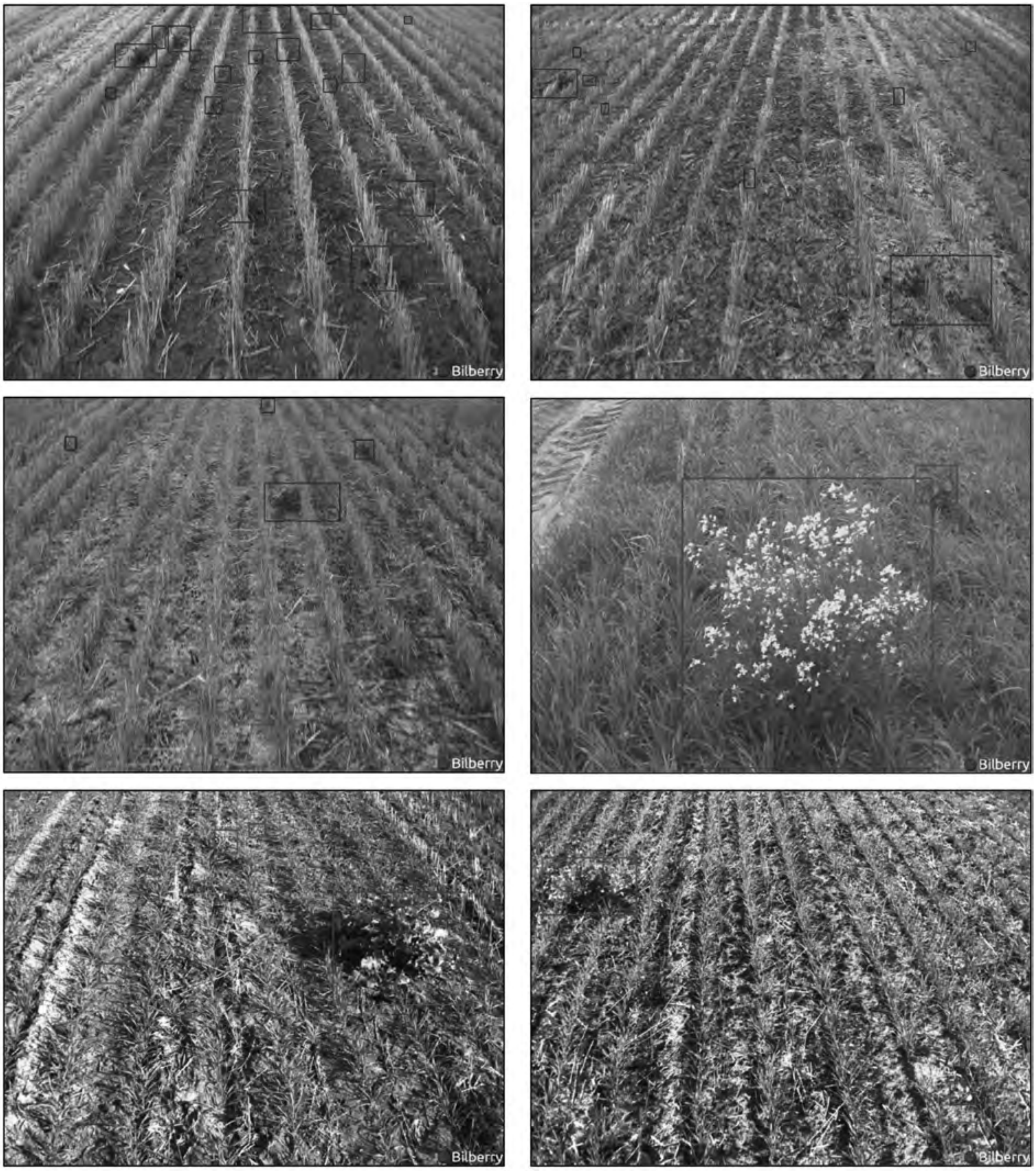

Figure 6. Weed detection on bare soil (3 first pictures) and wild radish detection in wheat (3 last pictures) - Images taken from Bilberry cameras - results in real time.

In real spraying conditions, capacity is of course lower, since the speed is not always 25 km/h and the sprayers need to be refilled.

Summer spraying in Australia (New South Wales example)

One Agrifac 48 metre boom is equipped with cameras in a farm in New South Wales. Before the cameras were used by the grower and his team, a comparative test was made with current camera sprayer technology. It was then decided to use Bilberry cameras as much as possible on the farm.

Thus, the cameras have been used since the beginning of the 2018-2019 summer spraying season, directly by the grower and his team. Over a 3 weeks period, here are the most important figures:

Figure 7. Test field after spraying with dye.

Table 1. Figures from the 2018-2019 summer spraying season.

Total area sprayed	Ha / day	Ha / hour	Chemical savings
6199 ha	413 ha	75 ha	93.5%

The carrier volume used was generally set at 150 litres / ha.

It is very important to note that the chemical savings are directly linked to the extent of weed infestation in the paddocks. A paddock with high weed infestation will get little savings whereas a paddock with low weed infestation will get high savings.

Spraying dock weeds in grasslands (Netherlands)

In the Netherlands, a 36 meters Agrifac boom is equipped with Bilberry cameras and uses an algorithm to spray dock weeds on grasslands. The same testing process as described earlier was used to ensure the algorithm was working properly.

Once the grower validated that the algorithm was working, it was used during the whole spraying season. About 500 ha were sprayed during the season, and the average chemical savings were above 90 %. The cost of the chemical is about 50€/ha for this specific application, which means 45€ chemical savings / ha with the cameras.

Here is a link to see the machine spraying dock weed (to see the sprays happening, play the video in high quality): https://drive.google.com/file/d/1EF1qqIRjzj0pVCYf67cSBlHvh47xDHKz/view

Future machine capabilities

Obviously, the biggest focus is to develop new weeding applications (which means new algorithms) to be able to use the cameras more often.

Other important development focuses we have right now include:

- Working at night (already working on rail tracks, but not on sprayers)
- Working at 30 km/h
- Delivering a weed map after a spray run (already working on rail tracks, but not on sprayers), to compare with the application map
- New weed applications

In the future, we believe that every time the sprayer goes in the field, the cameras should be able to bring value to the grower. Sometimes it would mean direct application (for instance for weed spraying) and other times it would mean building maps (maps to give growth stage throughout the paddock or disease status or anything that could help growers and agronomists do their job).

We will also look into algorithms for modulating nitrogen and fungicide applications.

In a completely opposite direction, spraying with cameras will generate a lot of data. The data will be very precise (because the data is saved with the GPS coordinates) and will give agronomists and farmers new tools to improve their overall farm management strategy.

Concrete implications for growers

Cameras that detect green on green bring multiple new possibilities for growers. The most important and immediate consequences are new possibilities to fight resistant weeds and impressive chemical savings and reduced herbicide environmental load. The potential to reduce the area of crop sprayed with in-crop selective herbicides, may also assist by reducing stress on stress interactions that are sometimes associated with in-crop herbicide use.

It is also very important to note that, as for any new technologies, it will only work well if growers get to know the technology, how it works, its limitations and possibilities. The first and most important thing for growers will be to be very attentive to the results of each spraying: first, are all weeds killed, and second, how much did I save? The cameras might work perfectly on 90% of their paddocks, and for some reason not perform as well on 10%. This can definitely be corrected within the algorithms (see above how to train an algorithm), but to correct an algorithm the designer of the cameras must be made aware there is an issue.

Acknowledgements

Presenting this green on green technology has been possible thanks to the interest and passion of the GRDC Update coordinators and the support of the GRDC to bring me to Australia to present at the Updates. I would also like to express my thanks to the first growers that believed in Bilberry in Australia.

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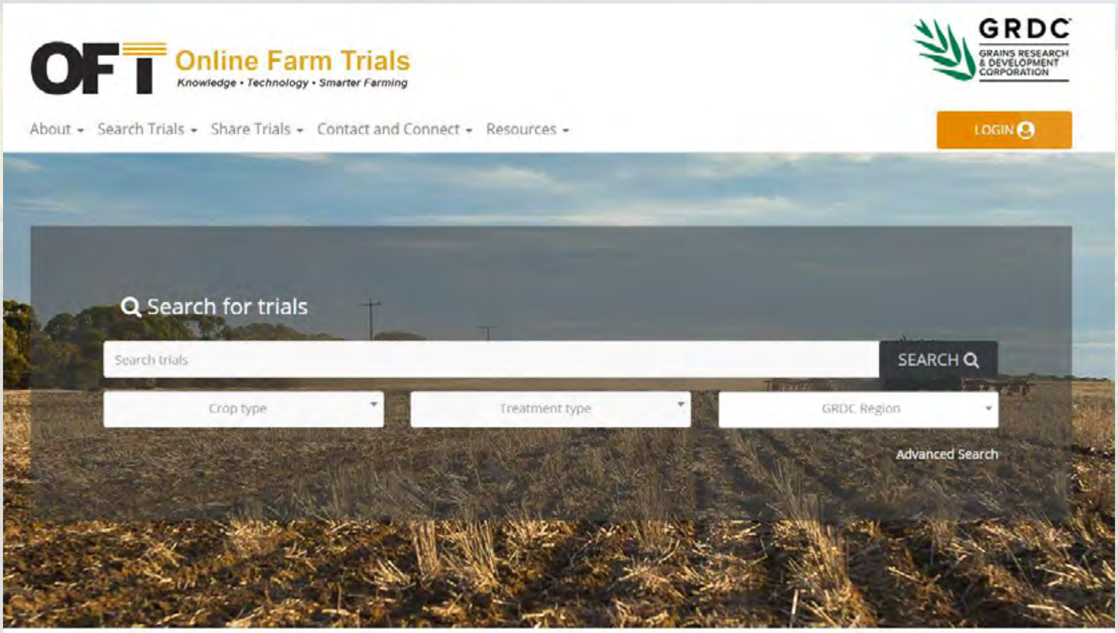

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Nitrogen and soil organic matter decline - what is needed to fix it?

***Jeff Baldock*[1].**

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GRDC project code: CSP00207

Keywords

- soil, nitrogen, N, soil organic matter, soil fertility, profitability, productivity.

Take home messages

- Stocks of soil organic matter (SOM) and nitrogen (N) are limited resources and current trends across Australian agricultural soils indicate that these are declining (Luo et al. 2010).
- Soil derived N can contribute to the amount of N available to a crop. As the capacity of a soil to deliver N declines, increased rates of fertiliser N will be required and optimising profit (where marginal benefit=marginal cost) may move to lower yields.
- N balance calculations are essential to define how management is altering the stock of soil N. A range of indices exist that can be monitored over time to provide an indication of how management is affecting N stocks.
- Altering management practices to maintain SOM and N status are likely to be associated with increased costs (either increased expenditure or opportunity costs). Mechanisms for offsetting increased costs associated with applying management practices to accumulate organic matter and N exist, and more are under development.
- Taking a long term (decadal) view on the economic implications is critical to ensure future productivity will not be compromised in an effort to maximise short term (annual) profits.

Introduction

SOM and soil organic carbon (SOC) are sometimes used interchangeably and on average SOM contains 58% carbon (C) (Hoyle et al. 2011). The majority of the balance is made up of other elements including nutrients (N, phosphorus (P) and sulphur (S)) as well as oxygen and hydrogen. It is important to recognise that SOM contents are therefore 1.72 times greater than SOC contents and attention must be paid to soil test values to confirm what has been reported.

A simple organic carbon (OC) cycle for agricultural soils is provided in Figure 1. OC enters the soil through the capture of carbon dioxide (CO_2) by crops and pastures and the subsequent deposition of residues on and within the soil. For surface deposited materials to contribute, the OC in the residues must be mixed into the soil or broken down and moved into the soil. Any removals of products or residues will reduce the flow of OC into the soil. Once in the soil, the activity of decomposer organisms will respire a portion of the OC back to CO_2.

Soil erosion can also contribute significantly to SOC loss with practices such as maintaining ground cover reducing the impact. Although analysis laboratories typically provide values for SOC content, the actual amount of OC present in a soil is referred to as the stock of OC and is calculated by defining the tonnes of C present in a soil to a defined depth according to Equation

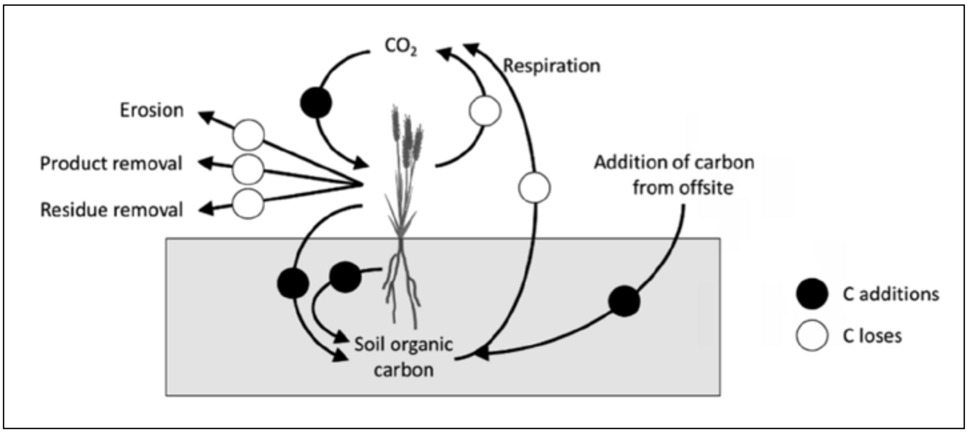

Figure 1. Carbon cycle in agricultural soils showing inputs and losses of organic carbon

$$\underset{(\text{Mg/ha})}{\text{Organic carbon stock}} = \underset{(\%)}{\text{Organic carbon content of <2mm soil}} \times \underset{(\text{g/cm}^3)}{\text{Bulk density of whole soil sampled}} \times \underset{(\text{cm})}{\text{Thickness of the soil layer sampled}} \times \left(1 - \text{Proportion of soil mass >2mm}\right)$$

Equation [1]. Equation used to calculate the stock of organic carbon in the soil.

[1] (Sanderman et al. 2011). Both the content and stock of OC content in a soil therefore represents the net balance between the rates of C addition and loss. Any alteration to management practices that can enhance rates of OC addition (flows with black circles in Figure 1) or reduce losses (flows with white circles in Figure 1) beyond that currently being attained have the potential to increase the amount of C in soil.

Declines in SOM and N status in agricultural soils

Conversion of native soils to agricultural production often results in a decline in SOC content or stock. Under Australian conditions, Luo et al. (2010) assembled data from 20 different studies indicating that cultivation of the 0cm-10cm soil layer resulted in a decline in SOC stocks to values approximately half those in soils in their native condition. However, the extent of loss did vary between 20% and 70% with similar, but more variable results when the 0cm-30cm soil layer was examined. The observation that significant amounts of SOC have been lost due to cultivation suggests that changes to management practices will be required to rebuild SOC. Although some changes have been implemented (e.g. reduced/zero tillage and reductions in stubble burning/removal), further change and the introduction of new approaches may be required.

The strong link between OC and N in SOM indicates that losses of SOC are also indicative of a loss of soil N. OC to N ratios of 10 to 12 are generally expected for mineral soils. Across a range of Australian soils varying in OC content from <1% to just over 14%, the OC to N ratio was found to be 11.1 on average (Kirkby et al., 2011). The implication of this is that where the OC content of the 0cm-10cm soil layer with a bulk density of 1.3 g/cm^3 and no gravel, declines from 2% to 1% by weight, approximately 1081kg N/ha will have been mineralised. The possible fate of the mineralised N would be uptake and removal in agricultural products or loss from the soil. If the loss occurred over a 20-year period, then the reduction in OC has provided an average of 50kg N/ha/year. As the OC within the soil continues to decline, two outcomes will become evident: 1) the rate of OC loss decreases, hence, less N is mineralised and potentially made available to growing crops and 2) once a lower threshold value of OC is passed, little N will be mineralised and released and crop production will become much more reliant on fertiliser N additions.

Implications of declining organic matter and N status

SOM contributes positively to a range of soil properties and functions considered important to defining the potential productivity of soil.

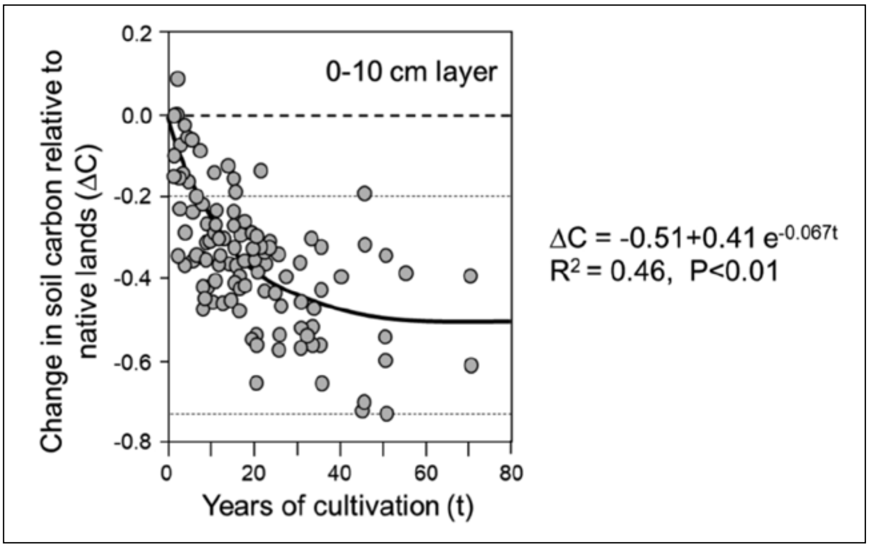

Figure 2. Change in soil organic carbon stocks of the 0cm-10 cm layer with increasing duration of cultivation relative to the stock in soils under native condition.

Across different types of soils (e.g. soils varying in clay content) the importance of organic matter contributions will vary. In Figure 3 a conceptual framework is presented that summaries the relative importance of organic matter; with the change in the width of the shapes providing an indication of the relative importance of organic matter to a particular function. As an example, for cation exchange capacity (CEC), organic matter will provide the only source of CEC in a sand and is therefore critical to the provision of this soil property. However, as clay content increases, the requirement for organic matter to provide CEC declines because the contribution of clay particles to CEC meets the needs of the soil. As a second example, consider the provision of energy for biological processes. Irrespective of clay content or nature of the minerals present in a soil, organic matter is the source of energy for organisms. Thus, the shape for this process remains wide across all clay contents.

With declining levels of organic matter in soil, the ability of the organic matter to contribute adequately to the functions identified in Figure 3 declines. If these contributions drop below the threshold values required to maintain adequate soil function, then soil productivity will be compromised. It is important to note however that for SOM to contribute to these properties and functions it needs to decompose

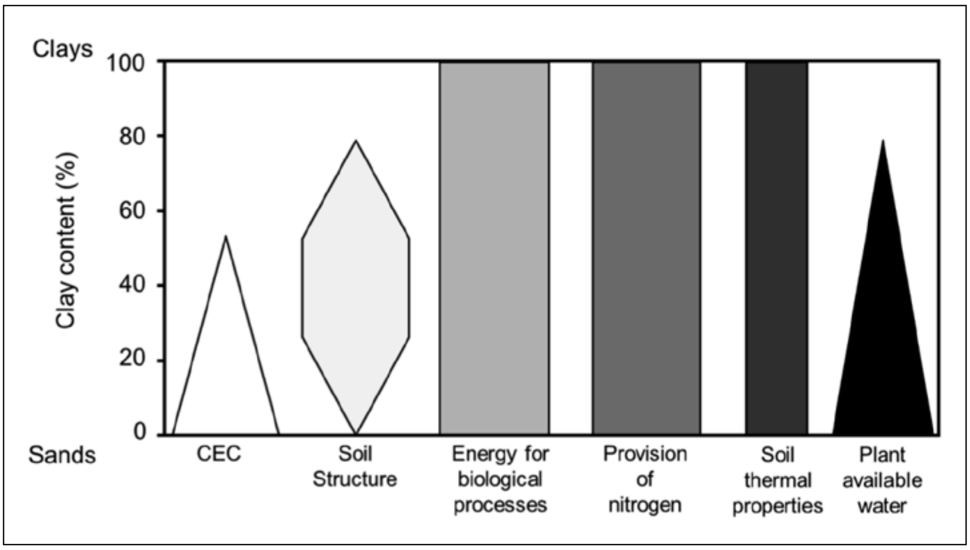

Figure 3. Conceptual contributions of the contribution of organic matter to various soil properties and functions and how this varies across soils with changes in clay content. The width of the shape corresponds to the ascribed importance at a given clay content.

and cycle. Thus, in attempts to build SOM, it is not desirable to stop its decomposition, rather attempts should be made to increase the rate of organic matter addition to result in a net gain and promote greater cycling and enhanced contributions to beneficial soil properties and processes.

Under dryland growing conditions in Australia, yield potential is typically defined by the availability of water to grow grain crops by summing plant available water stored in the soil at sowing and predicting the amount of rainfall that will be received. Using the amount of water that is potentially available to set a yield target and assigning a protein content for the grain allows the derivation of N requirements. Achieving a good match between crop N demand and N availability requires the prediction of N delivery from the soil and the addition of an appropriate amount of fertiliser N. A declining soil N status means that to achieve yield and protein targets defined by the availability of water, additional fertiliser N will be required.

Fertiliser rate trials have demonstrated that the efficiency of fertiliser N use declines as fertiliser application rates increase (for examples see Bell et al. 2014; Lester et al. 2009). Each incremental increase in yield requires a larger addition of fertiliser N, and therefore, costs more; particularly in progressing towards the biological optimum yield (e.g. point B on the yield curve in Figure 4a). A contributor to this relationship resides in the mechanisms by which available N can be lost from the soil/crop system (e.g. volatilisation, denitrification and leaching), and the increased potential for these losses to occur as the concentration of available N in soil increases in response to increasing fertiliser addition. As a result, where fertiliser N application rates have to increase in response to a decreased ability of the soil to supply N, the cost of achieving an additional yield increment will increase and the profitability ($/kg of fertiliser N applied) of applying additional fertiliser N will decrease. Under such circumstances, and assuming all other variable costs remain fixed, the economic optimum yield (where marginal benefit = marginal cost, point A on the profit curve in Figure 4a) will decline as the ability of a soil to supply N decreases (point D versus point E in Figure 4b). It is important to note that the different responses presented for the soils with a low and high N supply capacity in Figure 4 are conceptual and have been accentuated to demonstrate the points being made. A more complete economic assessment is required to quantify the magnitude of the proposed profitability differences and fully assess the implications.

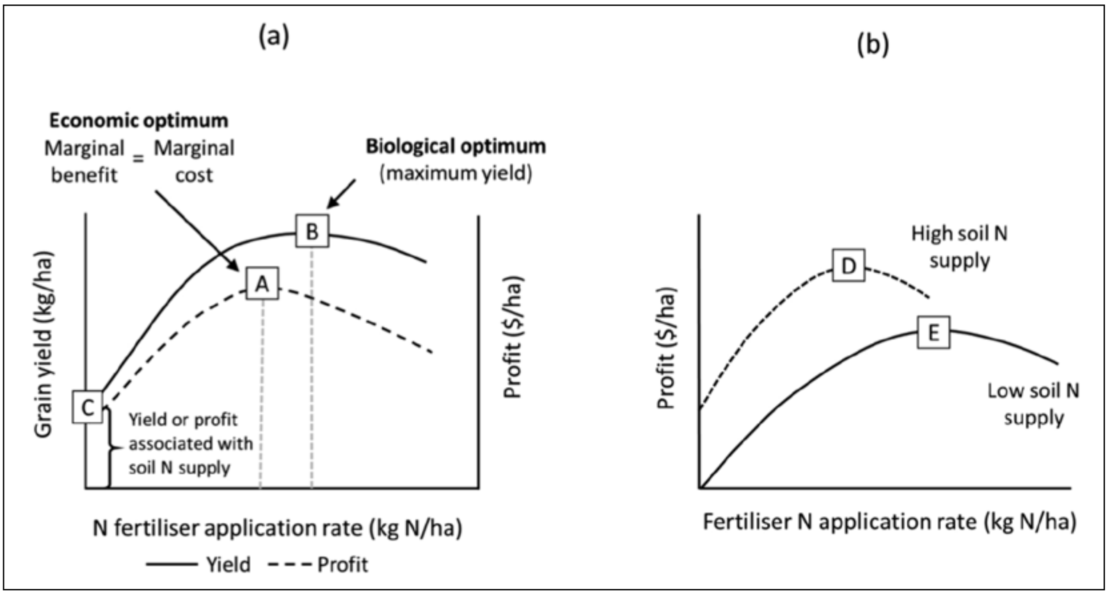

Figure 4. Changes in (a) the efficiency of fertiliser N use in terms of grain producing grain and potential relationship between biological and economic optimum yields (b) profitability of grain production with increasing fertiliser N application rates for soil with a low (solid line) or high (dashed line) N supply capacity. Note that these diagrams are conceptual and differences between low and high N supply capacity have been accentuated for the purpose of demonstrating potential differences.

Part of the benefit provided by soil N supply, relative to fertiliser N application, resides in the fact that N derived from organic matter decomposition is metered out over the growing season and responds positively to the same environmental conditions controlling crop growth and N demand (e.g. availability of water and temperature). With an increasing reliance on soil derived N, the supply and crop demand for N are likely to be better synchronised, leading to a lower chance of available N accumulating in the soil. However, if fertiliser N is added and creates an excess of available N, the slow release and more synchronous behaviour of N being mineralised from the SOM will be lost. This occurs because, when mineralised N enters the available N pool, it behaves in a manner similar to the added fertiliser N.

What is needed to fix it?

Increasing soil organic matter content or stock

Given that the amount of organic matter present in a soil results from the balance between inputs and losses (Figure 1), to shift SOM stocks to higher values will require an increase to the flow of OC into the soil. An exception to this may be where rates of SOM loss due to erosion can be reduced through maintaining a greater amount of soil cover. Questions that should be posed include:

1) Are organic materials being removed (e.g. crop residues) and can this practice be halted?
2) Are current management practices maximising water use efficiency (expressed in terms of dry matter production per mm of available water)? If not, are there alternative practices available that can be used to move towards greater water use efficiency and enhanced biomass production?
3) Is there scope to alter the production system to include a greater proportion of legumes, particularly legumes grown as a green or brown manure?
4) If erosion is an issue, can management practices be imposed that maintain a higher level of soil cover (for wind erosion) or can the movement of water over the soil be slowed (for water erosion).

Acknowledging that the current levels of SOM are a function of the history of management practices employed, if the answer to any of the above questions is yes, then there is scope to increase the storage of organic matter in the soil.

A tendency has existed to suggest that the adoption of defined management practices (e.g. reduced tillage, rotational grazing) can alter SOM stocks. Sampling many Australian grain growing soils has suggested that increasing stocks of SOM is less about the nature of management practice and more about whether C flow to the soil has been enhanced. Adopting a perceived 'C friendly' management practice provides no guarantee that soil C stocks will increase. The manner in which the practice is implemented and its impact on C flow to the soil is critical. For example, a grower maximising productivity of grain crops (continually achieving close to the water limited yield) and retaining all residues may end up with a better SOC stock than a grazier operating with a stocking rate that is too high.

Maintenance of soil N

Most of the N contained in a soil (>95%) is found in the SOM. Rates of change of SOM are slow (often requiring >5 years to detect true change) and given the extent of spatial variability across paddocks and variations in seasonal conditions, it will be difficult to quantify the implications of growing single crops on soil N status through direct measurement. As a result, a number of agronomic indices have been developed and used to quantify the effectiveness of nutrient management based on yield responses, N extracted in grain and the difference between added and extracted N. These indices have been presented and discussed in a previous GRDC update paper (Baldock et al., 2018). In demonstrating the use of these indices, Norton (2016) obtained results across 4-5 years for 514 paddocks indicating on average that growers were mining N from the soil resulting in a decline in soil N status over time.

For growers to gain an appreciation of the implications of their management practices on soil N status, it is important to conduct N balance calculations. Given the different annual inputs, extractions and losses of N as a function of variations in applied management practices, soil properties and environmental conditions, growers are encouraged to complete annual N balance calculations (Equation [2] (Baldock et al. 2018)). Deriving values for all of the components of the N balance calculation may be difficult, particularly for some of the loss mechanisms; however, monitoring the N balance result obtained over time would remain useful and provide an indication of any trend. Although a trend to increasing N stocks is encouraged, it should be acknowledged that temporary periods of mining N stocks are acceptable, provided the extent of N mining is

$$\text{N balance} = \left(N_F + N_{OA} + N_{dfa} + N_{dep}\right) - \left(N_R + N_L + N_V + N_{Den} + N_E\right)$$

N_F=N added to the soil in the form of chemical fertilisers

N_{OA}=N added to the soil in the form of organic amendments (e.g. manure, composts, etc.)

N_{dfa}=N derived from atmospheric N_2 by symbiotic and non-symbiotic fixation

N_{dep}=N deposition from the atmosphere

N_R=N removed in harvested products

N_L=leached from the root zone

N_V=volatilised as ammonia from fertilisers and soils

N_{Den}=N lost as N_2 and N_2O by denitrification

N_E=N lost by erosion

Equation 2. Calculation used to determine N balance.

quantified and followed by a rebuilding phase in which N stocks are replenished. It is recommended that annual N balance calculations be performed; however, the values should be integrated and accumulated over time to define the full effect of applied management practices and temporal trends. Such information will allow grain growers to implement appropriate actions to maintain their production base into the future and continue to maximise profitable grain yield outcomes.

Other than the application of fertiliser N, the main mechanism for growers to enhance N status is the inclusion of legumes in rotation with grain crops. This could include pulses and pasture options in rotation with grain production. To maximise N inputs, it may be appropriate to maximise the nodulation and biomass accumulation of a legume and retain all biomass (e.g. green manure). In essence, growers need to take a 'crop management approach' to growing a legume for augmenting the soil N status and contributing to SOM levels. Although this would be associated with a significant opportunity cost, the benefits to subsequent crops and long-term implications on soil N status and productivity may be positive. Longer term (>10 years) economic analyses of such options need to be considered since the most profitable short-term result will always be to maximise the extraction of N from the soil (i.e. mine the soil N reserve) thereby reducing the cost of production. Such analyses should also take into account other potential benefits including, but not limited to, diversification of the farm business, enhanced or additional weed control options and provision of crop disease breaks.

Options to offset the opportunity cost of maintaining SOM and N

Valuing SOM/C

Quantifying the value of SOM to production is essential. However, this is challenging, given the diversity of positive contributions SOM potentially makes to productivity and the different amount and types of organic matter required to achieve adequate functioning for different soils. Having such values will aid in the economic assessments of current investments or opportunity costs associated with management practices designed to maintain the SOM and N status. Where appropriate and consistent with farm business planning, entry into C markets may also contribute.

Valuing the natural capital of soil

Currently, the natural capital contained within soil does not contribute significantly to property valuation and little reward exists for the maintenance of natural capital. Based on the example provided earlier in this document, for every per cent by weight of OC in the 0cm-10 cm soil layer about 1000kg of N is present. Using a value of $1 to buy and apply a kg of N per ha, the N resource within the 0cm-10cm soil layer could be valued at $1000 per ha; however, such values rarely enter into the assessment of farm capital values. Movement by financial institutions towards valuing natural capital is now being discussed. Potential options include the provision of reduced interest rates on loans in response to being able to demonstrate that applied agricultural practices are maintaining or enhancing soil. Tools such as those being developed by Digital Agricultural Services (https://digitalagricultureservices.com/) will help facilitate natural capital valuation and its inclusion in financial decisions. Assessing the costs and benefits associated with changes in natural capital value will be required to clearly articulate the impact of such approaches on the farm business with both short- and long-term analyses being completed.

Accounting for the true cost of production

When the value of grain and products derived from grain are assessed, often little consideration is given to how their production has altered the resource base from which they were derived and the costs associated with maintaining the base. Interest exists in tracking the provenance of commodities and attaching information about how they were produced. Being able to demonstrate effective management practices that maintain or enhance the soil resource base may allow entry into markets that attract higher returns and help to offset any opportunity costs.

Conclusions

- Stocks of soil organic matter and N are limited resources and current trends across Australian agricultural soils indicate that these stocks are declining. Declines in SOM are likely to result in decreased productivity and sustainability into the future. Establishing threshold values of composition and stock appropriate to different combinations of soil type and climate is required.
- Soil derived N can make significant contributions to the amount of N available to a crop. As the capacity of a soil to deliver available N to crops declines, increased rates of fertiliser N will be required. As fertiliser N rates increase, the potential for N loss increases and typically leads to reduced fertiliser N use efficiency. As a result, with decreasing soil N supply capacity, optimised productivity (where marginal benefit=marginal cost) may move to lower yields.
- Completing N balance calculations is essential for grain growers to gain an understanding of how their management practices are altering the stock of N present in their soils. N balance calculations should be completed annually but integrated over time. Where negative N balances are obtained, the soil N resource is being mined. Under such circumstances, it is important to consider whether future long term (decadal) productivity and potential profit is being eroded to maximise short term (annual) values.
- Altering management practices to maintain SOM and N status are likely to be associated with increased costs (either increased expenditure or opportunity costs). Mechanisms for offsetting these costs exist and more are coming on line. Taking a long-term view on the economics of current management on future productivity is important.

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Notes

Notes

Statistics 101 and making it sexy

Dale Grey.

Agriculture Victoria, Bendigo.

Keywords

- statistical, analysis, data.

Take home messages

- The *p* value needs to be less than 0.05.
- It is good if the CV% is less than 10%.
- Difference between values must be greater than the LSD to be significant.
- Always ask for the statistical analysis or parameters.

Background

For many first-year science graduates, statistics was the particular subject that was considered most abstract and hardest to grasp. So, it is not surprising that statistical knowledge is something that people either try to avoid or they use it in error. The problem is that agriculture often consists of scientific trials and data presentations that require a rudimentary knowledge of statistics to be understood properly.

Discussion

Number of observations

These are a couple of letters I like to see in all data presentations i.e. how many observations are in the data set where comparisons are being made. This is particularly important in survey data as often there is no replication. For example, the conclusions where n=24 could be much more meaningful if n=240 or n=2400. In other words, we should have greater confidence in result findings when data is collected in greater numbers, or on the flip side greater caution if the dataset is small.

Replication

Replication or reps (sometimes called blocks) is also a critical number. Is there none, three, or eight? The validity of the data analysis is backed up by the amount of replication. In agricultural experiments, three is usual, four is better, while two is dicey. In laboratory-based trials of pots or agar plates, higher replication numbers are common. Because we are dealing with science and not the arts, replicates help to overcome the possibility that each applied treatment does not behave in a uniform way, usually for reasons unknown. Trial managers are always on the lookout for the 'mythical' area of uniform soil type. My experience in Victoria is they are very hard to find. All is not lost though. If your trial goes from light to medium to heavy soil, do not run the replicates down the variation so that every replicate has a bit of each soil type. Run each replicate along a similar soil type so that each treatment in the replicate has the same soil type effect. Similarly, for variations in slope, stubble density, spray wheel tracks, etc.

P value

In trials analysed by Analysis of Variance (ANOVA), the whole point of the analysis is to find the probability that the data is not all the same. In other words, what is the probability that there is something significant happening (i.e. a real treatment effect) in the data? The p value tells the probability of all of our data being statistically similar. P values for agricultural research are often set at 0.05 or 5% or less i.e. for something to be considered statistically significant, there has to be only a 5% chance of the numbers being the same. While some fields of research might accept 0.1 or 10%, others might want to be more emphatic and require 0.01 or 1% or 0.001 or 0.1%. Once it was common to allocate *'s to the significance level, 0.05 =*, 0.01=**, 0.001=***

of significance. Old journal papers often used this system. The major school of statistical thought says that if there is no significance in the ANOVA then you are not entitled to present an LSD value, even if that LSD can show a difference in the data. Use of the terms 'a trend towards', 'a suggestion of' should indicate that the data has not met the 0.05 level.

ANOVA has some important rules for use that often are ignored. The major one is that the data must be distributed normally. When the data range is plotted, it should look similar to Figure 1.

Every fundamental of an ANOVA is based on the data being normalised as in figures 1 and 2, or else some other statistical technique must be used. If the data does not normalise (i.e. is skewed to one end of the range), then transformations of the data using log, arcsin or some other statistical means might be needed to make them normally distributed – in which case it might be time to seek professional statistical advice. Experience has told me to never score plots with yes/no categories as this type of data is often not normally distributed. It is always best to use a scale of 1-5, 1-10 or similar. However, visual scoring is often problematic. For example, with data such as rust, lodging or head loss, the majority of the data is often at one end of the rating scale (i.e. only a few resistant varieties and everything else susceptible), making it not normally distributed.

Coefficient of variation percentage

The coefficient of variation percentage or CV% is a measure of how variable the data set is around the average. It is calculated by dividing the standard deviation by the mean. The larger the variability in the data, the higher the CV% — if the data points are all the same then the CV% is zero. If there are large differences in the numbers in the data set, it could be close to 100%. The CV% can be calculated for

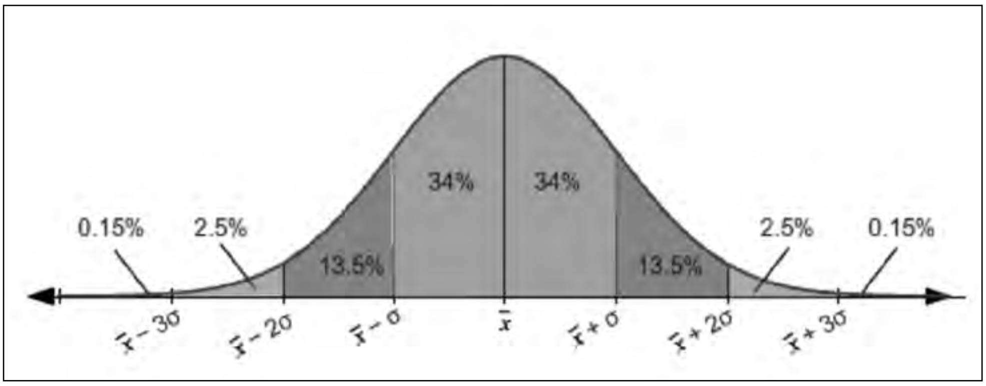

Figure 1. Graph of a normal distribution showing the mean and +/- 2 to 3 standard deviations from the mean.

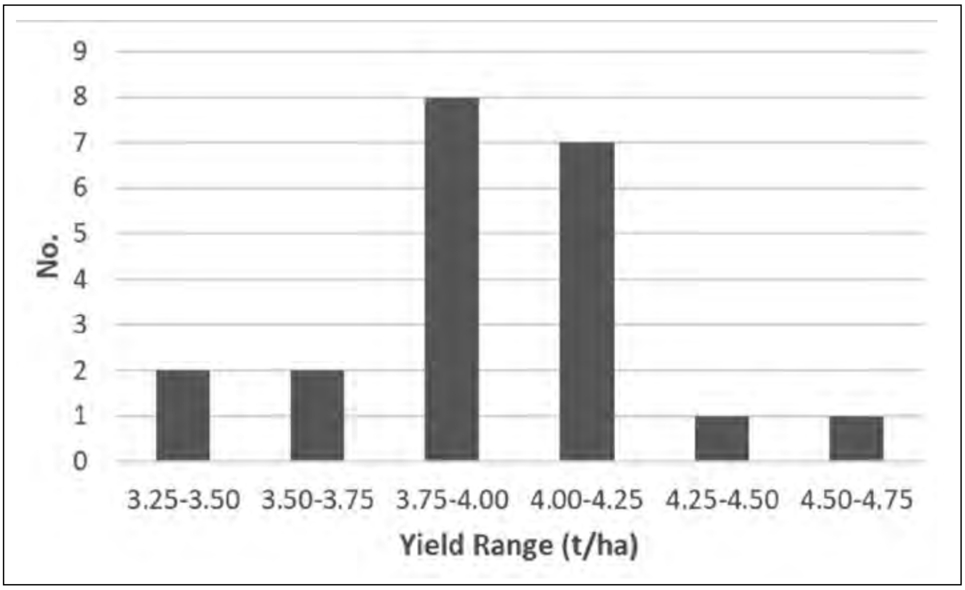

Figure 2. Soybean yield histogram showing normally distributed data, n=21.

a whole trial, within replicates or across replicates, each indicating something about the variation of the site and the treatments.

To demonstrate the effect data spread has on the CV%, consider the following three data sets:

46, 47, 50, 52, 55 has an average of 50, a standard deviation of 3.7 and a CV% of 7.3.

40, 45, 50 ,55, 60 has an average of 50, a standard deviation of 7.9 and a CV% of 15.8.

20, 40, 50, 60, 70 has an average of 50, a standard deviation of 15.8 and a CV% of 31.6.

In cereal and canola trials, a CV% between 0-10% is considered desirable, while less than 5% is best. Values higher than 15% often indicate an unreliable trial and should be treated with caution — in the instance of the NVT database, they are deleted from analysis. Pulse crops are generally more variable and values such as 10%-15% might be deemed suitable for the lack of anything better.

Least significant difference

The least significant difference (LSD) number is a different metric to the p value that is used to indicate the significance between data values (the p value only indicates that there is a difference **somewhere** in the data but not exactly what it is). LSD is often quoted with a probability value as well, often at the 0.05 or 5% level, but like *p* values, LSD can be seen at higher or lower levels of confidence. Higher probability LSDs may mean the author is 'fishing' for significance, but it can be frustrating if your treatment effect is significant at the 6% level — usually the author should state if and why they have deviated from an LSD of 5%.

In brief, if two data values (e.g. treatment means) are greater than the LSD apart, then there is only a 5% chance that they can be statistically the same. If the difference is **equal** to the LSD, it is not significant at the 5% level. For a simple trial where variety is the treatment, the LSD quoted simply shows which yields are statistically the same and which are not. More complex trials such as rate experiments might often show an LSD for the whole trial, and for individual treatment means. This is often where statistical communication breaks down —when the treatment means are not presented and you are supposed to work them out in your head.

Table 1 shows the mean data for a whole factorial experiment comparing three varieties sown at two densities by two row widths. It includes all ANOVA analysis for both p value and LSD for comparison across all treatments and the interactions between treatments. Obviously, such a table can be difficult to interpret. All that the analysis shows is that sowing width and variety are significant ($p<0.001$), but nothing else is. Often people will only include that analysis and disregard the others. The use of the * holds a special significance in ANOVA treatment descriptions as it is called the interaction. It looks for statistical significance in combinations of treatments that are different to the mean of the treatments by themselves. In my experience, interactions are rare, however they sometimes happen.

Such a large number of statistics can be summarised in a much simpler way, clearly showing 35cm rows yielding statistically higher than 70cm and each variety statistically significant in yield from each other (Table 1b and 1c).

Table 1. Sowing rate x sowing width x varieties from a soybean yield trial (t/ha).

Density	35p/m^2			50p/m^2		
Width	96248-23	Djakal	Snowy$^{(b)}$	96248-23	Djakal	Snowy$^{(b)}$
35cm	4.09	5.09	4.58	4.29	5.25	4.72
70cm	2.97	3.98	3.51	3.33	3.96	3.57
	mean	4.11				
	CV%	9.9				
	p Width	<.001	LSD Width	0.24		
	p Rate	0.21	LSD Rate	0.24		
	p Variety	<.001	LSD Variety	0.29		
	p Width*Rate	0.89	LSD Width*Rate	0.34		
	p Width*Variety	0.85	LDS Width*Variety	0.41		
	p Rate*Variety	0.73	LDS Rate*Variety	0.41		
	p Width*Rate*Variety	0.83	LSD Width*Rate*Variety	0.58		

Table 1b. Sowing width x soybean yield trial (t/ha).

Width	Yield
35cm	4.67
70cm	3.55
mean	4.11
CV%	9.9
p	<.001
LSD 5%	0.24

Table 1c. Varieties soybean yield trial (t/ha).

Djakal	4.57
Snowy⁽ᴰ⁾	4.10
96248-23	3.67
mean	4.11
CV%	9.9
p	<.001
LSD 5%	0.29

Another way of showing significance between data is the lettering system. Here the term 'treatments containing different letters denote statistical significance' usually appears. This data presentation method has worked out all significant data by placing different letters after them. However, it is better used for smaller numbers of comparisons rather than larger ones, otherwise it becomes too cumbersome. In the example in Table 2 comparing the yields of 11 soybean varieties, some may say "variety F148-4 topped the trial"— it may well have, but it is actually not statistically significant to all the varieties below it until F191a-4 is reached. The top five varieties have an 'a' after them, denoting they are statistically the same. A correct statement is variety F148-4 yielded statistically higher than F191a-4, but not higher than anything between those two varieties. Similarly, all varieties with a 'c' code are the same and so Djakal was statistically higher yielding than Snowy⁽ᴰ⁾.

Table 2. Soybean variety trial (t/ha) using letter codes for LSD significance.

Variety	Yield
F148-4	3.46a
99091A-4	3.29ab
Djakal	3.21abc
F215-9	3.16abcd
Empyle	3.13abcde
F191a-4	2.80bcdef
96248-23	2.63cdef
Snowy⁽ᴰ⁾	2.60def
F191B-4	2.54ef
F157-2	2.46f
99024-76	2.41f
Mean	2.88
CV%	12
p	0.01
LSD 5%	0.59

R^2

The R^2 value is often presented on a graph to explain what percentage of a fitted line or function matches the data. Theoretically, if the data perfectly matched the line of best fit, the R^2 would be 100%. Good or bad R^2s are a bit arbitrary as it depends on what is done with the data afterwards. For simple linear lines of best fit, a larger R^2 is nearly always desirable. Simple rules of thumb are where the line might be used to make predictions for farm management and precision is not important, an R^2 above 50% might be fine. If precision is required from a modelled line of best fit for making decisions, an R^2 > 80% may be desirable. In psychology, an R^2 below 50% is as good as it gets, because humans are not as predictable as natural systems. In statistical regression analysis which attempts to match a line to the data, it is possible to have statistically significant parameters around the line of best fit, but still have a poor R^2. It is possible to have a good R^2 from some data, but still have a line of best fit that grossly overestimates or underestimates small or large values put into the model, perhaps rendering it useless for practical purposes.

REML and the National Variety Testing (NVT)

Individual locations of NVT trial site data are analysed by ANOVA and provide p value, CV% and LSD. Combined site data or regional analysis (multi-environment trials (MET)) are undertaken using residual maximum likelihood (REML). To the uninitiated, REML is the 'black box of statistics' and should be carried out by a competent statistician. The statistician applies simple and complex models to best explain a set of transformed data, and the best model then is used to analyse the data. The model can then also be used to predict data, sometimes where it was not actually tested. REML is an incredibly powerful tool as it can be used for data that is not normally distributed, trial designs that are unbalanced, data that has variability within the replicate, and across sites that might be differently designed experiments. Trust is required when looking at REML analysed data — trust that the statisticians have done the best they can. REML was invented by Australians and has stood the test of time as a legitimate, but complex statistical technique.

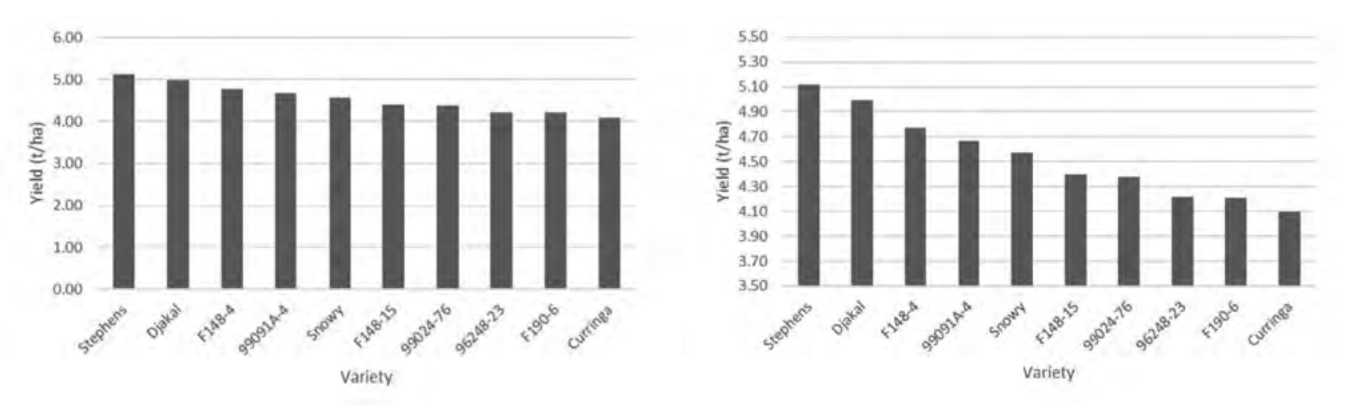

Figure 3. Showing the impact Y axis scale has on apparent significance (LSD is 0.75).

A caution on the economic analysis of data

At a field day in my first year as an agronomist, I presented statistically analysed data of a nitrogen trial and the associated gross margins based on the treatment means. A learned agronomist approached me afterwards and advised me that if there was no statistical difference in some of my treatments, then I was not entitled to make an economic assessment as if there were. I have never forgotten this. The bottom line is that for minimal extra work you can create a gross margin for each data point and do a full statistical analysis of the economics — sadly it is very rare to see this. Economic analysis needs to also stand up to statistical inquisition.

'Gruen' for agronomists

Read the scale of graphs

The major point is to include the full range of data (including zero) on the vertical axis. If you don't, the graph might suggest differences that are not actually there. This can be easily tested if an LSD is also provided. The graphs in Figure 3 show the same data, but with a changed scale. Sometimes this can be justified for ease of reading, but if there is no LSD value, the data may or may not be significant.

Exclusion of nil control

Excluding the nil control may fool you into thinking that a treatment is as good as another, but if they are no different to the nil control this indicates that doing nothing was just as useful.

The following trial shows that all four methods of *Rhizobia* inoculation were statistically similar — apparently a good result.

Inclusion of the nil control (3.96 t/ha) shows that this trial site was an unresponsive site to inoculation and the existence of a background population was probably enough to nodulate the crop.

If there is no data presented for a nil control, ask why and treat with caution.

Table 3. Soybean inoculation trial (t/ha) **without** (left) and **with** (right) the control.

Method	Yield	Method	Yield
liquid	4.26	liquid	4.26
freeze dried	4.16	freeze dried	4.16
granules10	3.90	granules10	3.90
peat slurry	3.86	peat slurry	3.86
peat dust	3.85	peat dust	3.85
granules5	3.52	granules5	3.52
		control	3.96
mean	3.93	mean	3.93
p=	0.01	p=	0.01
CV%	6.9	CV%	6.9
LSD 5%	0.48	LSD 5%	0.48

Significance by omission

At its worst, significance by omission might be because it is handpicked data, not including the whole data set, such as leaving out current industry leading varieties, or sites that tell a different story, or data that yielded higher than a particular point. The NVT website is a good place to visit for yield data that includes all varieties at all sites.

Table 4 contains two sets of data, one with omitted data (left) suggesting that Snowy⫽ is the highest yielding variety, and the other (right) where two varieties, Stephens and Djakal, also yielded similarly. Beware of statistics with omissions. This is one of the most common ways of manipulating data until it shows what the author wants it to say. It can also be the hardest to detect.

Table 3. Soybean yield trial (t/ha) showing omission of higher yielding varieties (left).			
Variety	Yield	Variety	Yield
		Stephens	5.12
		Djakal	4.99
		F148-4	4.77
		99091A-4	4.66
Snowy⦇	4.57	Snowy⦇	4.57
96248-23	4.22	96248-23	4.22
F190-6	4.21	F190-6	4.21
Curringa	4.09	Curringa	4.09
F169-41	3.98	F169-41	3.98
F169-34	3.97	F169-34	3.97
Empyle	3.90	Empyle	3.90
F215-9	3.89	F215-9	3.89
F191A-4	3.69	F191A-4	3.69
F157-2	2.92	F157-2	2.92
F170-6	2.81	F170-6	2.81
mean	3.97	mean	3.97
F Prob	<0.001	F Prob	<0.001
CV%	7.82	CV%	7.82
LSD 5%	0.75	LSD 5%	0.75

Conclusion

This paper has hopefully provided you with a basic understanding of how data should be presented and interpreted correctly. Ii is important also to remember to seek professional statistical advice when in doubt.

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Herbicide residues in soil – what is the scale and significance?

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GRDC project code: DAN00180

Keywords

- plant-back, phytotoxicity, soil function, soil biology.

Take home messages

- Herbicides including trifluralin, 2,4-Dichlorophenoxyacetic acid (2,4-D), diuron, glyphosate and diflufenican were detected in soils in more than 30% of paddocks surveyed prior to planting.
- Herbicides, when applied at label rates, do not cause significant impacts on soil microbial functions. In particular, glyphosate, even with repeated application over time, had no significant deleterious effect.
- There are a small number of examples where herbicide residues detected at planting exceed toxicity thresholds for the crop. Some of these thresholds have been confirmed in laboratory assays.
- Tenosols (light textured sandy soil) are considered at greatest risk of crop damage from residual herbicides due to their lower capacity to bind herbicide, therefore rendering a greater proportion of the residual herbicide as bioavailable.
- Growers need to carefully adhere to recommended plant back periods for sensitive crops and be especially careful if the seasons have not lent themselves to conditions suitable for complete herbicide breakdown. Carryover can result in reduced nitrogen fixation in a following legume crop.

Background

Increasing herbicide use over the last two decades has led to concerns over the potential effects herbicides (and their residues) have on soil health. There is some uncertainty as to whether there is a risk that herbicide residues are accumulating in soils, particularly in low rainfall environments. Risks include chronic low-level yield losses and reductions to profitability, or on the other hand, the perceived risk may be leading to decisions such as variety or crop selection which limits returns. This project was conducted to resolve the question of whether increased herbicide use has negative impacts on soil biological functions, and to benchmark levels of herbicide residues in soil at sowing to determine the possible extent to which they are responsible for causing crop damage and yield decline.

Methods

A risk assessment framework was used to assess the potential extent of soil and crop health decline due to herbicide residues across the grains industry (Figure 1). This requires a determination of exposure; i.e. how much herbicide is the soil/crop being exposed to, and toxicity; i.e. what is the residue level that reduces soil function (e.g. nitrification) or plant growth (e.g. shoot biomass) by 20%.

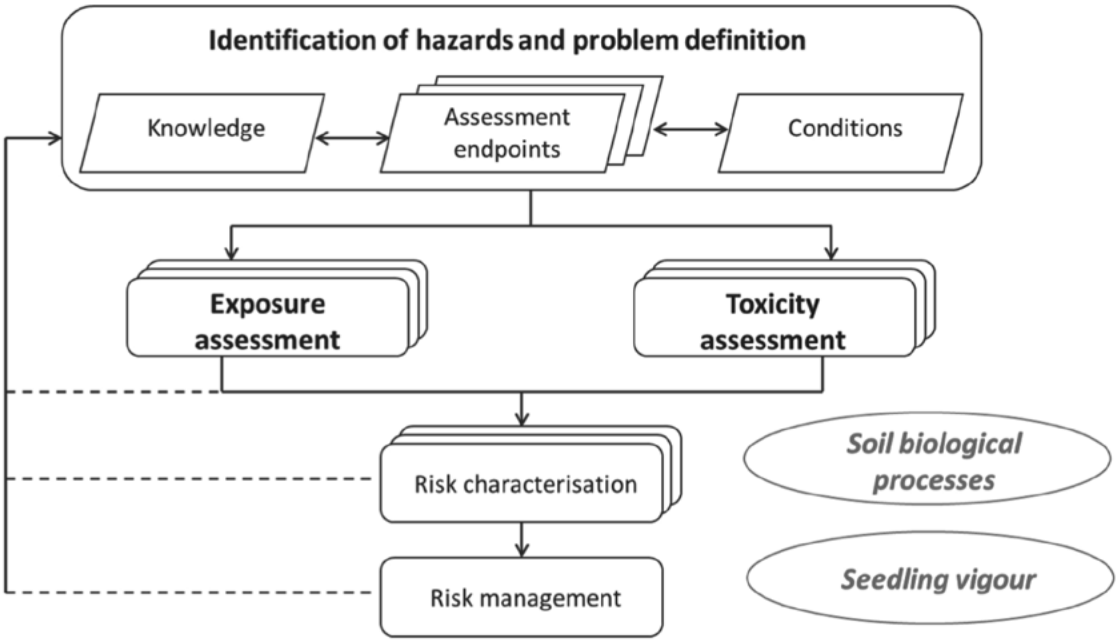

Figure 1. Risk assessment framework used to assess the potential scale of reduced soil and crop health due to herbicide residues in soil.

Exposure to herbicide residues was determined by conducting two field surveys of herbicide residues in soil at sowing. The first survey in February 2015 to April 2015 analysed samples from 40 paddocks around Australia at two depths, 0-10cm and 10-30cm. The second survey used a subset of samples from 40 paddocks within the National Paddock Survey (BWD00025), in which composite samples were taken from 0-10cm from two different zones in each paddock. Samples were analysed by multiresidue techniques, using targeted extraction and liquid chromatography with mass spectrometers (LC-MS/MS) and gas chromatography in combination with mass spectrometry (GC-MS) analysis. Note that extraction methodologies were optimised to determine the total soil concentration of herbicides rather than the bioavailable fraction.

Toxicity to soil biological functions was determined through meta-analysis of the published literature and laboratory soil incubation experiments. Information extracted from over 340 peer-reviewed journal articles was compiled to identify and rank herbicides according to toxicity to soil biological functions, including carbon turnover, nutrient cycling and disease suppression. Literature findings were validated under Australian soil conditions by applying seven commonly used herbicides (glyphosate acid, 2,4-dichlorophenoxyacetic acid [2,4-D], metsulfuron-methyl, trifluralin, diuron, atrazine and diflufenican) and one fungicide (tebuconazole) to five contrasting cropping soils at a recommended and five times recommended rate. Soil functionality was assessed using a range of tools including multi-enzyme (e.g. β-N-acetylglucosaminidase and leucine aminopeptidase contributing to organic N transformation), substrate-induced respiration techniques and the nitrification assay.

An experiment was also conducted to determine the potential effects of repeated applications (1, 3 or 9 doses) of glyphosate at 2.2 kg a.i./ha to three contrasting soil types over a period of 10 months. Microbial community structure was determined at the end of the incubation by next-generation sequencing of 16s ribosomal RNA (rRNA) and internal transcribed spacer (ITS) regions for bacteria and fungi, respectively.

In order to assess the relevance of soil borne herbicide residues on crop growth, international literature was accessed and compiled to identify toxicity thresholds. To meet required quality criteria, the work needed to include a dose-response curve, where a crop was sown into soil with increasing herbicide concentrations, and a shoot or root growth response measurement (either length or biomass). Search terms included ‘herbicide’ and ‘soil’ and ‘phytotoxicity or bioassay’ and ‘crop’ or ‘plant’, where iterative searches were conducted using the specific **herbicide** as a search term. Where relevant papers were found, references and citations of those papers were checked for additional relevant papers not picked up by the original database searches. To validate literature data (trifluralin, sulfonylureas) or provide missing data (clopyralid), dose-response bioassays were conducted for soil borne trifluralin phytotoxicity to wheat, and trifluralin, metsulfuron-methyl and clopyralid phytotoxicity to lupins. The soil used was a sandy Tenosol from Wongan Hills, Western Australia, with low organic matter. This represented a 'high-risk' cropping soil due to its low herbicide sorption and low microbial activity hence slower herbicide degradation. Increasing doses were applied to soil one month before sowing and soil was analysed for herbicide residue level at sowing. Shoot biomass was measured 18 days after sowing. The effective dose required to reduce shoot biomass by 20% (ED_{20}) was calculated by fitting log-logistic response curves to each data set. Due to the lack of data from literature meta-analysis, toxicity thresholds were pooled for monocots (oat, wheat, barley) and dicots (lupin, lentil, field pea, canola) and the geometric mean of the ED_{20} for each crop type was used as an estimated 'average' threshold. Hazard assessments were performed by comparing herbicide dose-response thresholds (toxicity) to residue survey data (exposure) and qualitatively characterising sites where toxicity exceeded exposure.

Results and discussion

Exposure assessment – benchmarking herbicide residue levels in soils

Results for the 2015 and 2016 soil survey demonstrated similar trends of herbicide residues in soil just prior to planting, despite being undertaken on different paddocks, taken by different staff and in different years. Report levels from the 2016 survey are reported here, with results from 2015 presented in a previous update paper (Rose et al., 2016). As with the 2015 survey, glyphosate and aminomethylphosphonic acid (AMPA) were frequently detected (67% and 93% of samples, respectively), with similar median concentrations of 218µg/kg and 308µg/kg, respectively. In 2016, the most frequently detected herbicide (in 94% of all samples) was 2,4-D; but as with the 2015 survey, 2,4-D concentrations were generally low, with 75% of samples containing <3µg/kg (i.e. <1% of a conventional application dose). Trifluralin was also frequently detected (>50% of samples) with similar 75th percentile values to 2015, but with a substantially higher maximum residue concentration

Table 1. Concentration of herbicide residues in 0-10cm soil samples taken prior to sowing (March-April) in 2016.

Group	Active	Detection Frequency (%)	Median concentration (µg/kg)	75th Percentile concentration* (µg/kg)	Maximum concentration (µg/kg)
A	Clethodim	5	0	0	14
B	Triasulfuron	12	0	0	3.3
	Metsulfuron-Methyl	4	0	0	0.6
	Sulfometuron-methyl	0	0	0	0.0
	Chlorsulfuron	4	0	0	0.7
C	Simazine	13	0	0	40
	Atrazine	6	0	0	25
	Terbuthylazine	5	0	0	29
	Metribuzin	2	0	0	6
	Diuron	30	0	12	275
D	Trifluralin	51	4	95	5345
F	Diflufenican	60	12	20	137
I	MCPA	42	0	0	66
	Dicamba	0	0	0	0
	2,4-D	94	1	3	107
	Fluroxypyr	4	0	0	1
	Triclopyr	26	0	0	34
	Clopyralid	5	0	0	6
J	Prosulfocarb	7	0	0	28
K	Pyroxasulfone	18	0	0	27
	Metolachlor	18	0	0	60
M*	Glyphosate	67	218	588	3640
	AMPA	93	308	615	2270

** i.e. 25% of samples contained residue levels above the concentration shown in this column* of 5345μg/kg in 2016 compared to 590μg/kg in 2015. Diflufenican, MCPA and diuron were also detected in 30% or more of the 2016 samples. Of the additional herbicide residues screened in 2016 that were not analysed in 2015, pyroxasulfone and metolachlor were both detected in 18% of samples, with maximum concentrations of 27μg/kg and 60μg/kg, respectively.

Toxicity assessment – soil functions

A review of over 340 peer-reviewed articles found that there is little evidence for consistent, long-term impacts to soil (microbially-mediated) functions caused by herbicides when used at registered label rates. Some site-specific exceptions include the interaction of sulfonylurea herbicides with certain pathogens (e.g. rhizoctonia) causing greater disease risk as well as inhibition of N-cycling on alkaline soils. Our controlled laboratory experiments screened the impacts of seven different herbicides (glyphosate, metsulfuron-methyl, 2,4-D, atrazine, diuron, trifluralin, diflufenican) on soil enzyme activities and nitrogen (N)-cycling in five different soil types and confirmed that effects are minimal at maximum label rate application. Application over label rate (5 times) of metsulfuron-methyl had significant but minor impacts (<25% of control level) on N-cycling in three of the five soils tested (impact on two alkaline soils and one low OM soil). In a subsequent nine-month incubation experiment, single or repeat application of glyphosate at 2.2kg a.i./ha every three months at label rates had no significant effects on soil microbial communities or their function, across the three different soil types

Table 2. Effect of repeated dose of glyphosate (as Roundup CT®) over 10 months on soil biological functions.

Glyphosate application over the 10-month incubation	Chromosol	Vertosol	Tenosol
1 dose at start	No significant effect	No significant effect	No significant effect
1 dose at end	No significant effect	No significant effect	No significant effect
3 doses	No significant effect	No significant effect	No significant effect
9 doses	No significant effect	No significant effect	Arabinose (↓ 15%) Glucose (↓ 15%) Cellulase (↓ 30%) Phosphatase (↑ 25%) Chitinase (↑ 25%)

Table 3. Dose-response thresholds (ED_{20}) for 20% reduction to crop growth (either root or shoot) in short-term bioassays (<28 day). Values are from numerous literature sources and averaged (geometric mean) across plant types. Dicotyledonous crops include lentil, field pea, lupins, canola, chickpea, mungbean and sugarbeet. Monocotyledonous crops include oats, wheat and barley.

Group	Active	Estimated average ED_{20} for Dicotyledonous crops (μg/kg)	Number of data points obtained	Estimated average ED_{20} for Monocotyledonous crops (μg/kg)	Number of data points obtained
A	Clethodim	NA		NA	
B	Sulfonylureas	0.2	40	NA	
C	Triazines	160	14	60	10
	Diuron	NA		900	1
D	Trifluralin	NA		130	8
F	Diflufenican	NA		NA	
I	Phenoxys	NA		NA	
	Triclopyr	NA		NA	
	Clopyralid	50	1	NA	
J	Prosulfocarb	NA		NA	
K	Pyroxasulfone	NA		NA	
	Metolachlor	NA		NA	
M*	Glyphosate	>1200	5	>1400	2
	AMPA	NA		NA	

* *Although thresholds are soil type-dependent for all herbicides, the relatively high variability in glyphosate bioavailability across soil types makes it difficult to ascribe a single threshold value. The value given is the lowest observed threshold; occurring for lupin (dicot) or wheat (monocot) growing in a sandy soil with banded phosphorus (P) fertiliser. NA = no suitable data found from the review of public literature.*

(Table 2). Monthly application of glyphosate only caused negative impacts in the Tenosol soil type (sandy, low organic matter) but not the heavier-textured Chromosol or Vertosol soil type (Table 2).

Toxicity assessment – crop biomass/vigour

Despite reviewing over 250 peer-reviewed or publically available documents, only a small number of relevant data could be obtained to determine the threshold soil concentrations of herbicides that cause crop phytotoxicity. The majority of these were for the sulfonylurea herbicides, mainly because bioassay techniques were previously the most sensitive method for detecting residues. Sulfonylureas can still be biologically active against dicotyledonous crops at levels near the limit of detection of chemical analysis techniques, with an estimated average ED_{20} at 0.2µg/kg. There were a useful number of threshold values also available for trifluralin and the triazines simazine

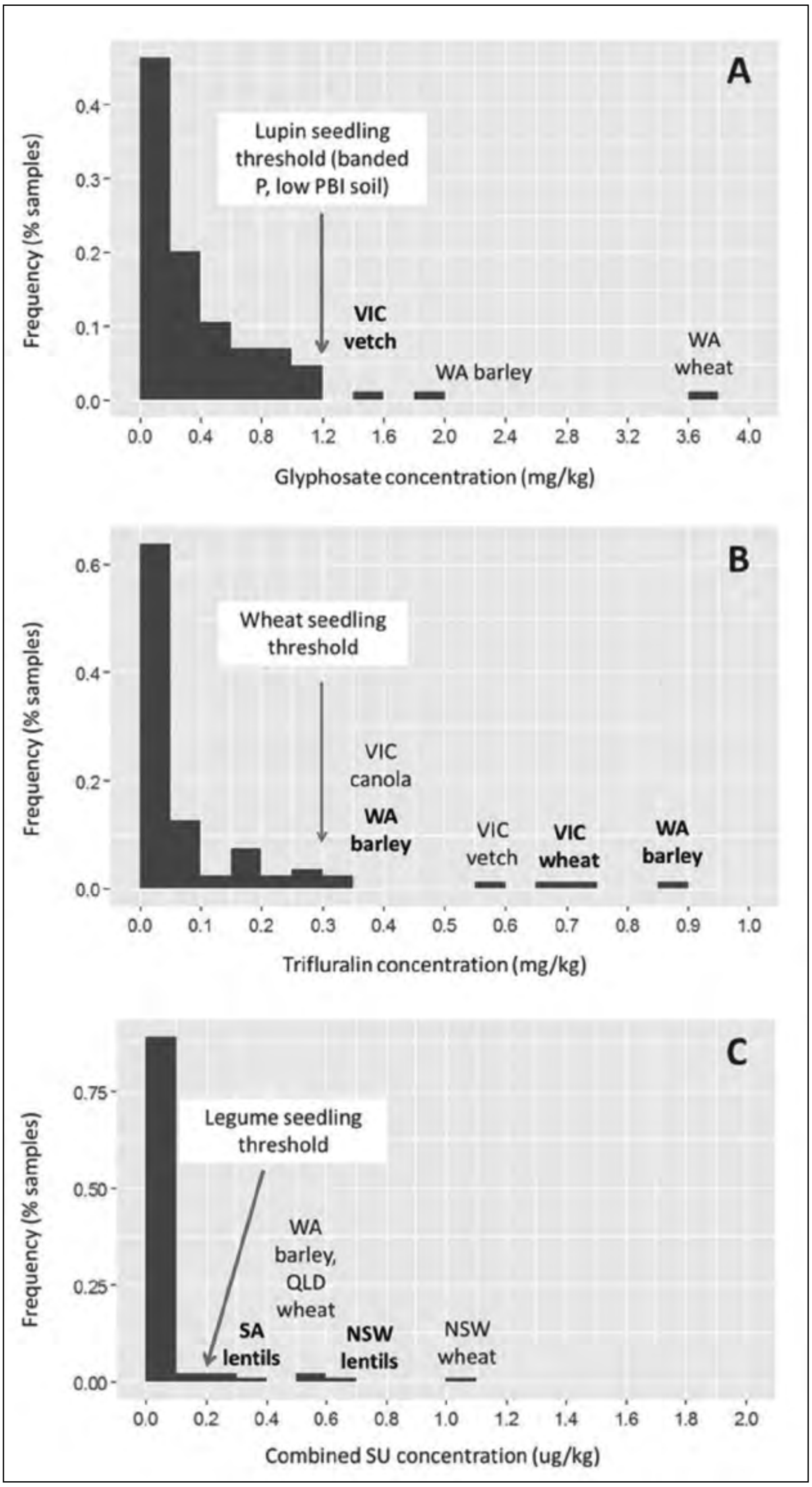

Figure 2. Hazard assessment for A) glyphosate, B) trifluralin and C) sulfonylurea residues in soil. Text in bold indicates potential negative impacts on growth of sensitive crop. Normal text indicates paddocks exceeded thresholds for sensitive crops but when planted with a tolerant crop unlikely to suffer impacts.

and atrazine (Table 3), but a significant knowledge gap for many herbicides detected in the residue survey; including diuron, diflufenican, pyroxasulfone, metolachlor and group I herbicides remains. This paucity of knowledge is a significant drawback in the interpretation of the practical implications of soil residue data.

Hazard assessment – crop biomass/vigour

Taking into account the lack of threshold data available for many of the herbicide residues detected, a hazard analysis was performed for glyphosate, trifluralin and the sulfonylurea herbicides, for which adequate thresholds were available. For glyphosate, only three paddocks from the 40 analysed contained residues that would potentially impact upon legumes grown in Tenosol with P fertiliser (Figure 2A). Of these, two were cropped with cereals, which are much more tolerant to glyphosate residues, even when P is applied, and are unlikely to have suffered injury. Previous work (Rose et al., 2018) has shown that the co-application of banded P in particular can increase the availability of glyphosate in soil as is competes for similar binding sites and allows for greater phytotoxicity. The tolerance of vetch is unknown. For trifluralin, three paddocks contained residues that could potentially injure the cereal crop sown that season, two of which were in WA and one in Vic (Figure 2B). Whether or not some early damage eventuated would depend on where these residues were located within the profile in relation to the placement of the seed, and the influence of soil type on the bioavailability of the residues. The lighter-textured WA soils are not expected to bind the trifluralin as well as the heavier-textured Victorian soil, and therefore, these soils are more likely to see potential crop damage. For sulfonylureas, seven out of the 40 paddocks sampled contained residues that could affect legume crops (Figure 2C). Of these, two paddocks were planted with lentils, one of which was PBA Hurricane⁽ᴰ⁾ variety, which exhibits some tolerance to sulfonylurea (SU) residues. Overall, there was a small number of paddocks with potentially phytotoxic residues, which may limit flexibility of crop selection, but in the majority of cases the potential damage appears to have been avoided by planting tolerant crops.

Future research

A newly established project in the GRDC Northern Region will focus on measuring diuron and imazapic residues to minimise potential carryover damage, particularly for grain legumes. This project will develop techniques for determining bioavailable residues of these two residual herbicides and critical thresholds for susceptible crops, which will allow growers and adivsers to weigh up the risk of crop damage prior to planting.

Conclusion

A risk framework was used to guide the determination of impacts of residual herbicides on soil biological functions and potential plant-back issues. Within this framework, assessment of what residues of herbicides were in soil had to be conducted first prior to planting the winter crop. Analysis of 80 paddocks in total, across two seasons identified that trifluralin, 2,4-D, diuron, glyphosate and diflufenican are commonly detected in soils. Interestingly, residue levels between 2015 and 2016 were not substantially different, despite analyses of different paddocks in different regions. This data may provide further guidance for future studies. Importantly, the project has clearly identified the lack of major impacts of herbicides on soil biological functions. When herbicides are used as per label instructions, it is unlikely that they will have any long term or significant impact on soil biology. However, risk assessment studies showed some examples where residual herbicides at planting may impact on crop establishment. This was particularly noted for legumes which tend to be more sensitive and the impacts displayed included lower nodule formation, which impacts biological N_2 fixation.

Useful resources

- https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2016/02/herbicide-residues-in-soils-are-they-an-issue-northern
- https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/02/impacts-of-residual-herbicides-on-soil-biological-function
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Fixing more N – improving the performance of rhizobial inoculants in suboptimal conditions

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GRDC project code: 9176500

Keywords

- soil acidity, dry-sowing, inoculation, nodulation, faba bean, lentil, N_{2} fixation.

Take home messages

- Inoculation of faba bean, lentil and field pea with rhizobia is critical to pulse performance on acid soils.
- Strains of rhizobia selected for improved acidity tolerance have improved nodulation of bean/lentil in the field, with corresponding improvements in overall production and yield.
- Doubling the inoculation rate improves nodulation in acidic and dry soils. Granules have shown potential, but their performance is dependent on the number of rhizobia delivered.
- Contact between rhizobia and pesticides should be avoided where possible, when sowing pulses on acid or dry soils that are inoculation responsive.
- The addition of lime to very acid soils remains important to improve plant root growth, overall performance of the pulse crop and to prevent further soil acidification.

Background

Expansion of the pulse industry is seeing crops increasingly sown on soils that are challenging to plant establishment and growth. In these areas, pulses are often grown in the paddock for the first time, or have been infrequently grown and are therefore likely to benefit from rhizobial inoculation. In these situations, soil constraints such as acidity, particularly when combined with practices such as dry sowing or the application of pesticides to seed, can profoundly affect the success of nodulation and subsequent performance of the pulse crop. This paper examines the impact of the aforementioned factors on legume nodulation, dry matter and grain production and provides an overview of work being undertaken to improve the performance of rhizobial inoculants.

Results

Acid tolerant strains of rhizobia – an update of progress

Relationship between soil pH and the nodulation of legumes in the E/F inoculation group (pea/bean/lentil/vetch)

Detrimental impacts of soil acidity on legume nodulation are widely reported, with pea, bean and lentil symbioses considered moderately sensitive, based on observations of inadequate field nodulation (Burns et al. 2017) and reduced rhizobial survival in acidic soils (Drew et al. 2012a).

Rhizobia strain WSM-1455 (Group F) is used to make commercial inoculants for faba bean and lentil, and is sometimes also used on field pea. Recent assessments of nodulation by WSM-1455 in field trials illustrates the impact that decreasing soil pH (measured in $CaCl_2$) has on the number of nodules per plant formed by this inoculant strain (Figure 1). Nodulation decreased rapidly below pH 6 and was negligible at pH 4. The significance ($P<0.01$, R^2 = 0.88) of the relationship across a range of growing conditions and legume species demonstrates the key role acidity plays in limiting the nodulation of this legume group. There was no obvious difference between legume species within the inoculation group. The data indicate a maximum level of nodulation of about 75 nodules per plant. This is less than current industry guidelines for the satisfactory nodulation for legumes in this inoculation group (100 nodules per plant, Drew et al. 2012b) and indicates some revision of the benchmark is needed.

In a paper presented in the 2018 GRDC Grains Research Update proceedings (https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/02/pulse-rhizobia-performance-on-acid-soils), it was suggested that the opportunity to improve the performance of the commercial inoculant strain produced for bean and lentil was between pH 4.5 and 5.0. Based on the data shown in Figure 1, it appears this opportunity may extend further to pH 5.5, where decreased nodulation by WSM-1455 is evident. Below pH 4.5, nodulation will likely be compromised, regardless of the rhizobial strain used (data not shown) and soils must be limed to achieve satisfactory levels of nodulation.

Seeking rhizobia strains with improved acidity tolerance

A cohort of rhizobia strains with improved acidity tolerance has been undergoing field testing since 2015. Rhizobial strains were initially selected for their ability to increase field pea nodulation in low pH (4.2) hydroponic solutions, the pH point where nodulation by inoculant strain WSM-1455 is known to be severely reduced in the test system.

The most promising strains selected using the hydroponic screen (SRDI-954, SRDI-969, SRDI-970, SRDI-1000 and WSM-4643) have since been evaluated at up to 19 field sites, mostly on bean and lentil.

Several strains have consistently improved legume nodulation (Figure 2). Strain SRDI-969 increased nodulation most (by 55 percentage units across 16 field sites) compared to the commercial inoculant strain.

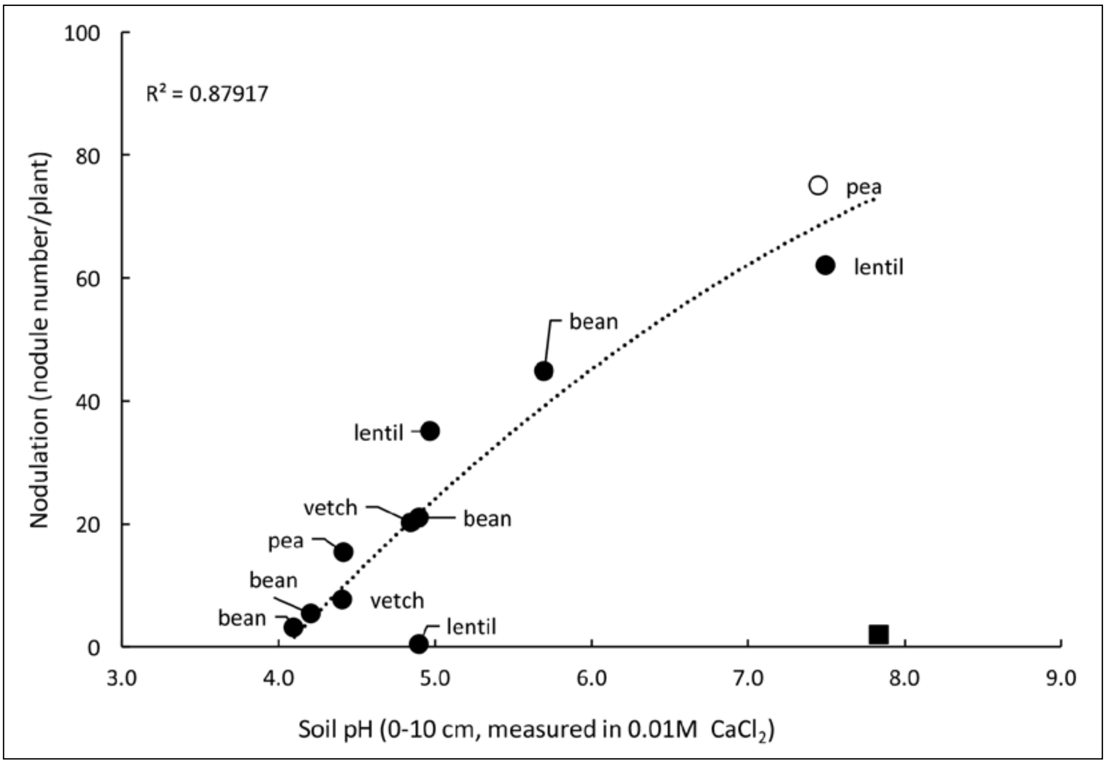

Figure 1. Relationship between soil pH_{Ca} (0-10cm) between pH 4.0 and pH 8.0 and the field nodulation (number of nodules per plant) of legumes inoculated with rhizobia strain WSM-1455. Value for pea at pH 7.5 (open circle) is an average of data collected from 12 sites with background rhizobia. All other values based on single sites. Value for pea at pH 7.8 (square) was unduly influenced by dry conditions at sowing and is excluded from the regression.

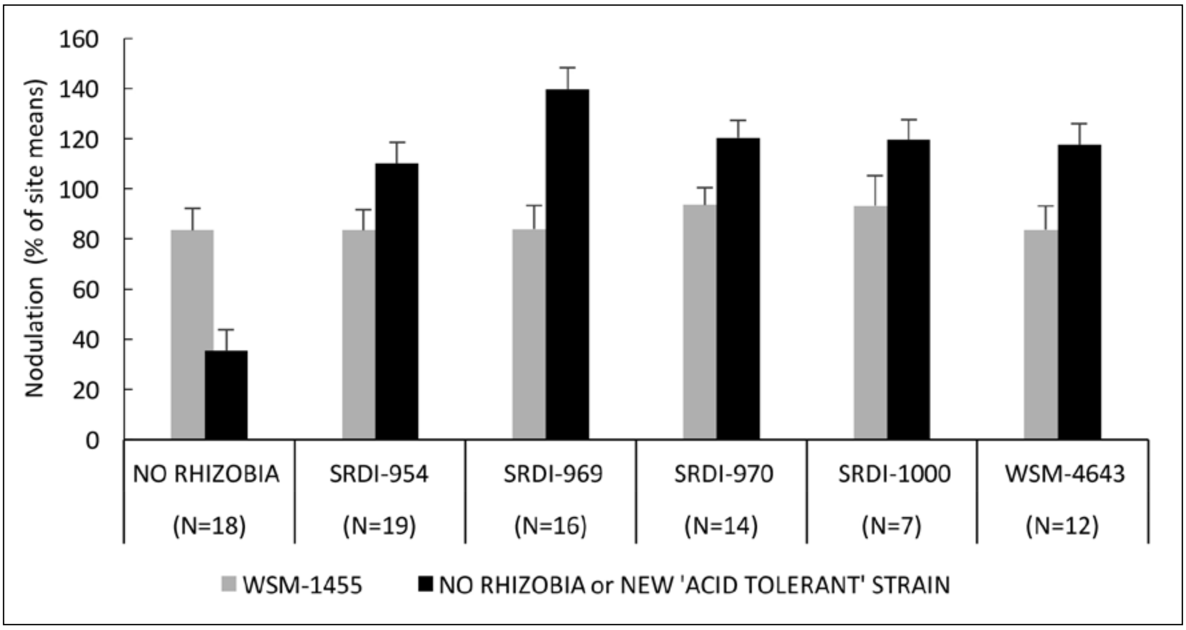

Figure 2. Nodulation of bean/lentil/pea/vetch at acidic field sites. Pairwise comparison (expressed as a % mean nodulation at sites) of new rhizobia strains against Group E inoculant strain WSM-1455. Number of sites included in each pairwise comparison shown in parentheses. Bars on columns indicate inter-site standard error.

Most sites were responsive to inoculation, with large increases in nodulation (+48 to +104 percentage units above the uninoculated treatment) measured for the inoculated treatments. This result highlights the importance of inoculation to the establishment of viable faba bean, lentil and field pea crops on very acidic soils.

Increases in total above ground dry matter production, amount of nitrogen (N) fixed and grain yield were significantly increased at some, but not all sites. However, where performance is considered across multiple sites, improved nodulation was positively correlated with both maximum dry matter production and grain yield (Figures 3 and 4).

Grain yield of uninoculated and WSM-1455 treatments was on average 69% and 98% of the site means, respectively. Strain SRDI-969 performed best at 113%.

Indications are that N-fixation has also been improved (up to 34 percentage units above WSM-1455 across five sites). This will be confirmed pending the completion of N-fixation analyses from 2018 trials.

Overall, the performance of the new rhizobia strains across a number of measures has been encouraging and there are good prospects for commercialisation. That said, it is expected that the benefits of the new strains to be limited below pH 4.5. This was borne out at two Victorian sites in 2018 (Stawell, pH 4.2 and Telangatuk, pH 4.1) where faba bean nodulation, even with the new rhizobia, was limited to less than 10 nodules per plant, which is well below the industry benchmark. At sites below pH 4.5, liming remains the most effective strategy to improve nodulation.

Improved rhizobia will still be of benefit where soils are limed, especially where there are moderately acidic sub-surface soil layers that are difficult to remediate due to the slow movement of lime down the profile.

What still needs to be done before the new strain is available commercially?

Colonisation and persistence of the strains in soil will be measured in 2019, in order to demonstrate they are as competent as WSM-1455 and to define the critical soil pH level where re-inoculation is needed, each time the crop is grown. Previously (2016 trials, pH 4.6 to pH 4.8) neither the commercial inoculant strain or the new strains were able to be consistently recovered from the soil, during summer following the pulse crop. Whether the new strains provide any benefit at higher pH is still to be determined.

The compatibility (N-fixation capacity) of the strains with the range of bean and lentil varieties available to growers is being tested. In particular, the effectiveness of the symbioses formed between beans and different strains of rhizobia varies

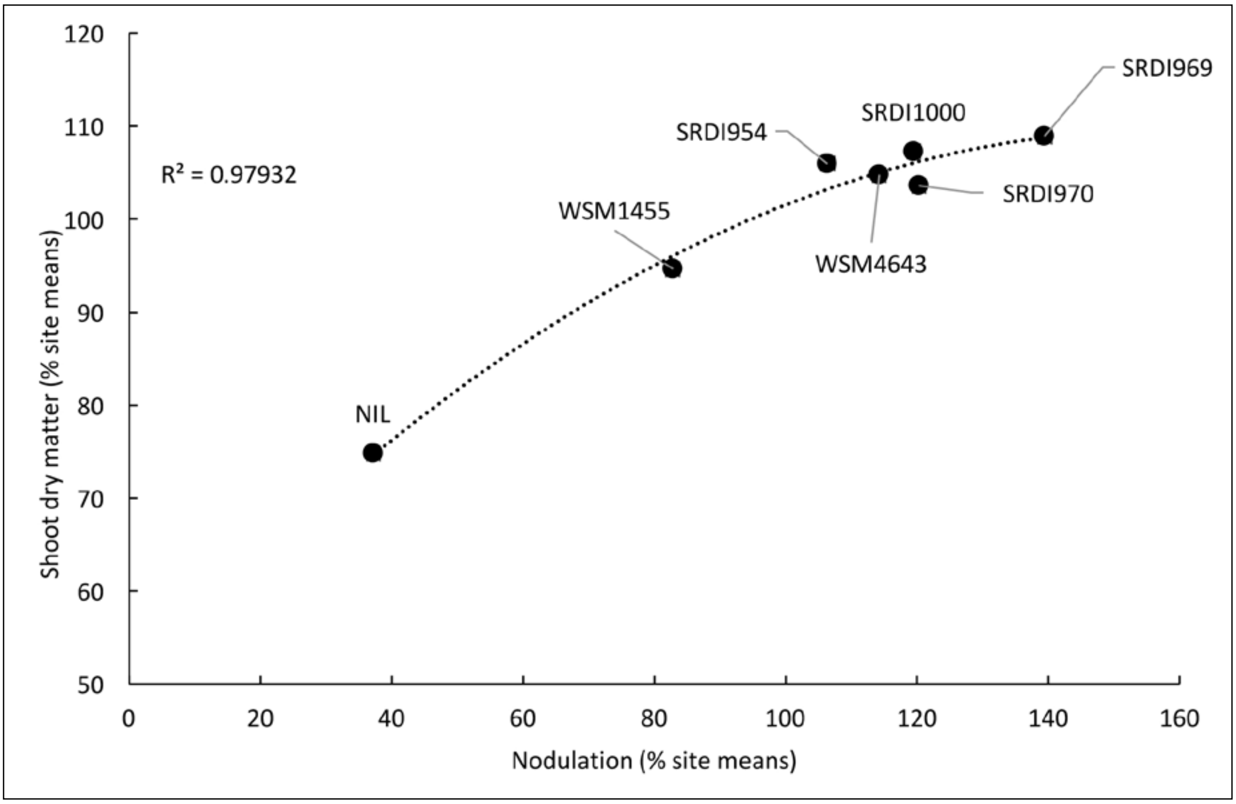

Figure 3. Relationship between nodulation by the different rhizobia strains and total above ground dry matter production (at mid pod fill) of legumes at acidic field sites.

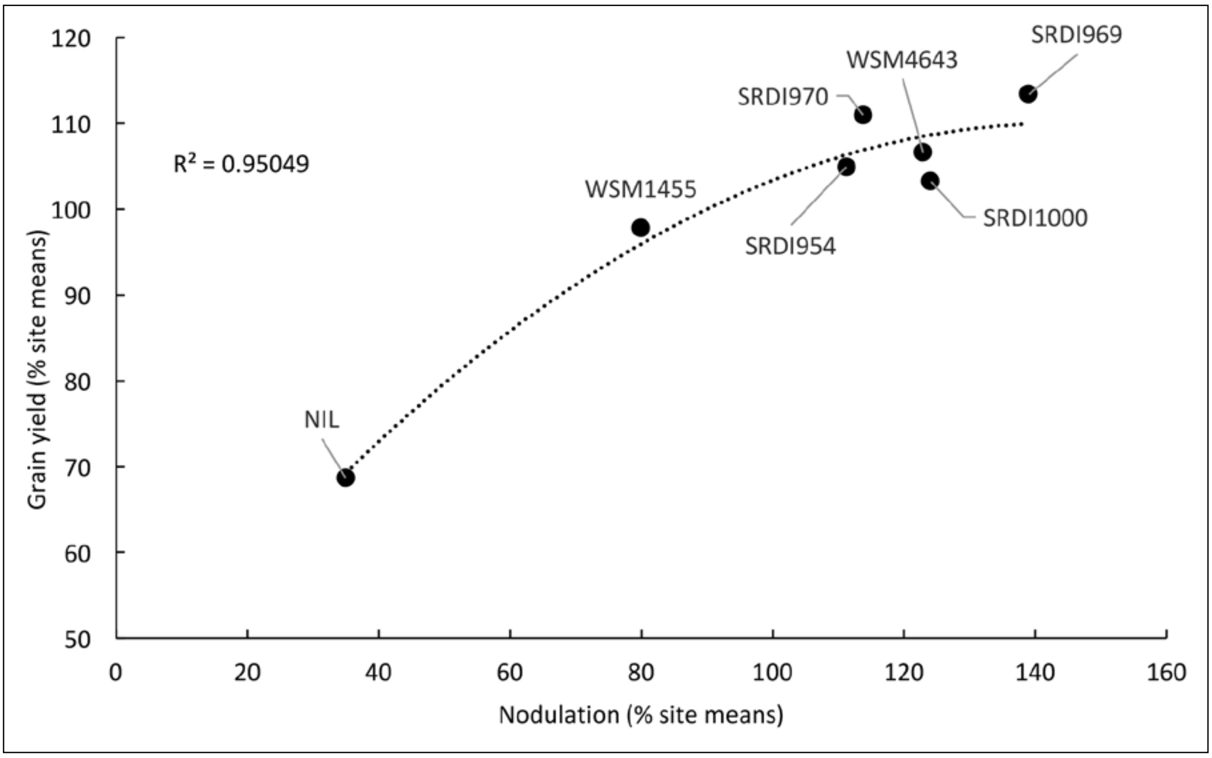

Figure 4. Relationship between nodulation by the different inoculant strains and grain yield.

considerably and may be significant in determining the strain recommended for release.

The experimental program will be completed in 2019 and the technical case for strain replacement completed in 2020.

Inoculation rate and formulation

Increasing the rate of inoculant applied as a peat slurry to seed improves nodulation, where soil conditions at sowing are suboptimal. An example from 2018 is shown in Figure 5, for chickpea sown into a sandy soil that remained dry for 18 days after sowing. The moist peat and peat granule inoculants were produced at SARDI. At this inoculation responsive site, nodulation increased from 2.5 to 5.6 to 8.3 nodules per plant with each doubling of inoculation rate. For this experiment, a peat granule was also produced to help understand if the application of rhizobia in furrow is as effective as seed application and to improve our understanding of the potential of granulated inoculants. Past efforts (Denton et al. 2009), as well as our more recent work, have been affected by variations in the carriers (peat vs. clay) and the varying number of rhizobia in commercial granules, necessitating the production of an 'experimental' granule by our laboratory.

The experimental peat granule produced nearly seven times the number of nodules produced by the lowest peat on seed rate (Figure 5). Most of the increase was in lateral root nodulation, probably the result of the rhizobia being more widely distributed in the soil. The result demonstrates the potential of a 'high count' granule to improve nodulation. The performance of two commercial granules in the trial (data not shown) was comparable to the experimental granule. However, in other trials the number of rhizobia in commercially produced granules has varied and almost certainly affected the consistency of their performance. It points to the need for improved quality control, similar to that mandated for moist peat inoculants.

The number of nodules on chickpea was lower than what we have previously measured on bean/pea/lentil. Further work is needed to determine optimal nodule number for chickpea.

Improved nodulation in response to increased inoculation rate is commonly reported (Denton et al. 2013, Roughley et al. 1993) and provides a practical way of improving nodulation where legumes are sown for the first time, especially on hostile soils. However, a note of caution. Growers have provided feedback that seeder blockages have resulted

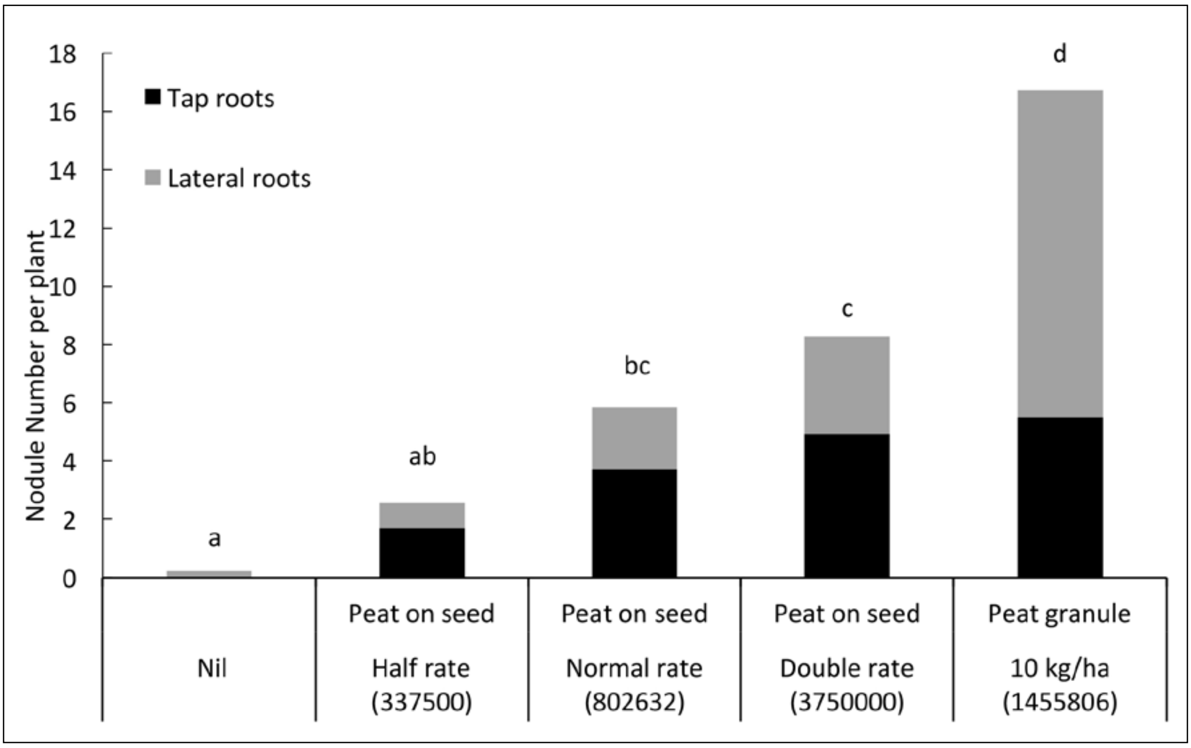

Figure 5. Effect of inoculation rate and formulation on chickpea nodulation (nodule number per plant) at Lameroo, SA. Number of rhizobia per seed indicated in parentheses under inoculation rate. Commercial inoculants at manufacture, applied at normal rate deliver about 600,000 rhizobia per chickpea seed. Letters above columns indicate significance ($P<0.05$). Columns marked with the same letter are not significantly different.

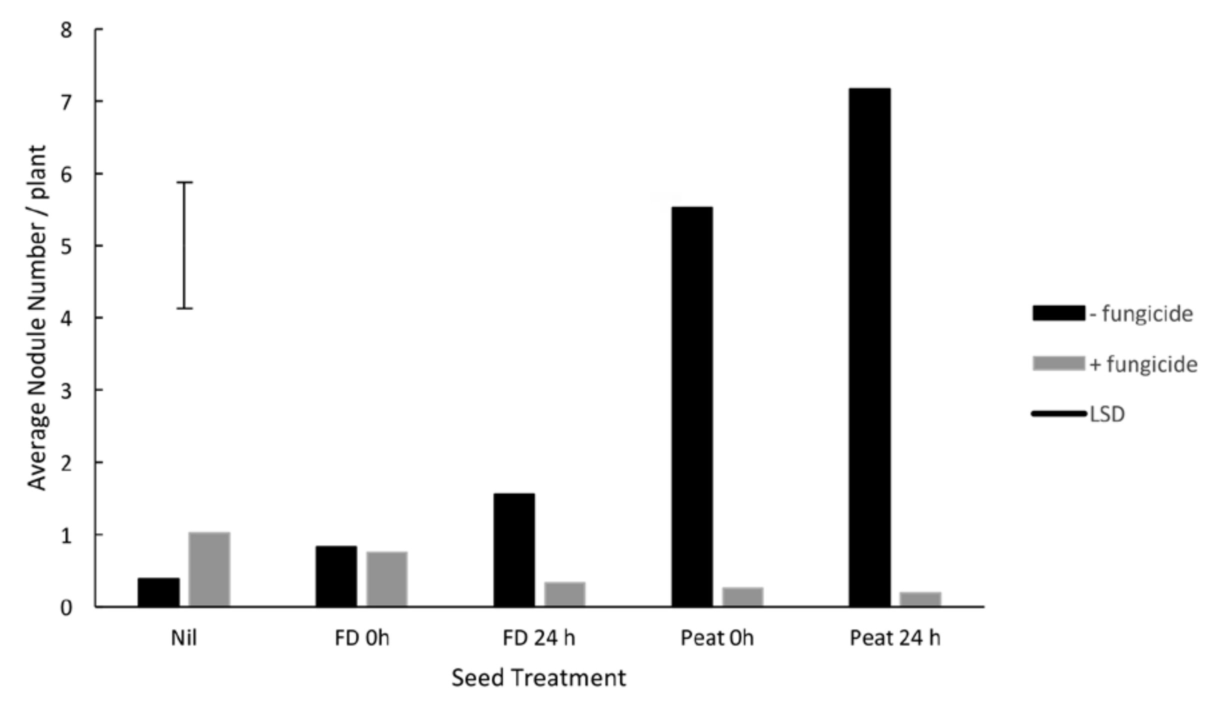

Figure 6. Effect of P-Pickel T® fungicide, formulation type (FD = freeze-dried, and peat) and time between inoculation and sowing (0hr or 24hr) on the nodulation of pea cv. Oura⊕, Minnipa, SA, 2018. LSD is the least significant difference at P<0.05.

when they have increased the inoculation rate, so we suggest testing a small test batch of seed first to avoid such problems.

Pesticides

Particular care needs to be taken where rhizobia are applied with pesticides on seed, especially where it is to be sown in suboptimal soil conditions. This was clearly shown in a trial at Minnipa (Eyre Peninsula, SA) in 2018. Seed of field pea (cv. Oura⊕) was coated with the fungicide P-Pickel T® (PPT, containing thiram and thiabendazole) at commercial rates, or left uncoated (control). Commercial peat (WSM-1455) or freeze-dried inoculant was applied to pesticide-coated and uncoated seeds and sown into a dry sandy soil (8% g/g moisture) either immediately (within 2hr of inoculation) or 24hr after inoculation.

The only two treatments that resulted in a substantial number of nodules per plant were peat formulations applied immediately before sowing or 24hr before sowing, in the absence of PPT (Figure 6). Average nodule number was much lower on pea plants that were inoculated with a freeze-dried formulation, even where seed was not treated with PPT (Figure 6).

These reductions were partly the result of fewer rhizobia surviving on the seed (data not shown).

Where pesticide application is necessary, granular rhizobial inoculant or a peat slurry in furrow may provide a better option despite concerns about granule product quality, reducing direct exposure of the rhizobia to the pesticide.

Discussion

There are reasonable prospects that a strain of rhizobia with improved acid tolerance will be released for faba bean and lentil in 2021.

Where a rhizobia strain with improved acidity tolerance is combined with good inoculation practice, it should be possible to reduce the symbiotic constraints to faba bean and lentil production between $pH_{(Ca)}$ 4.5 and 5.5. None of the rhizobia strains tested thus far appear to be able to persist in soil below $pH_{(Ca)}$ 5.0, so re-inoculation will be essential each time the crop is grown. Further work is underway to clarify strain persistence.

Regardless of the rhizobia strain used, where sowing conditions are suboptimal and the paddock likely to be responsive to inoculation, growers should consider increasing their inoculation rate and avoid exposing the rhizobia to incompatible pesticides, where it is practical to do so.

Improved rhizobia should be seen as an accompaniment, not a replacement for liming. Liming remains important to prevent further acidification and is critical to the longer term sustainability of the farming system. Even where the improved rhizobia are used, nodulation will be suboptimal below pH 4.5 and liming remains the most effective strategy to improve nodulation. Plant root growth will also likely benefit from the addition of lime and improve overall performance of the pulse crop.

Granulated rhizobial inoculants have produced some good results in dry and/or acidic soils and could provide a viable alternative to peat on seed, particularly where pesticides are an issue. Increased levels and consistency of rhizobial number in commercial granules would see them more widely recommended and used.

Although the impact of seed-applied fungicides such as PPT may not be as detrimental to legume nodulation when conditions at sowing are not stressful (e.g. adequate soil moisture), the combination can be detrimental in stressful sowing conditions. In this case, separation of the inoculant from the fungicide, by using a granular formulation may be a better option. Where peat slurries are applied to seed treated pesticides, inoculant manufacturers recommend the seed is sown within four hours after inoculation for some pesticides. These guidelines should be strictly adhered to.

Useful resources

Inoculating Legumes: A Practical Guide:

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

Soil Acidity:

http://www.agbureau.com.au/projects/soil_acidity/

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Current management advice for Green peach aphid and Russian wheat aphid

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This paper was under review at the time of publication of proceedings and can be found in full at https://grdc.com.au/resources-and-publications/grdc-update-papers

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Russian wheat aphid - current investigations and recent findings

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GRDC project codes: 9176535 and CES00004

Keywords

- Russian wheat aphid, economic thresholds, green bridge, seed treatments.

Take home messages

- Development of regional economic thresholds for Russian wheat aphid (RWA) is in progress at trial sites throughout SA, Victoria, Tasmania, and NSW. Use of international thresholds are still advised until Australian thresholds are developed.
- RWA has been detected as far north as the Liverpool Plains, NSW. Growers can track changes in RWA distribution on a recently developed interactive map.
- Barley grass is a major host supporting RWA survival over summer. Symptoms have been rarely observed in non-crop grasses. Looking for symptoms is, therefore, not a good strategy for monitoring for RWA presence in weeds.
- Insecticide seed treatments, while efficacious, should be used with caution and given priority in areas of high risk of infestation of RWA in 2019.

Background

Russian wheat aphid (RWA) is one of the world's most economically important and invasive pests of wheat, barley and other cereal grains. Since first being discovered in SA in 2016, RWA has been found widespread in cereal growing regions of SA, Victoria, NSW and Tasmania. Their small size, green colour, elongated shape, very short antennae and apparent lack of siphuncles readily distinguish RWA from other pest aphids found in Australian cereal crops. Unlike other aphids, which cause damage through feeding on plant nutrients, RWA injects salivary toxins during feeding that cause rapid, systemic phytotoxic effects on plants, resulting in acute and observable plant symptoms, as well as potentially significant yield losses.

The first detection of RWA in Australia occurred on cereal crops in May 2016. Within one month, a combined industry-government biosecurity committee determined that an eradication attempt for RWA was unlikely to be successful. RWA is now a management concern for grain growers in regions where it has been found.

In a recent study by Avila et al. (2019) the potential spread and establishment of RWA in Australasia was assessed using a re-parameterised CLIMEX model that took into account currently known distribution records of the aphid and the presence of irrigated crops. According to the model results, RWA has the potential to establish in all key grain growing regions in Australia. However, since RWA has not been previously detected in Australia, it is not yet known what effect local agro-climatic conditions will have on the ability of RWA to establish and feed on hosts, which include wheat, barley and a large range of cultivated and wild grasses. A new GRDC investment, *'Russian wheat aphid risk assessment* *and regional thresholds'* (investment 9176535) has been launched to investigate regional risk and management tactics for RWA.

Current research

The South Australian Research & Development Institute (SARDI) and **cesar** are assessing the regional pressure of RWA with the aim of developing regional economic thresholds and gaining a better understanding of the role that green bridges are playing in supporting RWA populations between cereal cropping periods.

Currently only provisional intervention thresholds for RWA are available, which are based on US research (Pike and Alisson, 1991). This research recommends control at the following points: >20% of all plants infested up to GS30 and >10% of tillers infested from late stem elongation (following GS30). Since initial detection of RWA in Australia, growers have been advised to use these thresholds as they represent the best current knowledge.

Development of regional economic thresholds

In 2018, 15 trial sites were set up throughout SA, Victoria, NSW and Tasmania by Dr Maarten van Helden and Thomas Heddle (SARDI) in collaboration with regional organisations. Sites were chosen in regions where RWA was known to be established. Cereals tested at each regional trial site included spring wheat and barley. Winter wheat, durum wheat and oats were also tested at some sites. A subset of these trial sites was artificially inoculated with the aphid at a specific time point to ensure thresholds could be developed. This trial site work builds on the SA Grains Industry Trust (SAGIT) Time of Sowing trials conducted by SARDI in 2017 and 2018 in three regions – Bool Lagoon, Roseworthy and Loxton.

Each 2018 trial site included the following treatments – Gaucho® seed treatment, chlorpyrifos treatment, seed treatment plus chlorpyrifos, and no treatment. Yield data were collected for each treatment at each trial. Data on RWA abundance, presence of beneficials, and RWA migration times were also collected throughout the season at these sites.

As we currently have only one season of trial site data, no inferences can yet be made. However, these trials will be repeated in 2019, which will strengthen our data set and enable further investigation into the relationship between RWA numbers, plant symptoms and yield loss across regions, as well as allowing for development of regional economic thresholds.

Green bridge surveillance and risk assessment

There are many factors that will influence RWA survival during times when its favoured hosts are not available for nourishment, including the local climate, land use (e.g. vegetation on roadsides, irrigated public spaces), availability of alternate hosts, abundance of volunteer cereals, and predation by beneficials.

Surveillance for RWA over spring and summer from October 2018 to February 2020 is generating data about types of vegetation the aphid is surviving on between cropping, and what environmental conditions support its survival over this period, as well as collecting valuable information about beneficial species predation of RWA. Once enough green bridge data is collected, use of modelling algorithms will allow us to predict aphid population growth over this critical period.

The ultimate aim of the project is to develop additional guidelines for RWA management that are regionally specific. While trial site results are not discussed here, due to limited data so far, there is information included on preliminary findings of green bridge surveillance and a RWA population growth modelling tool under development that will make use of trial site data.

Where has RWA been found?

Our most current data indicates that RWA is present in a large and still expanding area covering all cereal growing regions of SA, Victoria, Tasmania and most of NSW. Our spring sampling shows that the aphid is widespread across these regions in at least low numbers, however it is not known how typical this spring distribution is as we have only sampled for one season. In late 2018, the aphid was detected at Coonabarabran and the Liverpool Plains (NSW), which is a northerly extension of range for this aphid.

A distribution map that is still commonly used to understand and demonstrate RWA distribution in Australia is derived from AusPestCheck (Plant Health Australia), which collected monitoring data from state governments when RWA was under active surveillance by biosecurity authorities. Through the current project, we have produced an RWA Portal which includes an up-to-date map, which sources data from 2018 green bridge surveillance and adviser reports to PestFacts services. This map updates in real time, approx. every three hours, and lists information sources for each data point, evidence of absence data, and allows users to toggle with the timeframe between 2016 and 2019.

It can be found on the RWA Portal (http://www.cesaraustralia.com/sustainable-agriculture/rwa-portal/).

What we know about the environmental conditions under which RWA will thrive

Despite few RWA issues reported to PestFacts services during the 2018 cereal growing season, our spring sampling detected RWA in all cereal growing regions where RWA has been reported previously. The presence of RWA in an area does not automatically mean it will cause damage to crops. RWA needs to infest cereals in early autumn in order to develop into damaging population levels in spring during booting and flowering.

While we are still accruing data about conditions that support RWA survival and can give limited advice, the following is what we can say:

- Hot and dry summer conditions reduce over-summering populations of the aphid, with RWA likely to persist where there is available moisture and green material (from rainfall or irrigation).
- Higher than average temperatures are unfavourable for RWA survival.
- Localised summer rainfall events resulting in germination of weeds like barley grass can provide refuges for the aphid.
- Field observations and experiments over the past three seasons indicate that RWA abundance and development on crops is much higher in low rainfall zones (<400mm per year) and on drought stressed crops.
- This year's field trial observations support international research findings that indicate mature crops (GS40 or higher) are less attractive and are less likely to be invaded by RWA in spring.

This work is ongoing – RWA is still a very new pest to Australia and we are continuing to learn about its biology as the current investment progresses. More pertinent information about environmental influences is likely to be gained at crop establishment, particularly in regard to area-wide aphid abundance and flight timing. Significant

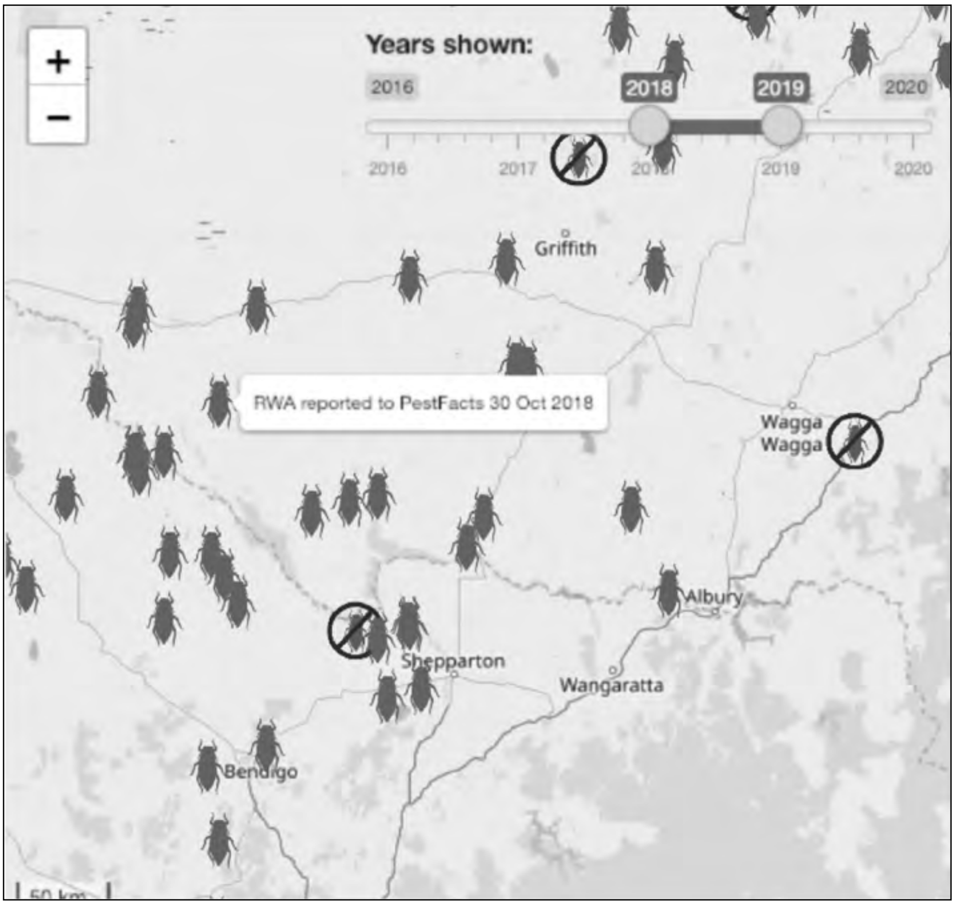

Figure 1. RWA Interactive Map. Detections span 2016-2018 and with data sourced from 2018 green bridge surveillance and adviser reports to PestFacts. Red (light) icon indicates RWA detection in that area. Green (dark) icon with cross out denotes no RWA found during summer surveillance (map developer – Dr James Maino, **cesar**).

early infestation of a crop will only occur through a combination of abundant green bridge and good flight conditions that would aid RWA migration to cereal paddocks during the seedling stage in early autumn. Good flight conditions for aphids are calm, warm days over 20°C. During the 2018 season, these conditions were not met in southern Australia.

Influence of region, season and local conditions on RWA populations

SARDI and **cesar** have been sampling RWA over spring, with summer time follow up surveys currently in progress to determine what conditions support survival of the aphid leading into autumn sowing. Data analysis is ongoing, but some early conclusions can be drawn regarding RWA abundance across region and season.

During the spring, RWA populations were found to be widespread in Victoria, NSW and SA, consistently appearing in randomly selected roadside stops, regardless of proximity of cereal crops or sources of water. The limiting factor for their presence seemed to be the presence of preferred host species, in particular barley grass. At most sites, populations of RWA were found residing in weeds outside of crops, however these populations were generally smaller than those found within crops. Within crops, large populations, causing visible symptoms, were most commonly observed in young tillers, particularly on paddock edges.

Populations in southern Victoria and Tasmania were comparatively sparse, while in Tasmania they were largely restricted to crops despite the abundance of green host weeds that were observed to be preferred in Victoria and NSW (such as barley grass). It is unclear if the lack of positive detections of RWA from the northwestern regions of Tasmania and the southern regions of Victoria are due to populations being too diluted among the plentiful green vegetation to detect or are due to unsuitability or incomplete dispersal.

While summer abundance data is still preliminary as surveys are currently in progress, early insights from the Victorian sites suggest that RWA populations have declined dramatically over the summer, however they are still present throughout Victoria (Figure 2). The few active populations that were detected appear once again strongly dependent on preferred hosts such as barley grass, which had become far less common, but also appeared more dependent on persistent sources of summer water that could maintain green host plants. Three of the five active populations detected during the summer in Victoria were found within city limits, in areas that would receive relatively consistent summer watering, including weedy lawns and ovals. Over-summering RWA populations were also detected on regrowth within cereal paddocks in the cooler, southern regions of Victoria (interestingly, in areas where they were not detected during the spring).

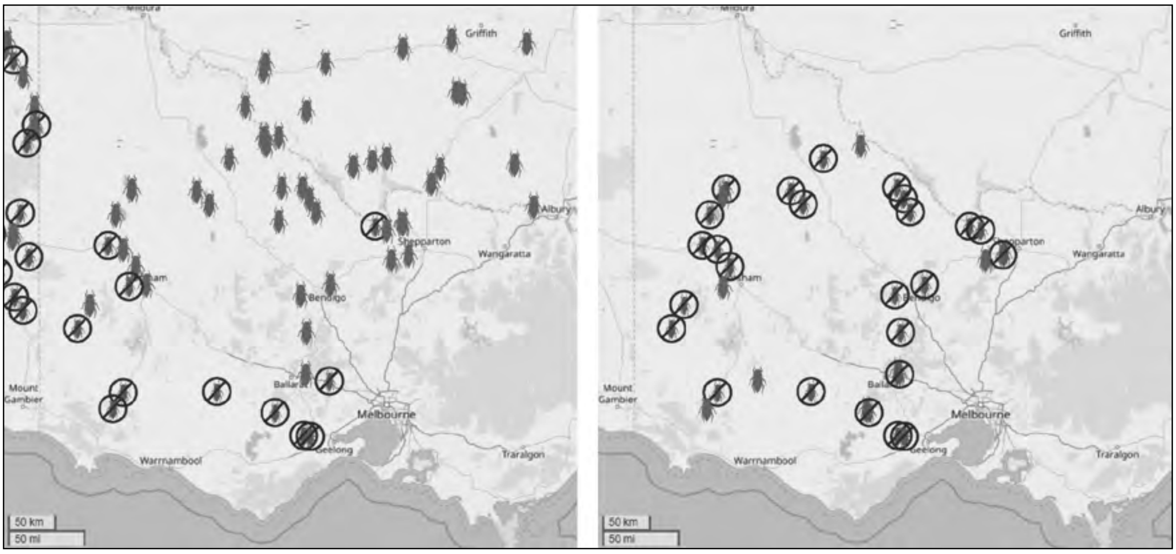

Figure 2. RWA population distribution and abundances across Victoria in the spring (left) compared to summer (right). Presences are represented by red (light) aphids, and absences by green (light) aphids with cross out.

What weeds and summer pasture species supported RWA over summer?

During the 2018 spring sampling, RWA was found on a variety of non-crop grasses, with barley grass appearing to be the preferred host, followed closely by brome grasses (including prairie grass) (Figure 3). Small colonies were sometimes found on wild oat grasses, and alates were occasionally found on phalaris grasses. Very sparse populations were found on young rice crops. These results are consistent with previous SARDI findings regarding possible host plants in SA (GRDC DAS000170 project), with *Bromus* species and barley grass being of highest preference of all weed grasses tested.

Symptoms (curled and striped leaves and trapped heads) were rarely observed in non-crop grasses, and when they were observed, were more subtle in appearance than those observed in cereal crops (Figure 4). Looking for symptoms is therefore not a good strategy for monitoring RWA presence in weeds.

Beneficial control of RWA

A diverse range of beneficial insects are known to predate on RWA and these populations will build in response to the presence of aphids throughout the season. Growers are encouraged to consider control options that will have minimal impact on beneficial populations. This investment is also investigating beneficial predation of RWA during the summer period, which will add to our knowledge of how to manage RWA at a regional level.

Beneficial invertebrates observed actively feeding on RWA populations during spring 2018 surveys included adult and larval ladybird beetles, larval brown lacewings, and parasitoid wasps. Other beneficial invertebrates commonly detected around RWA populations included spiders, hoverfly larvae, and predatory hemipterans. Large RWA populations frequently showed signs of heavy parasitism by wasps in the form of mummified aphids (Figure 5).

Using modelling to predict RWA population growth throughout the season

To extend the power of data collected through field trials, green bridge surveillance, combined with climate data, we can use modelling techniques to make inferences about how RWA populations will behave in the near future region by region.

However, robust predictions are achieved when additional data is incorporated on top of that which will be collected during the current project. For example, since RWA is an exotic pest we are using

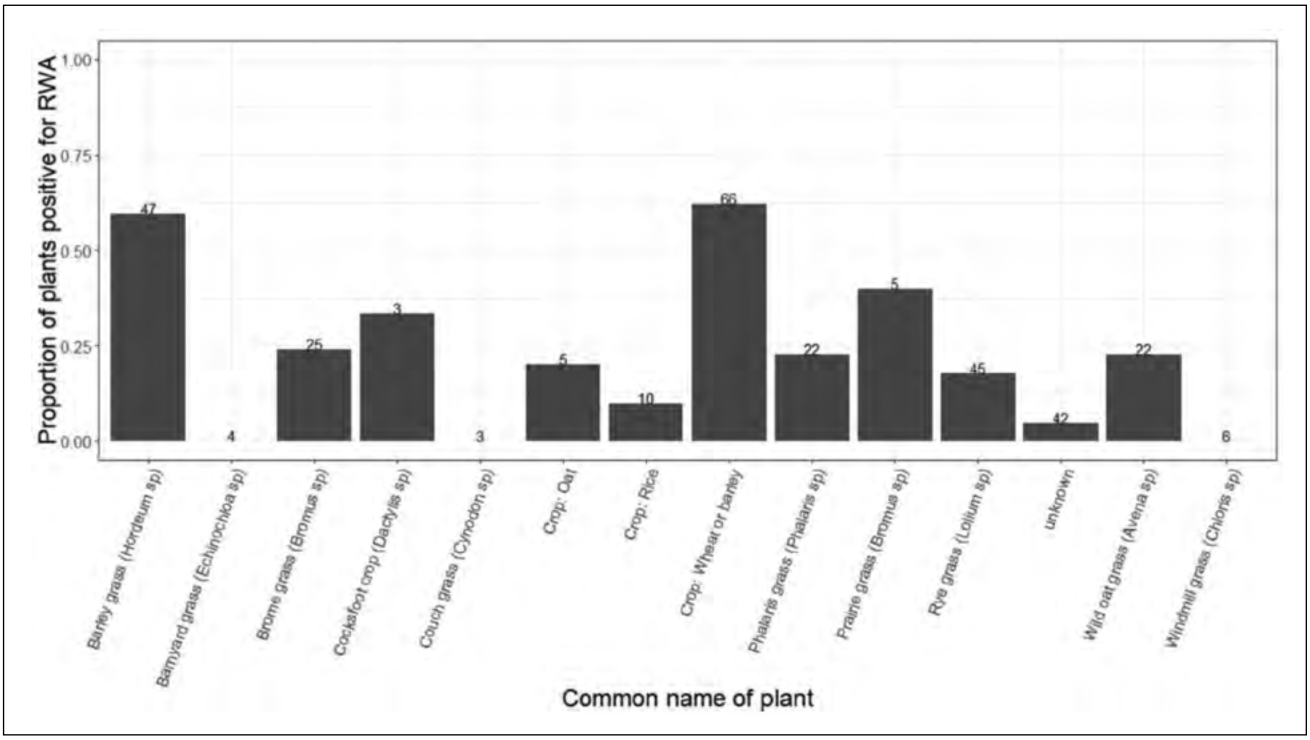

Figure 3. The proportion of individuals within each host plant represented during random plant searches that were positive for RWA (the number of plants searched per species is displayed above the bar). Please note these are preliminary data from Victoria, NSW and Tasmania during the spring sampling – formal plant identification is still required for some specimens.

Figure 4. RWA and damage symptoms on barley grass (left), brome (middle), and wheat (right), observed during spring monitoring. The brome grass pictured showed feeding symptoms (striping on the leaf), which was unusual among weeds (Credit: Dr Elia Pirtle, **cesar**). The wheat shows the striping symptoms that were frequently observed in younger tillers supporting RWA colonies.

Figure 5. A parasitoid wasp and several RWA mummies on a cereal (Credit: Dr Elia Pirtle, cesar).

the crop in relation to time of infestation during crop development. To forecast crop growth rates, we leveraged an existing model on cereal growth (Keating et al. 2003) that has been developed over decades of research and development - this is a model known as the Agricultural Production Systems sIMulator(APSIM). APSIM crop growth data was then linked to the RWA population growth model and the underlying assumption was made that a negative impact on biomass was related to the number of RWA on the plant.

As a preliminary test of the model data from one of the 2018 RWA trial sites (Birchip), one wheat variety (cv. Scepter$^{(D)}$) was considered in order to model population growth based on a variety of colonisation dates (Figure 6). The exact date of colonisation was known because this trial was artificially inoculated with RWA and when the actual date of RWA colonisation was inputted, the model generated a trend line that closely matched real RWA abundance data for the trial site (solid line), which was an encouraging proof of concept for the model. Additional colonisation dates were then inputted into the model (dashed lines).

By using APSIM, RWA abundance may then be transformed to predict impact on biomass (and thus, yield). However, as this is an early stage test of the model, based on limited trial data, it is important to not over generalise findings. In addition, natural events, such as heavy rain or immigration of beneficial species, can impact aphid numbers, and this model does not account for such events that may reduce populations at this stage. As the RWA research progresses, we will continue to test and refine this model, in the expectation that it may be developed into a useful prediction tool for assessing RWA population growth and likely yield impact on-farm.

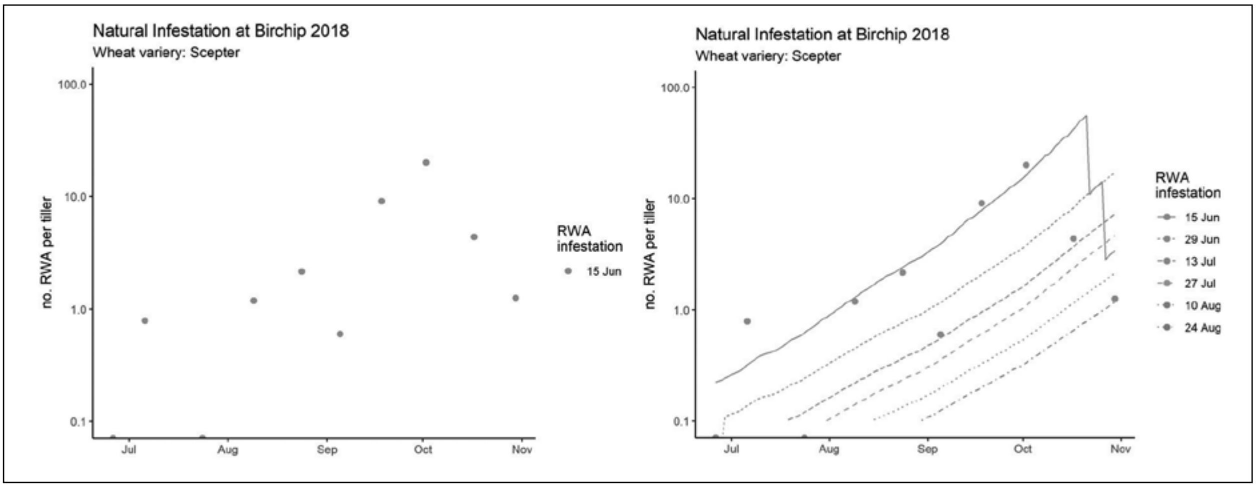

Figure 6. Actual RWA abundance data collected from the 2018 Birchip trial site (left) and RWA population growth as predicted by the new RWA-APSIM module based on variable colonisation dates (right) (module developer: Dr James Maino, **cesar**)

Completed research

Efficacy and length of protection provided by seed treatments

In a recent study led by **cesar** researcher, Lisa Kirkland, the efficacy and length of protection afforded by several insecticide seed treatments against RWA and oat aphid (*Rhopalosiphum padi*) were tested.

The experiment was conducted under 'semi-field' conditions using closed artificial microcosms with added aphids (Figure 7). As such, caution should be taken in applying the results of the experiment to field conditions – in closed microcosms watering is abundant and plant roots are limited to the container. Nonetheless, the results have revealed some insightful trends.

The seed treatments (shown in Table 1) were tested on wheat (cv. Trojan⁽ᴾ⁾) grown for sixteen weeks. The aphids were introduced two weeks after emergence. Each species was designated its own treatment and aphid populations were counted fortnightly. To simulate aphid colony establishment at different growth stages, after counting, the populations were 'reset' back to a level of 30 aphids per microcosm by removing or introducing individuals.

The results of this study are summarised in Figure 8. They show all insecticide seed treatments currently registered for use in Australian cereal

Figure 7. Semi-field conditions using closed artificial microcosms (Image credit: **cesar**).

Table 1. Rates and details of chemical treatments examined *(Source: Kirkland et al. 2018)*.

Cruiser and Cruiser Opti, products of Syngenta Australia, Sydney; Gaucho, product of Bayer CropScience, Melbourne

Product name and treatment level	Active ingredient(s) ($g\ L^{-1}$)	Application rate (g a.i. $100\ kg^{-1}$)	Field rate ($mL\ 100\ kg^{-1}$)
Untreated	–	–	
Cruiser, low	Thiamethoxam 350	35	100
Cruiser, high	Thiamethoxam 350	70	200
Cruiser Opti, low	Thiamethoxam 210 + lambda-cyhalothrin 37.5	34.7 + 6.2	165
Cruiser Opti, high	Thiamethoxam 210 + lambda-cyhalothrin 37.5	69.3 + 12.4	330
Gaucho, low	Imidacloprid 600	72	120
Gaucho, high	Imidacloprid 600	144	240

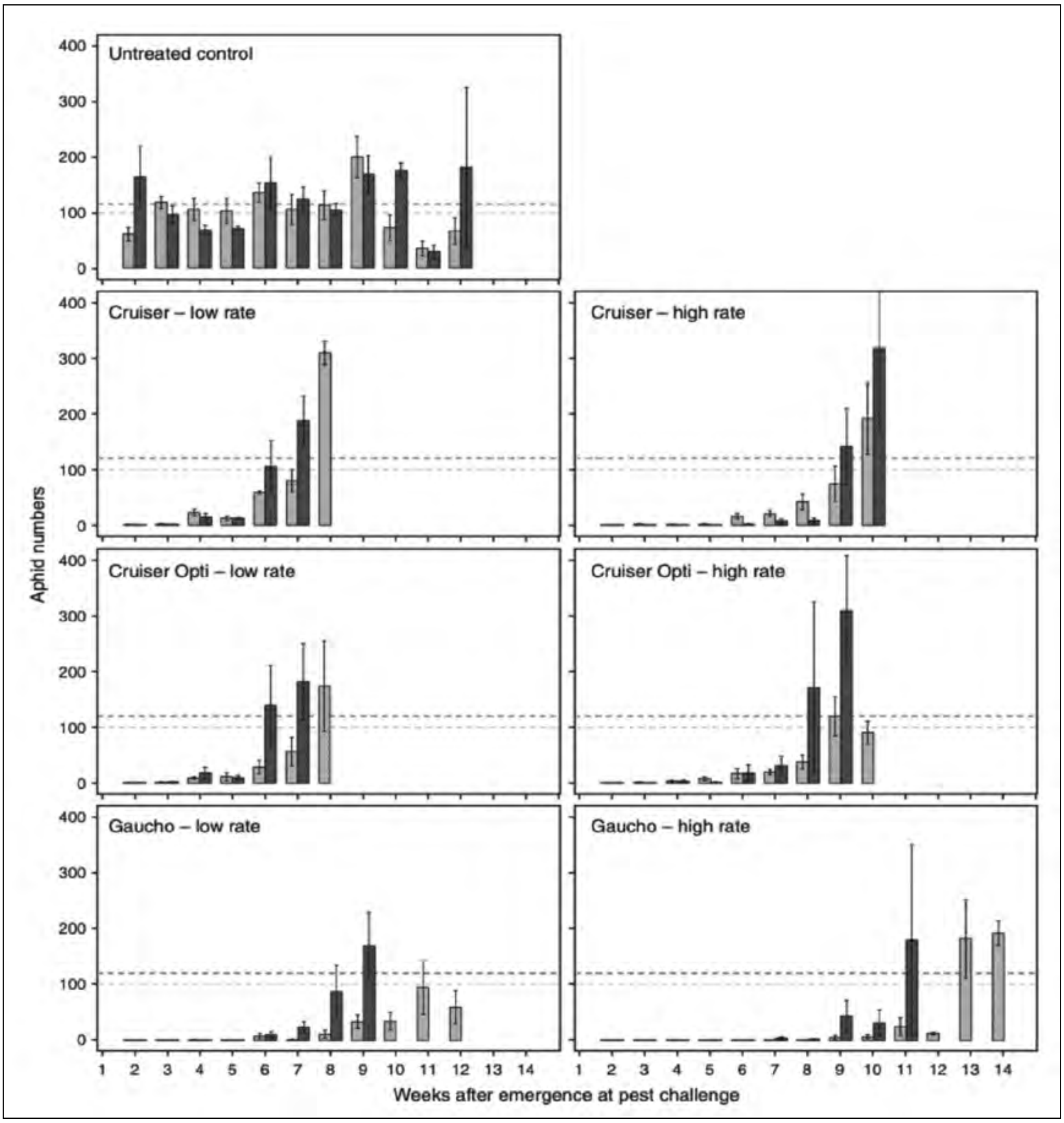

Figure 8. Average numbers of RWA (pale grey bars) and oat aphid (dark grey bars) at weekly intervals after wheat emergence for each chemical treatment. Counts are plotted against the week when aphids were introduced to tubs *(Source: Kirkland et al. 2018)*.

crops are effective against RWA and oat aphid. Specifically, higher label rates of Cruiser® and Cruiser® Opti increased the length of protection by 2-3 weeks in this trial, while the addition of the synthetic pyrethroid lambda-cyhalothrin in Cruiser® Opti did not provide clear benefits over Cruiser® in protection against these aphid species. Interestingly, oat aphid was able to persist and reproduce on wheat at an earlier growth stage than RWA. This indicates the oat aphid is more tolerant to certain insecticides and may therefore re-infest insecticide-treated wheat fields earlier than RWA.

APVMA minor use permits are in place for the use of imidacloprid PER82304 and thiamethoxam PER86231 based seed dressing treatment for the Russian Wheat Aphids in cereals are in winter cereals. Minor use permit can be obtained via the following link https://portal.apvma.gov.au/permits.

Future research

Regional threshold trial sites will be run again in 2019 throughout SA, Victoria, Tasmania, and NSW. These trial sites will give us two seasons worth of data for the verification of currently used international thresholds, or development of new, regionally specific thresholds.

Continuation of the green bridge surveillance over 2019/2020 will also add to our understanding about climatic (and biological) factors that influence RWA survival between harvest and sowing. Importantly, further verification of green bridge host plants favoured by RWA will allow us to develop guidelines for green bridge control to limit the risk of RWA moving into crops. Further, identification of key beneficials impacting RWA will continue, and this information may be used to update or develop integrated pest management (IPM) strategies.

Data collected from trial sites and green bridge work, particularly assessment of local climates that favour RWA population growth and RWA abundance data gathered throughout the year, will support us in further developing forecasting tools, such as the early stage RWA-APSIM module described here.

Current advice

- Monitoring for the aphid itself on green bridge hosts is advisable as classic RWA symptoms have been rarely observed on graminaceous species over spring and summer.
- Volunteer cereals and weedy grasses found within next season's cereal paddocks should be controlled at least 2-3 weeks prior to sowing. This will aid in reducing local numbers of the aphid pre-production.
- Registered neonicotinoid insecticide (mode of action Group 4A) seed treatments are very effective to avoid autumn infestation of crops if RWA are migrating (however, over the 2018 season, migrations into crops did not occur in most areas where RWA is present, most likely due to unfavourable conditions for aphid survival over summer and unfavourable flight conditions).
- To ensure seed treatments remain a long term viable control option for grains pests, industry stewardship and good resistance management are vital. Growers are urged to use neonicotinoid seed treatments judiciously, according to the regional risk, and using the Find, Identify, Threshold, Enact (FITE) approach.
- RWA is easy to detect in autumn and winter before yield is impacted. If RWA is present in potentially damaging numbers, it can be controlled efficiently by insecticide sprays around growth stage 32-40, eliminating the aphids before there is a risk of yield loss. The overseas threshold is >20% of all plants infested up to GS30 and >10% of tillers infested from late stem elongation (GS30 or later).

Useful resources

To view the RWA Interactive Map

http://www.cesaraustralia.com/sustainable-agriculture/rwa-portal/

GrowNotes Tips & Tactics for Russian Wheat Aphid

https://grdc.com.au/__data/assets/pdf_file/0025/289321/GRDC-Tips-and-Tactics-Russian-Wheat-Aphid.pdf

Russian Wheat Aphid Tactics for Future Control

https://grdc.com.au/__data/assets/pdf_file/0027/244377/Russian-Wheat-Aphid-Tactics-for-Future-Control.PDF

Russian Wheat Aphid Dynamics in 2017 (research update)

https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2017/08/russian-wheat-aphid-dynamics-in-2017

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Notes

Notes

Emerging management tips for early sown winter wheats

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GRDC project code: : (GRDC Management of Early Sown Wheat 9175069)

Keywords

- winter wheat, crop development, frost, dual purpose, vernalisation.

Take home messages

- Highest yields for winter wheats come from early to late April establishment.
- Highest yields of winter wheats sown early are similar to Scepter⁽ᵗ⁾ sown in its optimal window.
- Slower developing spring varieties are not suited to pre-April 20 sowing.
- Different winter wheats are required for different environments.
- Flowering time cannot be manipulated with sowing date in winter wheats such as spring wheat.
- 10mm of rainfall was needed for establishment on sands, 25mm on clays - more was not better.

Background

Winter wheat varieties allow wheat growers in the Southern Region to sow much earlier than currently practised, meaning a greater proportion of farm can be sown on time. The previous GRDC Early Sowing Project (2013-2016) highlighted the yield penalty from delayed sowing. Wheat yield declined at 35kg/ha for each day sowing was delayed beyond the end of the first week of May using a fast-developing spring variety.

Sowing earlier requires varieties that are slower developing. For sowing prior to April 20, winter varieties are required, particularly in regions of high frost risk. Winter wheats will not progress to flower until their vernalisation requirement is met (cold accumulation), whereas spring varieties will flower too early when sown early. The longer vegetative period of winter varieties also allows dual-purpose grazing.

The aim of this series of experiments is to determine which of the new generation of winter varieties have the best yield and adaptation in different environments and what is their optimal sowing window. Prior to the start of the project in 2017, the low to medium rainfall environments of SA and Victoria had little exposure to winter varieties, particularly at really early sowing dates (mid-March). Three different experiments have been conducted in the Southern Region in low to medium rainfall environments during 2017 and 2018, and one of these has been matched by collaborators in NSW for additional datasets presented in this paper.

Method

Experiment 1

Which wheat variety performs best in which environment and when should they be sown?

- Target sowing dates: 15 March, 1 April, 15 April and 1 May (10mm supplementary irrigation to ensure establishment).
- Locations: SA - Minnipa, Booleroo Centre, Loxton, Hart. Victoria - Mildura, Horsham, Birchip, Yarrawonga. NSW - Condobolin, Wongarbon, Wallendbeen.
- Up to 10 wheat varieties:- The new winter wheats differ in quality classification, development speed and disease rankings (Table 1).

Experiment 2

How much stored soil water and breaking rain are required for successful establishment of early sown wheat without yield penalty?

- Sowing dates: 15 March, 1 April, 15 April and 1 May.
- Varieties: Longsword⊕, Kittyhawk⊕ and DS Bennett⊕.
- Irrigation: 10mm, 25mm and 50mm applied at sowing.
- Locations: SA - Loxton. Victoria Horsham, Birchip.

Experiment 3

What management factors other than sowing time are required to maximise yields of winter wheats?

- Sowing date: 15 April.
- Varieties: Longsword⊕, Kittyhawk⊕ and DS Bennett⊕.
- Management factors examined: Nitrogen (N) at sowing vs. N at early stem elongation, defoliation to simulate grazing, plant density 50 plants/m^2 vs. plant density 150 plants/m^2.
- Locations: SA - Loxton. Victoria - Yarrawonga.

Results and discussion

Experiment 1

Development speeds

Flowering time is a key determinant of wheat yield. Winter varieties have stable flowering dates across a broad range of sowing dates. This has implications for variety choice as flowering time cannot be manipulated with sowing date in winter wheats like spring wheat. This means different winter varieties are required to target the different optimum flowering windows that exist in different environments. The flowering time difference between winter varieties is characterised based on their relative development speed into four broad groups — fast, mid-fast, mid and mid-slow for medium to low rainfall environments (Table 1 and Figure 1).

Table 1. Summary of winter varieties, including Wheat Australia quality classification and disease rankings based on the 2019 SA Crop Sowing Guide.

Variety	Release Year	Company	Development	Quality	Disease Rankings#			
					Stripe Rust	Leaf Rust	Stem Rust	YLS
Kittyhawk⊕	2016	LRPB	Mid winter	AH	MR	MR	R	MRMS
Longsword⊕	2017	AGT	Fast winter	Feed	RMR	MSS	MR	MRMS
Illabo⊕	2018	AGT	Mid-fast winter	AH/APH*	RMR	S	MRMS	MRMS
DS Bennett⊕	2018	Dow	Mid-slow winter	ASW	R	S	MRMS	MRMS
ADV08.0008	?	Dow	Mid winter	?	-	-	-	-
ADV15.9001	?	Dow	Fast winter	?	-	-	-	-
LPB14-0392	?	LRPB	Very slow spring	?	-	-	-	-
Cutlass⊕	2015	AGT	Mid spring	APW/AH*	MS	RMR	R	MSS
Trojan⊕	2013	LRPB	Mid-fast spring	APW	MR	MRMS	MRMS	MSS
Scepter⊕	2015	AGT	Fast spring	AH	MSS	MSS	MR	MRMS

**SNSW only*

AH=Australian Hard, APH=Australian Prime Hard, ASW=Australian Standard White, APW=Australian Premium White

R=resistant, MR=moderately resistant, MS=moderately susceptible

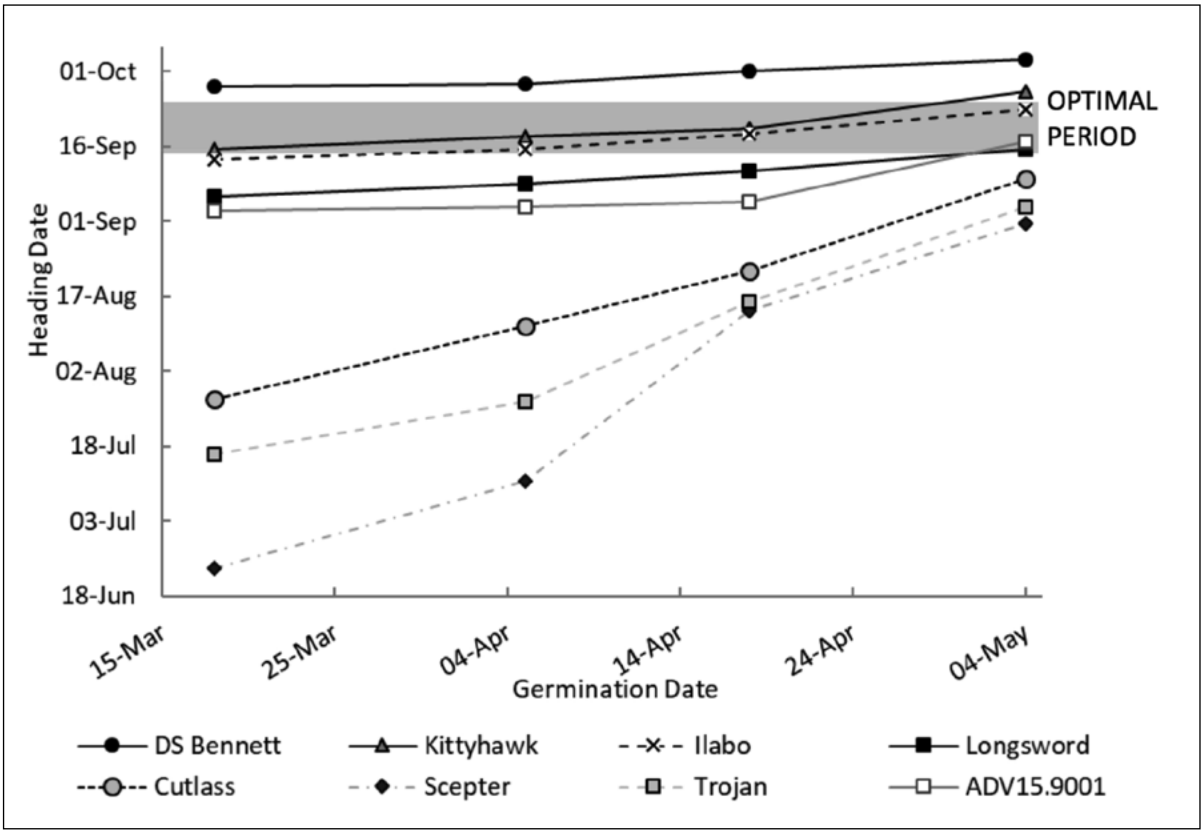

Figure 1. Mean heading date responses from winter and spring varieties at Hart in 2017 and 2018 across all sowing times — grey box indicates the optimal period for heading at Hart.

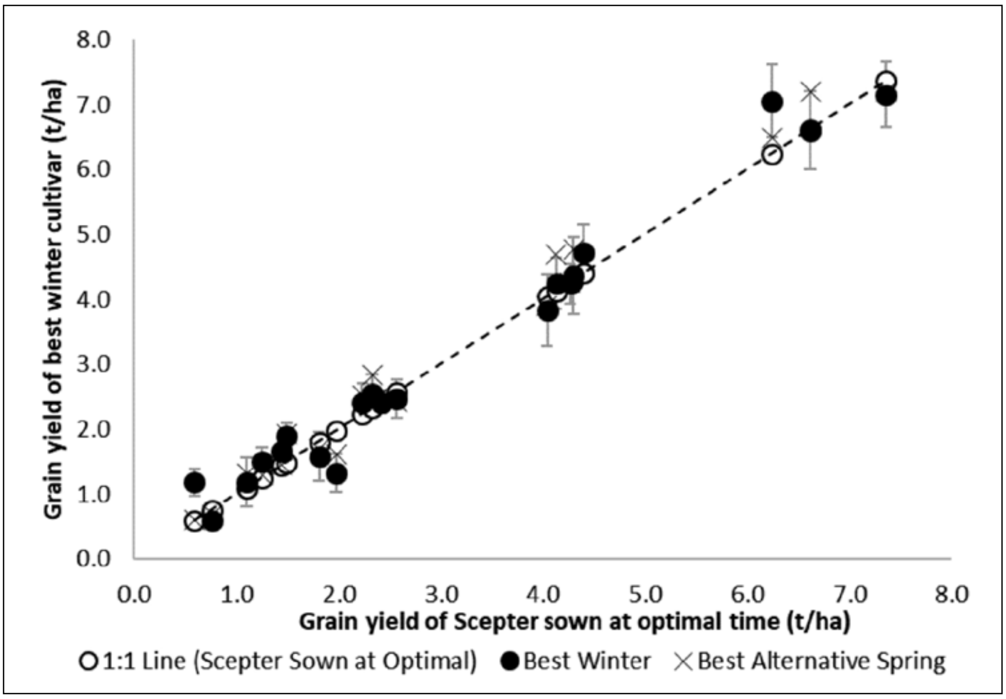

Figure 2. Grain yield performance of Scepter⊕ wheat sown at its optimal time (late April-early May) in 20 environments compared to the best performing winter wheat and best alternative spring wheat. Error bars indicate LSD (P<0.05).

For example, at Hart in the Mid North of SA, each winter variety flowered within a period of 7-10 days across all sowing dates, whereas spring varieties were unstable and ranged in flowering dates over one month apart (Figure 1). In this Hart example, the mid developing winter wheats such as Illabo(d and Kittyhawk(d were best suited to achieve the optimum flowering period of September 15-25 for Hart. In other lower yielding environments such as Loxton, Minnipa and Mildura, the faster developing winter variety Longsword(d was better suited to achieve flowering times required for the first 10 days in September.

Winter versus spring wheat grain yield

- Across all experiments, the best performing winter wheat yielded similar to the fast developing spring variety Scepter(d sown at the optimal time (last few days of April or first few days of May, used as a best practice control) in 16 out of 20 sites, greater in three and less than in one environment (Figure 2).
- The best performing winter wheat yielded similar to the best performing slow developing spring variety (alternative development pattern) at 14 sites, greater at four and less than at two sites.

Sowing time responses

- Across all environments, the highest yields for winter wheats generally came from early to late April establishment. The results suggested that yields may decline from sowing earlier than April and these dates may be too early to maximise winter wheat performance (Table 2).
- Slower developing spring wheats performed best from sowing dates after April 20, and yielded less than the best performing winter varieties when sown prior to April 20. This reiterates slow developing spring varieties are not suited to pre-April 20 sowing in low to medium frost prone environments.

Table 2. Summary of grain yield performance of the best performing winter and alternate spring variety in comparison to Scepter(d sown at the optimum time (late April-early May). Different letters within a site indicate significant differences in grain yield.

Site		Year	Scepter(d sown at optimum Grain Yield (t/ha)	Best Winter Performance			Best alternate Spring Performance		
				Grain Yield (t/ha)	Variety	Germ Date	Grain Yield (t/ha)	Variety	Germ Date
Yarrawonga*	Vic	2018	0.59 a	1.18 b	DS Bennett(d	16-Apr	0.61 a	Cutlass(d	16-Apr
Booleroo	SA	2018	0.77 a	0.59 a	Longsword(d	4-Apr	0.69 a	Trojan(d	2-May
Loxton	SA	2018	1.10 a	1.19 a	Longsword(d	19-Mar	1.32 a	Cutlass(d	3-May
Minnipa	SA	2018	1.25 a	1.50 b	Longsword(d	3-May	1.29 a	Trojan(d	3-May
Mildura*	Vic	2018	1.44 a	1.66 b	DS Bennett(d	1-May	1.46 a	LPB14-0293	1-May
Mildura	Vic	2017	1.49 a	1.90 b	Longsword(d	13-Apr	1.93 b	Cutlass(d	28-Apr
Horsham*	Vic	2018	1.81 a	1.58 a	DS Bennett(d	6-Apr	1.70 a	Trojan(d	2-May
Booleroo	SA	2017	1.98 a	1.33 b	DS Bennett(d	4-May	1.61 b	Cutlass(d	4-May
Minnipa	SA	2017	2.23 a	2.42 a	Longsword(d	18-Apr	2.52 a	Cutlass(d	5-May
Loxton	SA	2017	2.33 a	2.55 a	Longsword(d	3-Apr	2.83 b	LPB14-0293	3-Apr
Hart	SA	2018	2.41 a	2.42 a	Illabo(d	17-Apr	2.52 a	LPB14-0293	17-Apr
Rankins Springs	NSW	2018	2.57 a	2.47 a	DS Bennett(d	19-Apr	2.42 a	Trojan(d	7-May
Birchip	Vic	2018	4.04 a	3.83 a	Longsword(d	30-Apr	3.90 a	Trojan(d	30-Apr
Hart	SA	2017	4.13 a	4.25 a	Illabo(d	18-Apr	4.70 b	LPB14-0293	18-Apr
Yarrawonga	Vic	2017	4.27 a	4.24 a	DS Bennett(d	3-Apr	4.26 a	Cutlass(d	26-Apr
Wongarbon	NSW	2017	4.30 a	4.37 a	DS Bennett(d	28-Apr	4.77 a	Trojan(d	13-Apr
Tarlee	SA	2018	4.40 a	4.71 a	Illabo(d	17-Apr	4.62 a	LPB14-0293	17-Apr
Wallendbeen	NSW	2017	6.24 a	7.05 b	DS Bennett(d	28-Mar	6.49 a	Cutlass(d	1-May
Birchip	Vic	2017	6.62 a	6.60 a	DS Bennett(d	15-Apr	7.20 a	Trojan(d	15-Apr
Horsham	Vic	2017	7.36 a	7.15 a	DS Bennett(d	16-Mar	7.19 a	Trojan(d	28-Apr

**repeated frost during September followed by October rain.*

Which winter variety performed best?

The best performing winter wheat varieties depended on yield environment, development speed and the severity and timing of frost (Table 2). The rules generally held up that winter varieties well-adjusted to a region yielded similar to Scepter⁽ᵇ⁾ sown in its optimal window. These results demonstrate that different winter wheats are required for different environments and there is genetic by yield environment interaction.

- In environments less than 2.5t/ha, the faster developing winter wheat Longsword⁽ᵇ⁾ was generally favoured (Table 2, Figure 3).
- In environments greater than 2.5t/ha the mid to slow developing varieties were favoured — Illabo⁽ᵇ⁾ in the Mid North of SA, and DS Bennett⁽ᵇ⁾ at the Victorian and NSW sites (Table 2, Figure 4).

The poor relative performance of Longsword⁽ᵇ⁾ in the higher yielding environments was explained by a combination of flowering too early and having inherently greater floret sterility than other varieties, irrespective of flowering date.

Sites defined by severe September frost and October rain included Yarrawonga, Mildura and Horsham in 2018. In these situations, the slow developing variety DS Bennett⁽ᵇ⁾ was the highest yielding winter wheat and had the least amount of frost induced sterility. The October rains also favoured this variety in 2018 and mitigated some of the typical yield loss from terminal drought. Nonetheless, the ability to yield well outside the optimal flowering period may be a useful strategy for extremely high frost prone areas for growers wanting to sow early.

Experiment 2

2018 had one of the hottest and driest autumns on record and provided a good opportunity to test how much stored soil water and/or breaking rain is required to successfully establish winter wheats and carry them through until winter. The 10mm of irrigation applied at sowing in the sowing furrow was sufficient to establish crops and keep them alive (albeit highly water stressed in most cases) until rains finally came in late May or early June at seven of the eight sites at which Experiment 1 was conducted in 2018. The one exception was Horsham, which had very little stored soil water and a heavy, dark clay soil. At this site, plants that emerged following the first time of sowing in mid-March died after establishment and prior to the arrival of winter rains. Plants at all other times of sowing were able to survive. Experiment 2 was also located at this site, and 25mm of irrigation was sufficient to keep plants alive at the first time of sowing. A minimum value of 25mm for sowing in March on heavier soil types is supported by results from Minnipa in 2017, which

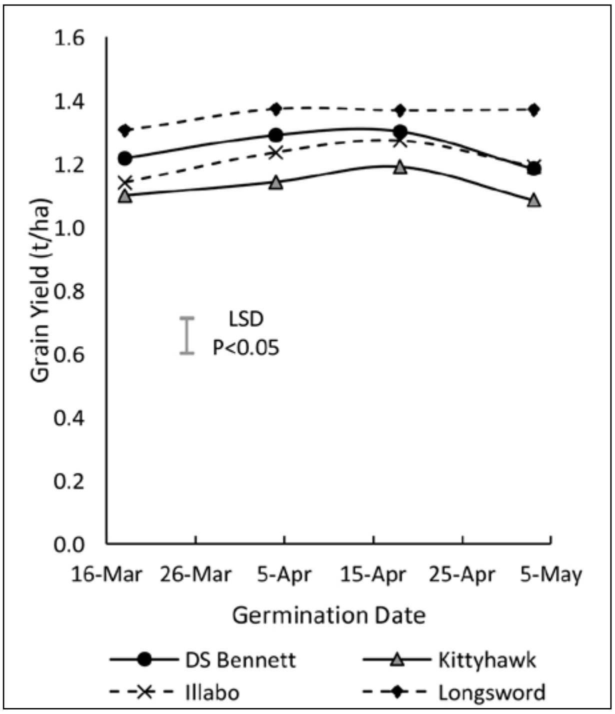

Figure 3. Mean yield performance of winter wheat in yield environments less than 2.5t/ha (11 sites in SA/Victoria)

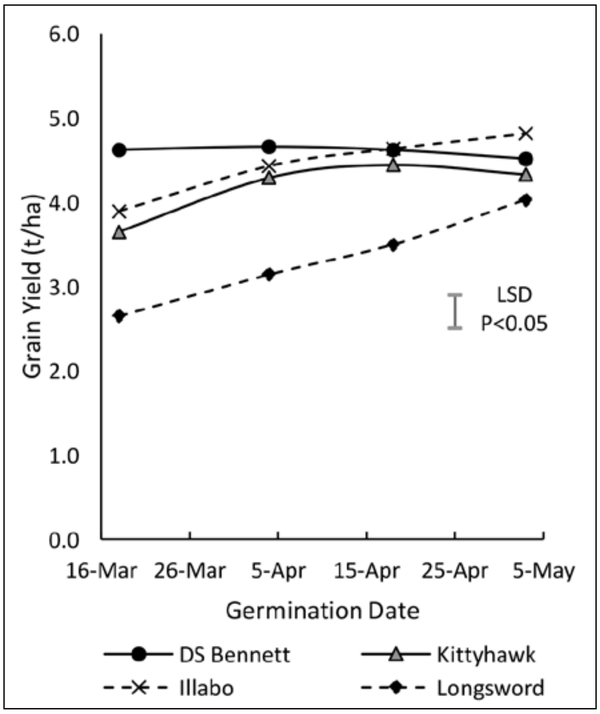

Figure 4. Mean yield performance of winter wheat in yield environments greater than 2.5t/ha (five sites in SA/Victoria)

also experienced a very dry autumn. In this case, approx. 30mm of combined irrigation, rainfall and stored soil water was sufficient to keep the first time of sowing alive. On lighter soil types, less water was needed and 10mm irrigation at sowing with 8mm of stored water plus an accumulated total of 13mm of rain until June allowed crops to survive on a sandy soil type at Loxton in 2018.

Based on these observations, it is concluded that when planting in March on clay soils, at least 25mm of rainfall and/or accessible soil water are required for successful establishment. Once sowing moves to April, only 10mm (or enough to germinate seed and allow plants to emerge) is sufficient.

Experiment 3

Yield responses to changes in plant density, N timing and defoliation have been small (Table 3). There have been limited interactions between management factors and varieties. The results from Experiments 1 and 3 confirm selecting the correct winter variety for the target environment and sowing winter varieties on time (before April 20) increase the chances of high yields. The target density of 50 plants/m^2 is sufficient to allow maximum yields to be achieved, and there is no yield benefit from having higher densities in winter varieties. Deferring N until stem elongation had a small positive benefit at Yarrawonga, and a negative effect at Loxton. Grazing typically has a small negative effect in all varieties, however the mean percentage grain yield recovery from grazing has been higher in Longsword$^{\Phi}$ (95%) compared to DS Bennett$^{\Phi}$ (87%) and Kittyhawk$^{\Phi}$ (82%), respectively.

Conclusion

Growers in the low to medium rainfall zones of the Southern Region now have winter wheat varieties that can be sown over the entire month of April and are capable of achieving similar yields to Scepter$^{\Phi}$ sown at its optimum time. However, grain quality of the best performing varieties leaves something to be desired (Longsword$^{\Phi}$=feed, DS Bennett$^{\Phi}$=ASW). Sowing some wheat area early allows a greater proportion of farm area to be sown on time. Growers will need to select winter wheats suited to their flowering environment (fast winter in low rainfall, mid and mid-slow winter in medium rainfall) and maximum yields are likely to come from early to mid-April planting dates. If planting in April, enough rainfall to allow germination and emergence will also be enough to keep plants alive until winter. If planting in March, at least 25mm is required on heavy soils. Reducing plant density from 150 to 50 plants/m^2 gives a small yield increase, while grazing tends to reduce yield slightly.

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Table 3. Mean main effects on grain yield (t/ha) from management factors at Loxton and Yarrawonga (2017 and 2018 = 4 sites).

Management Factor (Grain Yield t/ha)						Mean Management Effect (t/ha)
Variety choice	DS Bennett$^{\Phi}$ (2.21) & Kittyhawk $^{\Phi}$	(2.10)	Vs.	Longsword$^{\Phi}$	(2.40)	+0.30***
Seeding Rate (target density)	150 Plants/m^2	(2.14)	Vs.	50 Plants/m^2	(2.35)	+0.21***
Nitrogen Timing	Seedbed applied N	(2.32)	Vs.	N Delayed to Stem Elongation	(2.21)	-0.11 ns
Grazing^	Ungrazed	(2.38)	Vs.	Grazed	(2.11)	-0.27***
Sowing Date#	Early May Germination	(1.70)	Vs.	Mid-April Germination	(2.19)	+0.49***

*^grazing was simulated by using mechanical defoliation at Z15 and Z30, # Sowing date effect derived from Experiment 1 at Loxton and Yarrawonga. Level of significance of main effect indicated by ns=not significant, *** = P<0.001.*

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Underperforming sandy soils – targeting constraints for cost effective amelioration

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GRDC project code: CSP00203

Keywords

- sands, compaction, non-wetting, crop nutrition, ripping, spading, deep cultivation.

Take home messages

- Know the water limited yield potential and target the soil constraints to crop water-use: Assessing the yield gap relative to expected gains and seasonal risks, alongside identifying the key soil constraints, are important in developing an amelioration plan with cost effective outcomes.
- Yield responses to physical disruption are common but not guaranteed: Considering the depth and severity of compaction, any co-occurring constraints, and machinery specific impacts on soil strength offer an opportunity to optimise decisions for cost effective outcomes.
- Yield responses to increasing fertility at depth (i.e. deep placement/incorporation) are highly dependent on seasonal conditions with risks of neutral or negative yield responses in dry years. Depth of placement and form of nutrition (fertiliser, chicken litter, plant biomass) offer potential to manage nutrient carryover and crop growth responses over multiple years.
- Long term effects are essential for cost effective amelioration outcomes. Economic analysis of long-term trials (five years) has highlighted the importance of seasonal and crop sequence response effects on the cost benefit outcomes.

Background

Crop water use and productivity on sandy soils are commonly limited by a range of co-occurring soil constraints that limit root growth. Constraints include non-wetting behaviour and poor crop establishment; soil pH issues associated with acidity or alkalinity; a low ability to supply and retain nutrients; a natural tendency to compact or form hard-setting layers, and in some cases, subsoil sodicity and/or toxicities. There are opportunities to improve crop water use through optimising annual and low cost mitigation practices (e.g. seeding strategies, wetting agents, fertiliser placement) or through investing in more intensive and expensive soil profile amelioration approaches (deep ripping, spading, deep ploughing). In the low to medium rainfall zone of the Southern Region, it is important to consider the yield potential boundaries, seasonal risks, and the specific co-occurring constraints when developing an amelioration plan. The GRDC Sandy Soils Program (CSP00203) aims to improve the diagnosis and management of underperforming sandy soil in the Southern Region.

Research activities include:

- Understanding the potential for yield gains through improved estimates of the yield gap and associated physical, chemical and biological constraints in sandy soils across the region.

- Monitoring a range of existing long-term trials to assess the five-year impact of a range of amelioration strategies (ripping, spading) with/without amendments (clay, fertiliser, manure, crop biomass).
- Evaluating amelioration and mitigation approaches to improve crop water use and productivity where physical and nutritional constraints dominate, and where these co-occur with water repellence and/or acidity.
- Optimising amelioration approaches through understanding how machinery set-up can influence the impact on the soil profile, and strategies to manage seeding depth control and minimise erosion (e.g. one-pass spader-seeding).
- Assessing cost-benefit outcomes of a range of treatments through economic and risk analysis, and supporting decision making by prioritising the underlying soil constraints.

Methods

Characterisation of soil constraints

A range of physical, chemical and biological analyses have been conducted at core research trial sites to evaluate and describe the soil constraints present, the plant available water capacity, and improve our estimates of the yield gap in sandy soils of the Southern Region.

Research trials

Core project trials across the Southern Region include four long term amelioration sites (established 2014/2015), and seven new research sites (established 2017/2018) that include mitigation and amelioration treatments. Experimental details of the long term PIRSA spading trials (http://www.pir.sa.gov.au/__data/assets/pdf_file/0008/297719/PIRSA_New_Horizons_Trial_Sites_Summary_2017.pdf) and Trengove ripping trial (Trengove and Sherriff, 2018) have been described previously. These trial sites (Karoonda, Brimpton Lake, Cadgee and Bute) have been monitored for 4-5 years for ongoing yield effects, allowing the assessment of the percentage return on investment (marginal return/total costs*100) for a range of amelioration strategies.

New experiments targeted the dominant soil constraints evident at sites – physical and nutritional constraints alone (Waikerie, Carwarp, Bute, Ouyen) or in combination with water-repellence (Murlong, Lameroo) or acidity (Yenda). A summary of amelioration, amendment and placement treatments is provided in Table 1.

Amelioration experiments established in 2018 at Waikerie, Carwarp and Bute aim to evaluate whether increasing amelioration depth and/or nutrient supply within the profile results in cost effective outcomes. The Ouyen trial established in 2017 aims to evaluate the incorporation of farm grown biomasses (vetch hay, oaten hay), with comparison to other amendments (chicken litter, complex carbon compost) on profile nutrition, crop productivity, and the nitrogen (N) balance over multiple years (Moodie and Macdonald, 2018).

Addressing the management of severe water repellence, the 2018 Murlong site includes contrasting amelioration approaches (spading versus topsoil slotting i.e. inclusion plates ± N-rich biomass) alongside mitigation strategies evaluating wetting agent type and placement and furrow management. With acidity a common issue in NSW sandy soils, the Yenda amelioration experiment aims to evaluate deep 'sweep' cultivation (30cm) with/without amendments (urea, lime, 3-9t/ha chicken litter) to shatter and ameliorate a hostile layer approximately 15cm deep (Haskins et al., 2018).

Table 1. Summary of project amelioration trials indicating the type of physical amelioration approach, amendments used and placement strategy.

Site (Yr Est)	Physical amelioration* and depth (cm)	Amendment type#	Placement^
Waikerie (2018)	Rip 30, Rip 60	Chicken litter (2.5t/ha); fertiliser matched	deep, surface
Carwarp (2018)	Spaded 30, Rip 30, Rip 60	High-N biomass (6t/ha)	deep
Bute (2018)	Rip 30, Rip 50, TSSlot 50	Chicken litter (2.5-7.5t/ha)	deep, surface
Ouyen (2017)	Spaded 30, Rip 30	Crop biomasses (6t/ha), chicken litter, compost, fertiliser matched	incorporated, deep
Murlong (2018)	Spaded 30, TTSlot 30, TTSlot 40	High-N biomass (5t/ha); fertiliser	incorporated
Yenda (2017)	Sweep 30, Rip 30	Chicken litter (3-9t/ha)	incorporated

** including ripping (Rip), spading (Spade), topsoil slotting (TSSlot: ripping with inclusions plates), and sweep-cultivation (Sweep), with depth (cm) indicated. # amendments used vary depending on regional availability, where chicken litter is considered unavailable in the VIC Mallee and Eyre Peninsula. ^ placement of amendments includes 'surface' applied (no intervention), 'incorporated' through Spade and/or TSSlot, or actively placed at a controlled rate at the specified target depth.*

Results and discussion

Know the potential and target the constraints to crop water use

Estimates of the yield gap across sandy soil sites in the Southern Region vary from 2-3t/ha where growing season (GS) rainfall is less than 300mm (Table 2). The yield gap is based on an estimate of the yield potential for wheat in an average season minus the current attainable yield based on grower data. The estimated yield gap provides important information when developing an amelioration plan, helping to highlight the limits of productivity within the context of rainfall, and local knowledge of gains that can be achieved through annual strategies (e.g. fertiliser management, change in crop sequence). Further characterisation will refine the yield gap estimates taking into account the plant available water capacity measured at trial sites.

The selected trial sites reflect the prevalence of water repellence in the sands of SA, with lower occurrence of this constraint in Victorian and NSW Mallee soils (Table 2). Measurements of soil strength indicate that moderate constraints to root growth (1.5-2.5 MPa) are reached within 20cm, and severe physical constraints (2.5-3.5 MPa) are common

Table 2. Characteristics of Sandy Soils Experimental Sites; including estimates of the potential yield, current attainable yield and the yield gaps for an average growing season (GS, April-October). Rating of water repellence (top 5cm, based on molar ethanol drop) and soil strength (top 30cm, based on penetration resistance).

		Estimated Yields			Select constraint ratings	
Site Location	GS Rain (mm)	Potential Yield (t/ha)	Current attainable Yield	Yield Gap (t/ha)	Repellence	Soil strength (30cm)
Waikerie	157	2.9	1.0	1.9	Low	Severe
Carwarp	174	3.5	1.0	2.5	0	Severe
Ouyen	213	4.5	1.5	3	0	Severe
Karoonda	235	5	1.5	3.5	Moderate	Moderate
Murlong	251	5.2	1.5	3.7	Severe	TBD
Yenda	252	5.8	2.5	3.3	0	Severe
Lameroo	270	5.9	2.5	3.4	Moderate	Moderate
Bute	298	6.5	3.5	3	Low	Moderate
Brimpton	377	8.3	3.0	5.3	Moderate	TBD
Cadgee	410	9.5	1.3	8.2	Severe	TBD

** Potential Yield = ((0.25 x fallow rainfall)+ GSR – 60)*22*1.12. Repellence rating is based on molar ethanol drop (MED) testing of 0-5cm and 5-10cm soil samples. Soil strength rating is based on assessing penetration resistance within the top 30cm, where 1.5-2.5 MPa = moderate, 2.5-3.5 = strong, and >3.5 = severe.*

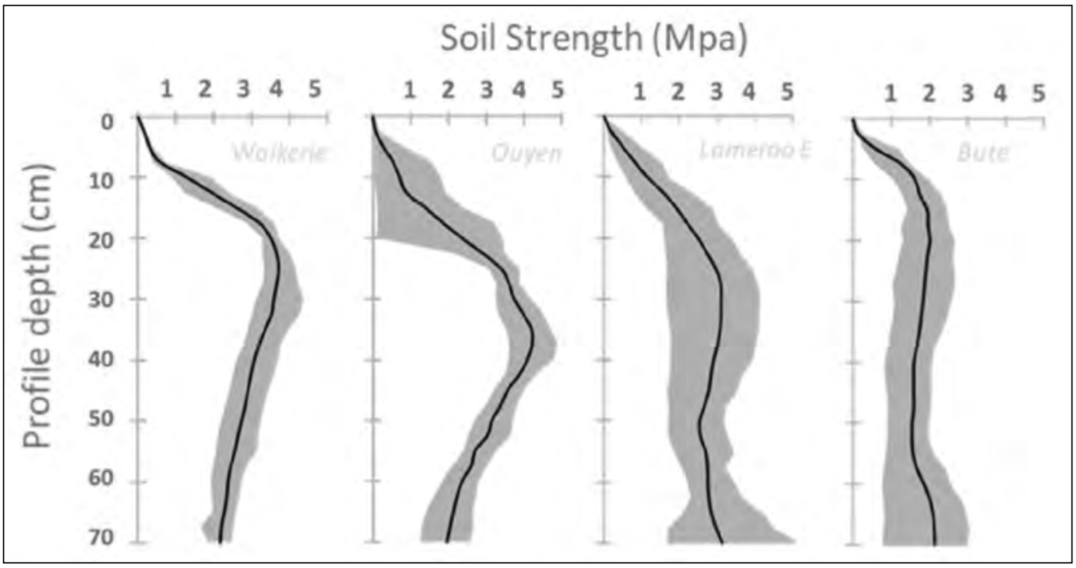

Figure 1. Examples of the variation in severity and depth of penetration resistance (MPa) in a range of sandy soil trial sites across the Southern Region. The black line indicates the site average, with grey shading indicating minimum and maximum readings across six measurements. Soil strength 1.5-2.5 MPa = moderate, 2.5-3.5 = strong, and >3.5 = severe.

within 30cm (Table 2), with examples of the variation in soil strength with depth shown in Figure 1. Nutrients commonly identified as marginal in the top 30cm included N, phosphorus (P), zinc (Zn), copper (Cu) and manganese (Mn).

Monitoring long term amelioration trials

PIRSA long term trials on water repellent sands that have physical and nutritional constraints (Karoonda, Brimpton Lake) or acidity and nutritional constraints (Cadgee) have been monitored for five years. Cumulative yield gains across three cereal years (Table 3) demonstrate that yield gains at Karoonda and Brimpton Lake have been responsive to spading (approx. +2t/ha at both sites). Incorporation of N-rich crop biomass (10t/ha lucerne) has resulted in 1.3-1.6t/ha, and largely accounted for in the first two years. Yield gains from clay incorporation were only evident at Cadgee (+1.8t/ha), which had little response to spading, but a positive and continuing response to N-rich biomass (+1.6t/ha). The lack of strong physical constraint and the presence of acidity at Cadgee are likely drivers of the different responses.

Table 3. Cumulative cereal yields (2014, 2015, 2017) across PIRSA long term amelioration trial.

	Cumulative Yields (3 years, t/ha)		
	Karoonda	Brimpton Lake	Cadgee
Unmodified	2.17	4.36	3.21
Spading	4.13	6.58	2.82
Spading +lucerne	5.39	8.15	4.83
Spaded clay	4.14	7.49	4.62

Lucerne =10t/ha

These long-term experiments have demonstrated lasting responses to spading across three sites, broadly similar gains to the incorporation of lucerne, and site/seasonal responses to clay. A new experiment at Murlong builds on these results to evaluate the potential of topsoil slotting compared to spading, as a lower risk approach to address repellence (severe), compaction and nutritional constraints. The new experiment is co-located with a mitigation experiment evaluating wetter chemistry and placement. Comparing annual lower cost strategies against higher cost amelioration will be important in developing a framework to support grower decisions for cost effective outcomes on repellent sandy soils.

Yield responses to physical disruption and increasing profile fertility

A wide range of experiments have demonstrated that physical interventions (ripping, spading, deep cultivation) can improve crop productivity in compacted sandy soils (for example, Trengove et al. 2018; Moodie and Macdonald, 2018). The extent of the opportunity to further increase yield gains for effective cost benefits through incorporating amendments (fertilisers, manure, crop biomass) is less well understood. Depth of placement and type of amendment influence the rooting depth, the timing of nutrient supply, and access to profile moisture. These factors influence the balance of crop growth, development, and grain filling. A series of experiments across the southern rainfall range have been established to address these questions in deep compacted sands with nutritional limitations (Waikerie, Carwarp, Bute, Ouyen).

Targeting the depth of amelioration to compaction thresholds (with/without deep placement of amendments), three new trials (2018) demonstrate a range of site-specific responses (Figure 2). The potential for yield gains at Waikerie was limited by available water (95mm GS rainfall), with small yield gains under 60cm ripping treatments (+0.26t/ha) and no significant response to deep placed nutrition.

At Carwarp (approximately 70mm GS rainfall), the yield responses to a range of amelioration approaches (ripping, spading) were relatively consistent (+0.5t/ha) and unaffected by depth, despite evidence of deeper crop water use. Increasing profile nutrition through incorporation of N-rich biomass had either no benefit (deep placed) or a negative yield effect (spading) associated with high early biomass production.

In contrast to the dominance of physical effects at Waikerie and Carwarp, crop yields at Bute were more responsive to improved nutrition (7.5t/ha surface chicken litter), demonstrating yield gains of approx. 0.9t/ha compared to an average gain of 0.29t/ha from physical interventions alone. The Bute site had the lowest severity and depth of physical constraint across project sites (Figure 1). All trials will continue for a further two years to evaluate the longevity of physical and nutrient carry-over effects.

Established in 2017, a trial at Ouyen is evaluating the incorporation (spading) of farm grown biomasses (vetch hay, oaten hay). It includes other amendments to allow regional comparisons (chicken litter) and assess longevity compared to complex/stable carbon inputs (compost). In the first-year spading suffered an establishment penalty (110 vs. 60 plants/m^2), resulting from sub-optimal seeding depth control, with spaded yields tending to only have a small benefit (+0.4t/ha) compared to the control (1.3t/ha). The two-year cumulative gain from spading alone was 0.58t/ha. Incorporation of

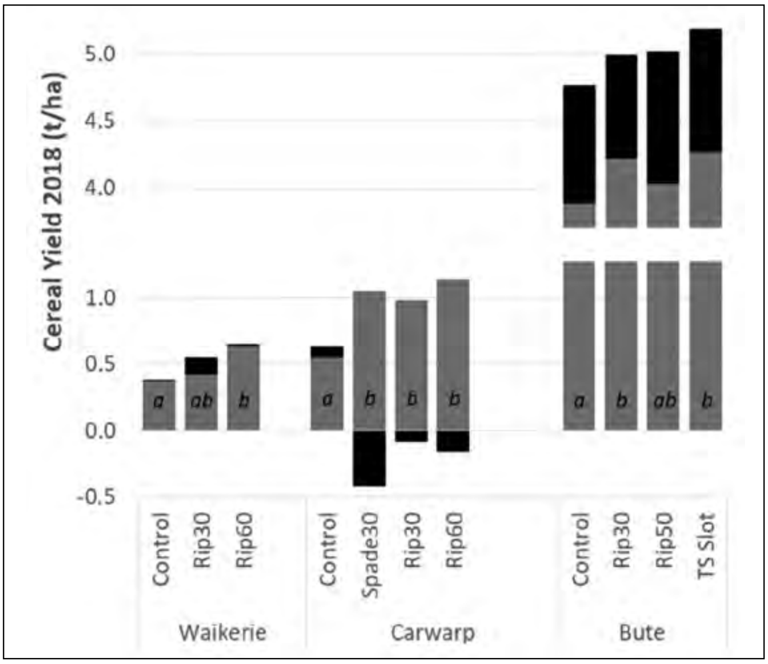

Figure 2. Cereal yields across three amelioration trial sites including non-ameliorated control, ripped (Rip30, Rip50, Rip60), spaded (Spade30), or topsoil slotted (TSSlot30) treatments, and where numbers indicate depth (cm) of intervention. Grey bars represent yields under control fertiliser inputs, while black bars indicate gains/losses under nutrient enriched treatments. Letters indicate significant amelioration impacts within sites (n=4), noting broken y-axis to account for higher yields.

N-rich amendments (vetch, chicken litter, compost) supported higher yields over both years (2.9-3.5t/ha cumulative totals), representing gains of 0.85-1.73t/ha over and above the spaded control. Where high fertiliser additions (156kg N/ha, matching vetch N input) were incorporated through spading, yields were comparable but far more variable between replicates. Measurement of the rates of microbial decomposition and changes in soil N pools (mineral N, microbial biomass N and dissolved organic N) indicate differences in nutrient cycling between treatments that will be monitored over time.

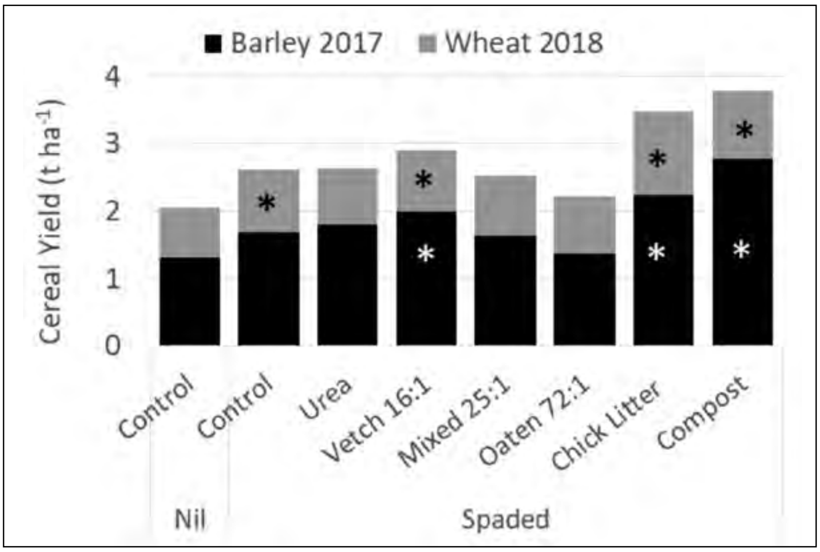

Figure 3. Cereal yields in response to spading and amendment incorporation at Ouyen, Victoria. Yields include two consecutive years following establishment in 2017; significant within year differences from the unspaded (Nil) control are indicated (*). Treatments include an undisturbed (Nil) control, and spaded treatments with no additional inputs (control), urea, three hays including vetch, oaten hay and a mixture of the two (C:N ratio indicated), chicken litter, and compost.

Conclusions

There are substantial opportunities to increase yield on underperforming sandy soil in the Southern Region. However, it is important to consider the current yield gap, the expected yield gains, and the seasonal risks within the low to medium rainfall environment. Identifying the key soil constraints limiting crop root growth and water extraction is central to developing a targeted and cost-effective amelioration plan.

Across the Southern Region, compaction and yield responses to physical disruption are common but not guaranteed. Considering the depth and severity of compaction and the co-occurring soil constraints is important. Opportunities to optimise physical amelioration include understanding machinery specific impacts on soil strength and mixing ability and improving seeding depth control for even crop establishment. Experiments aiming to increase yields through incorporating or deep placing fertilisers or organic amendments demonstrate high seasonal variability, with risks of neutral or negative yield responses in dry years. Understanding the impact of placement depth and amendment form on the timing of nutrient supply and water use is required to harness any additional potential above physical intervention alone. Interactions with site, season and/or crop sequence have been demonstrated and highlight the need to better understand post-amelioration agronomy.

Useful resources and references

PIRSA GRDC Sandy soils (CSP00203) site results summary. (http://www.pir.sa.gov.au/__data/assets/pdf_file/0008/297719/PIRSA_New_Horizons_Trial_Sites_Summary_2017.pdf)

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Optimised canola profitability — looking into key findings of four years of research

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GRDC project code: CSP00187

Keywords

- canola, phenology, biomass, sowing date, flowering date, frost, nitrogen, grain yield.

Take home messages

- Selecting mid-fast canola hybrid varieties with flexible phenology in the Wimmera manages risk and captures great upside when seasonal conditions are favourable.
- Fast hybrids have performed well but avoid the temptation to plant these early if an early break eventuates.
- Selecting slow developing varieties comes with the added risk of requiring germinating rain in the first week of April or earlier in low to medium rainfall environments.
- The best return on investment in nitrogen (N) results from application to hybrids that flower at the optimum time for the environment.

Background

Understanding the phenological responses of a canola variety will guide sowing decisions to ensure flowering starts in the optimal window to maximise yield potential. Timing flowering to avoid the stresses of frost and disease (too early), and drought and heat (too late) will allow the favourable conditions required for canola to grow and produce a high yield potential. Research through the GRDC supported Optimised Canola Profitability Project (CSP00187) has been carried out in the Wimmera region from 2015 to 2018. Findings of this research, focusing on time of sowing, have shown that phenological differences are amplified when canola is sown before mid-April, meaning that there may be a matter of a few days difference in start of flowering between a fast and slow variety when sown in early May, but weeks for the same varieties sown in early April. Therefore, varieties should be chosen carefully, based on phenologyin the event of early sowing.

In 2017 and 2018, the Birchip Cropping Group (BCG) included N application rates (aimed at decile 3 and 9 seasons) to assess the response of varieties sown at different times (mid-April and early-May) This work found that open pollinated triazine tolerant (OP TT) varieties did not respond to the application of N as well as hybrid varieties due to the hybrid vigour setting more yield potential at the start of flowering (Brill and Taylor 2017).

Method

A replicated split plot design trial was sown at two times of sowing. Crop was established with drip irrigation in crop rows of 15mm on TOS 1 and 7.5mm on TOS 2 due to prior rainfall. Assessments carried out in the trial included establishment counts, normalized difference vegetation index (NDVI), flowering dates, biomass at start of flowering, yield (from harvest cuts taken at varietal maturity), harvest index and grain quality. Nitrogen treatments were top-dressed as urea at either a low rate (targeting 1.4t/ha yield) or a high rate (targeting 5t/ha yield). The

Table 1. Treatment outline in 2018 Longerenong trial Variety x Time of Sowing x Nitrogen treatment.			
Variety	Phenology	Time of Sowing (TOS)	Nitrogen Application
Diamond	Fast	TOS 1 (13 April)	Low rate @41.5kg urea/ha 5 June 2018 (Targeting 1.4t/ha yield)
ATR Stingray⁽ᴾ⁾	Fast		
44Y90 CL	Fast - mid		
ATR Bonito⁽ᴾ⁾	Fast - mid		
45Y91 CL	Mid - slow	TOS 2 (8 May)	High rate @667.5kg urea/ha split application 5 June and 2 July (targeting 5t/ha yield)
45Y25 RR	Mid - slow		
ATR Wahoo⁽ᴾ⁾	Mid - slow		
Archer⁽ᴾ⁾	Slow		

starting soil N was 68kg N/ha to 1m depth Nitrogen applications were applied with significant rainfall events predicted after application.

Results and discussion

2018 Wimmera trial results

Biomass

There was a general trend of greater biomass at flowering from all varieties sown on 8 May (TOS 2) compared to the 13 April sowing, except for Archer⁽ᴾ⁾ as there was a time of sowing by variety interaction (P=0.014). 45Y91 CL and 45Y25 RR, with their similar phenology, produced on average the same biomass in the respective sowing times. Diamond and ATR Stingray⁽ᴾ⁾, also with similar phenology to each other, had a large difference in biomass at flowering, due to the hybrid vigour of Diamond. This trend was observed for 44Y90 vs. Bonito⁽ᴾ⁾ and Archer⁽ᴾ⁾ vs. Wahoo⁽ᴾ⁾ when comparing varieties with similar phenology. On average, the 8 May sowing time produced 0.7t/ha more biomass than the April sowing.

An interaction was also observed between varieties and N application rates, where all varieties showed on average greater biomass at flowering under the high N application. The high N treatments averaged 1.2t/ha more biomass at the start of flowering cutting timing. The later developing hybrid varieties 45Y91 CL, 45Y25 RR and Archer⁽ᴾ⁾ had the largest response to N and produced significantly more biomass at this timing than the other varieties in the trial (Figure 1).

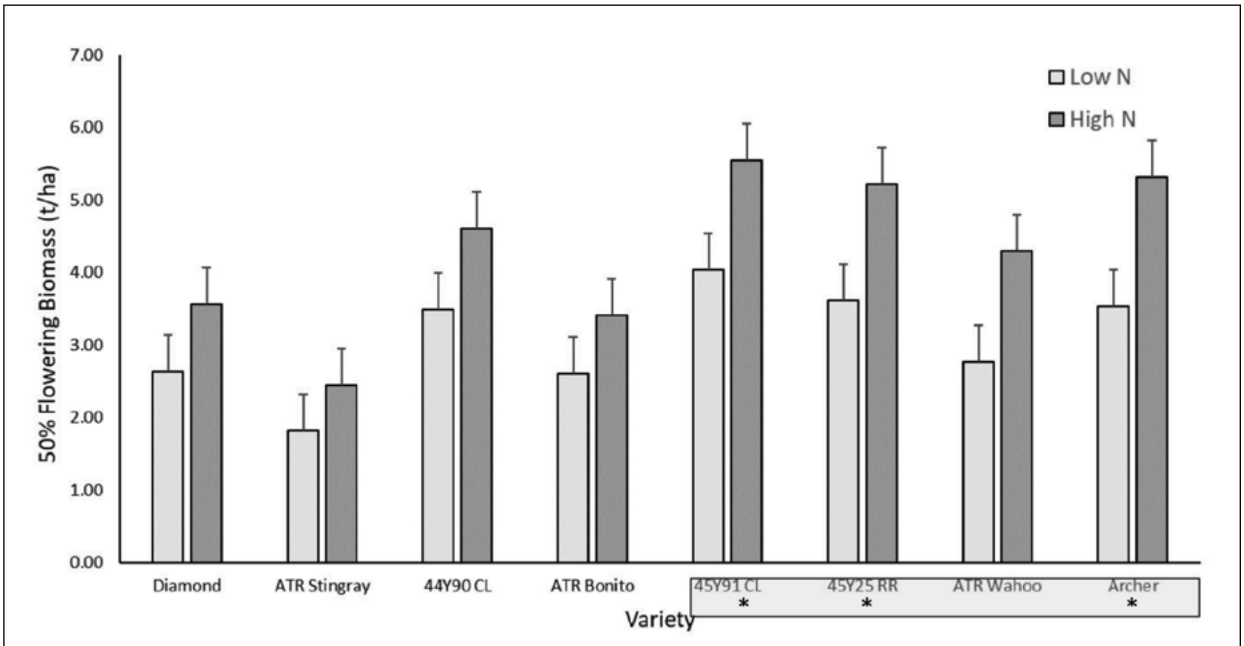

Figure 1. Mean of start of flowering biomass (t/ha) for varieties at different N application rates. Stats: P=0.009, LSD= 0.50 t/ha, CV 13.5%.

Table 2. Grain yield (t/ha) of varieties at different times of sowing (13 April, 8 May) and under different N application rates (high N, and low N) in 2018.				
Variety	TOS 1 (13 April)		TOS 2 (8 May)	
	Low N	High N	Low N	High N
Diamond	1.04	1.21	0.96	1.15
ATR Stingray⁽ᵈ⁾	0.64	0.97	0.85	0.42
44Y90 CL	0.89	1.46	0.91	1.19
ATR Bonito⁽ᵈ⁾	0.51	0.51	0.86	0.47
45Y91 CL	0.76	1.24	0.83	0.35
45Y25 RR	0.83	0.62	0.64	0.31
ATR Wahoo⁽ᵈ⁾	0.61	0.27	0.59	0.16
Archer⁽ᵈ⁾	0.92	0.68	0.69	0.55
Sig. Diff.	P<0.001			
LSD (P=0.05)	0.26			
CV%	24.4			

Yield

Yield was variable across treatments with an interaction found between varieties, time of sowing and N rate. 44Y90 CL at the early sowing topped the trial yields with 1.46t/ha, closely followed by 45Y91 CL and Diamond yielding 1.24t/ha and 1.21t/ha, respectively, all sown in the early April timing. As a fast hybrid variety, Diamond showed the most consistent yield across times of sowing and N rates (Table 2). Diamond has performed consistently well in the past three years of the trials (Table 4).

Research from 2017 found that OP TT varieties did not respond as well to N as hybrids (Brill and Taylor 2017). ATR Bonito⁽ᵈ⁾ and ATR Wahoo⁽ᵈ⁾ had a negative yield response to a high rate of N application in 2018, but ATR Stingray⁽ᵈ⁾ had a yield increase with a high rate of N application in the early time of sowing and a negative effect in the later sowing time. In general, TT varieties showed less of a response to N application than fast developing varieties and early sown mid developing varieties in 2018. 45Y25 RR, ATR Wahoo⁽ᵈ⁾ and Archer displayed a negative yield response to N application similar to the TT varieties.

The application of a high rate of N reduced the yield of some varieties. The effect was more evident with slower developing and OP TT varieties at the later sowing timing. This is likely due to the very high N levels causing canola to hay off in the 2018 seasonal conditions.

This theory is substantiated by biomass at maturity, where biomass did not always reflect final yield, unlike other seasons (Figure 2). ATR Wahoo⁽ᵈ⁾,

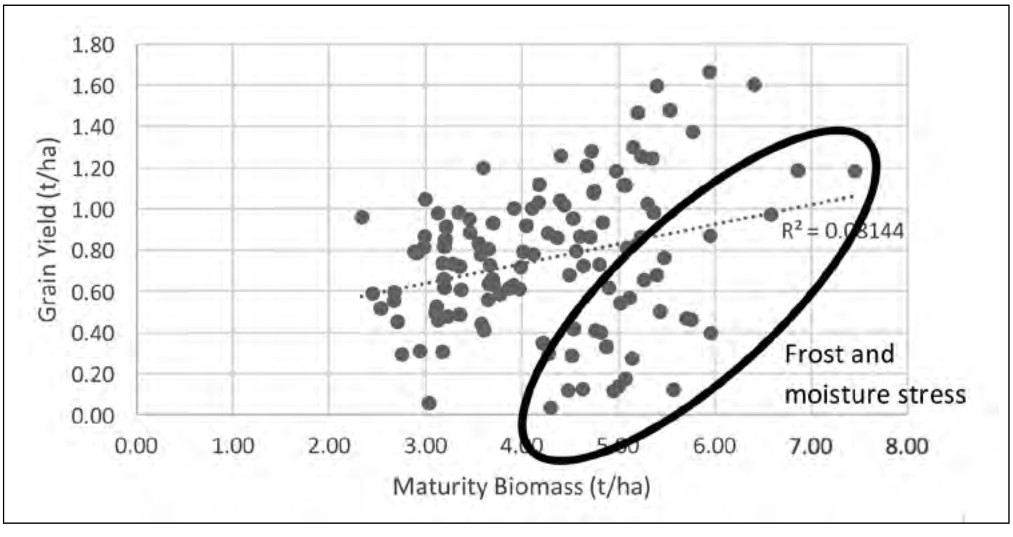

Figure 2. Maturity biomass (t/ha) and grain yield in 2018 at Longerenong. Black circled area represents the data points either affected by frost and/or moisture stress causing a 'haying off'effect.

Table 3. 2018 Longerenong Canola Phenology Trial: Mean oil (%) of varieties at different sowing times (15 April and 8 May) and under different N application rates (target decile 3 & 9).

Variety	TOS 1		TOS 2	
	Low Rate	High Rate	Low Rate	High Rate
Diamond	40.9	34.4	38.9	33.1
ATR Stingray[(l)]	37.2	36.5	39.9	35.8
ATR Bonito[(l)]	40.7	37.7	41.2	39.0
44Y90 CL	41.0	36.3	38.9	36.8
45Y91 CL	40.2	36.6	39.7	38.5
45Y25 RR	38.9	36.2	40.7	37.2
Archer[(l)]	38.3	35.9	38.6	36.8
ATR Wahoo[(l)]	40.1	34.5	38.6	33.5
Sig. Diff.	P=0.016			
LSD (P=0.05)	1.8			
CV%	3.2			

a later maturing variety, had greater biomass at maturity from high N application treatments, however, low N application treatments out-yielded at each time of sowing suggesting it may have hayed off early, limiting the ability to fill grain.

Grain quality

Oil content was below 42% for all treatments with high N application reducing oil. The lowest oil content was found in the high rate of N treatments for Diamond and ATR Wahoo[(l)] (Table 3). This is an expected trend as high N is known to have a negative impact on oil content (O'Brian and Street, 2017). All test weights were within the acceptable range for canola. ATR Stingray[(l)] consistently averaged the highest test weight between times of sowing and N application rates.

Start of flowering windows

Diamond, an early maturing variety, was the first to begin flowering in both times of sowing with both flowering within the optimal start of the flowering (OSF) window for Horsham (18 July-25 August). There was a trend towards a decrease in yield when flowering was not reached by the end of the OSF on 25 August. Sowing on 8 May (TOS 2) was too late for the majority of treatments to begin flowering within the OSF window, driven by maturity (Figure 3).

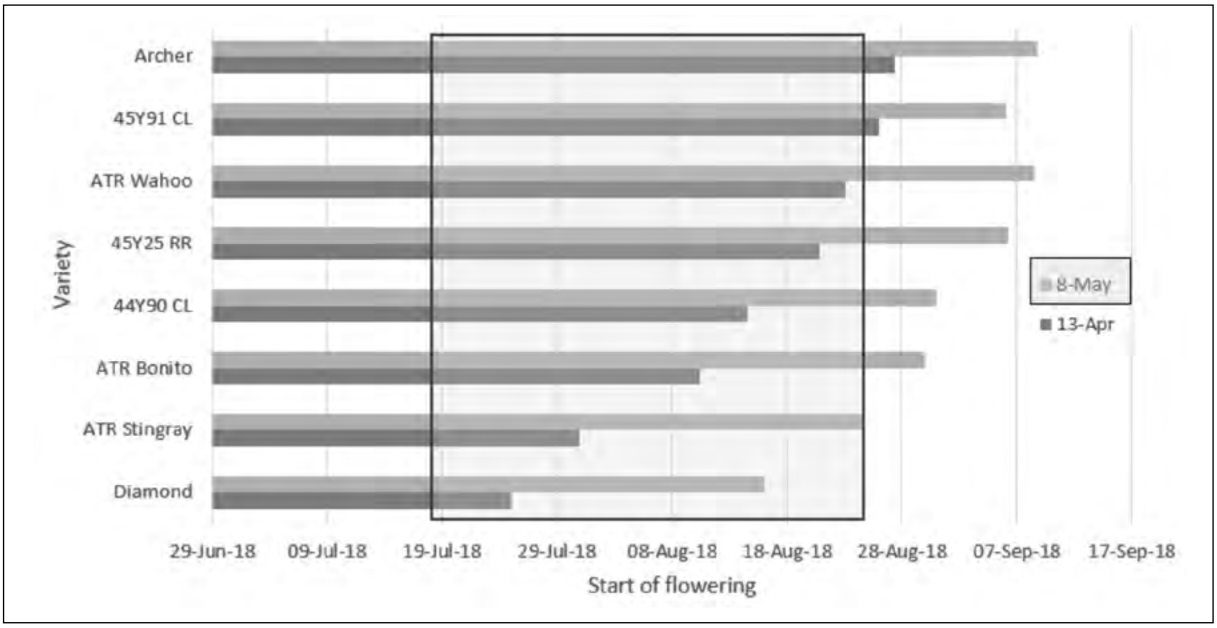

Figure 3. Canola phenology trial at Longerenong time of sowing effect on the start of flowering date. Start of flowering optimal window for Horsham highlighted.

Earlier sown varieties flowered earlier and averaged a higher grain yield. When the OSF date had passed, there was a general decrease in yield observed for all herbicide tolerant groups. It is important to note frost data has not been taken into account to quantify the contribution to yield losses.

Conclusion

Overall canola production 2015-2018 in the Wimmera

Growing canola in the Wimmera over the past four seasons has been highly variable with considerable risk. Wimmera canola phenology trials have averaged 2.0t/ha (Table4). The findings from the trials have indicated that with good variety choice, N management and by taking early sowing opportunities to match the varieties' optimal phenology windows, the risk of variations in the seasons can be managed, with a maximum upside of 2.77t/ha average over the four years.

Variety selection based on yield

The past two years of trial work at Longerenong, have suggested that fast to mid-fast sown hybrid varieties have proven to be consistent high performers. Hybrid varieties have been out-performing OP varieties consistently through the years when comparing amongst phenology groups (Table 5). When considering a long season canola in the Wimmera, germination early (first week of April) in the season is required to ensure the greatest chance of profitability. Considering the increased cost of holding a long season canola variety and relying on a germinating rain in early April, there may not be an opportunity to access seed and sow in a timely fashion. Selection of a variety such as 44Y90 CL with flexible phenology (slows from early sowing but speeds up with late sowing) will help capitalise on early breaks, while also yielding well in later starts.

Nitrogen application

When applying N to canola, the rule of thumb has been to supply 80kg/ha of N (between soil, fertiliser and mineralisation) for one tonne of grain yield potential. The previous two seasons have seen positive responses to biomass when applying high levels of N to fast to mid-fast developing varieties, which translated into higher yields. Key growth stages to assess the canola's potential yield are at the start of flowering and maturity. At the start of flowering 4t/ha of canola biomass needs to be reached to have maximum yield potential (Figure 4). If the canola dry biomass was less than 4t/ha at the start of flowering, then the maximum yield potential was limited and N applications from this point should be adjusted to reflect a lower potential if the season looks favourable for high yields (Figure 4). At maturity (windrowing time), the biomass (less

Table 4. Summary of rainfall, average biomass and yield production from2015-2018 canola phenology data in the Wimmera.

Year	2015	2016	2017	2018
Previous crop type	Wheat	Faba Bean	Lentil	Barley
Rainfall (Nov-Oct)	228	467	424	284
Rainfall (Apr-Oct)	125	374	303	187
Biomass 50% flower initiation (t/ha)	1.62	4.13	4.83	3.7
Biomass maturity (including grain) (t/ha)	2.08	11.85	11.70	5.01
Yield (t/ha)	0.12	3.46	3.83	0.75
Harvest index	0.06	0.29	0.32	0.15

Table 5. Yield by time of sowing from 2017-18 Longerenong trials presented as a percentage of the mean.

Breeding Method	Phenology	Variety	2017 (3.82)		2018 (0.75)		Average (2.29)	
			TOS 1	TOS 2	TOS 1	TOS 2	TOS 1	TOS 2
Hybrid	Fast	Diamond	108	106	150	141	129	123
Open pollinated	Fast	ATR Stingray⍉	92	95	107	84	99	89
Hybrid	Mid-fast	44Y90 CL	104	107	161	140	132	123
Open pollinated	Mid-fast	ATR Bonito⍉	90	91	68	88	79	90
Hybrid	Mid-slow	45Y25 RR	108	106	92	59	100	83
Open pollinated	Mid-slow	ATR Wahoo⍉	99	91	59	49	79	70
Hybrid	Slow	Archer⍉	101	97	105	82	103	90

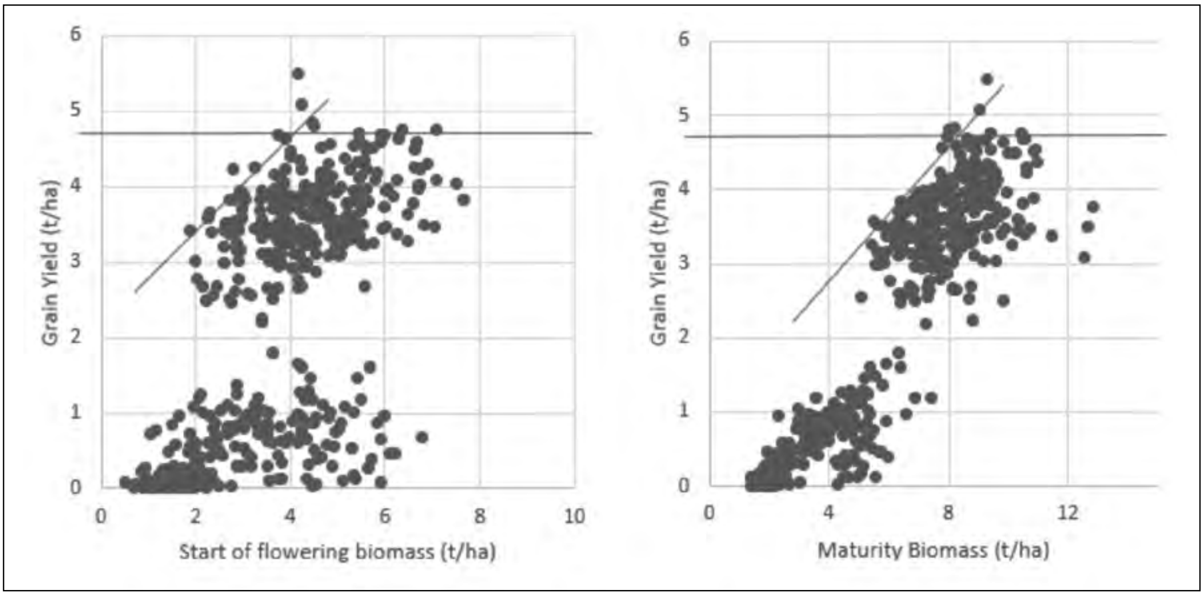

Figure 4. Start of flowering biomass and maturity biomass (t/ha) vs. grain yield (t/ha) for all Wimmera phenology trials 2015 to 2018.

the grain weight) has needed to be at least 8t/ha to achieve the maximum yield (Figure 5). When choosing a variety with fast development, it is important not to sow too early (start of April) as it will not have enough time to accumulate biomass if trying to achieve a high yield potential. This is the reason why hybrid varieties can set higher yield potential than OP TT varieties in the experiments.

In 2017, it was observed that hybrid varieties were better able to capture a higher yield potential when larger rates of N were applied compared to OP TT varieties. In 2018, higher biomass was achieved in all varieties when N was applied, but the high N treatments had a 'haying off' effect on yield in the slower hybrids and the later sown OP varieties. The fast and mid-fast phenology varieties increased or maintained their yield with higher rates of N applied as biomass continued to increase from start of flowering to maturity. The slow developing varieties did not increase their biomass through this period. The results suggest that there is less risk in applying higher rates of N to fast and mid-fast varieties sown in the correct window with a large upside in a good season and risks mitigated in a poor season.

Useful resources

http://grdc.com.au/Resources/Factsheets/2015/09/Blackleg-Management-Guide-Fact-Sheet

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

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Cereal foliar and root disease update 2019

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Keywords

- yellow leaf spot, rust, septoria, stubble borne disease, root lesion nematodes, crown rot, cereal cyst nematode, net blotch.

Take home messages

- Proactive disease management can minimise losses associated with root and foliar diseases.
- Avoiding highly susceptible varieties where possible provides effective disease control.
- Identifying paddocks at risk of root disease prior to sowing using PREDICTA® B testing enables strategies to minimise yield loss to be implemented.

Background

Dry conditions during 2018 meant cereal diseases were generally of limited concern. However, Agriculture Victoria (AgVic) field trials still measured yield losses of 12% due to foliar diseases and more than 50% due to crown rot, highlighting the importance of effective disease management strategies.

Cereal disease management in 2019

Cereal diseases will require proactive management prior to and during the 2019 season. Often, following dry seasons where diseases had limited impact, there is a temptation to be complacent about preventative disease management strategies, especially when cash flows are constrained. However, 2016 should serve as a reminder of how challenging disease management can be in a wet season following the dry season of 2015.

The widespread early summer rain across Victoria (December 2018) will likely support a green bridge (volunteer cereals growing over summer/autumn) that will carry over rust and viral diseases to provide early infection of crops in 2019. Likewise, dry conditions during 2018 will have limited the breakdown of stubble. This is likely to increase the carryover of stubble borne pathogens (e.g. crown rot, yellow leaf spot (YLS) and net blotch fungi) into 2019, even from cereal crops grown in 2017.

For 2019, a disease management plan that considers variety rating (consult a current disease guide) and inoculum loads within a paddock (consider stubble and soilborne diseases and cropping history) and the district (consider the green bridge) should be adopted. A fungicide strategy should then be developed for each crop based on the identified risks. Diseases can be cost effectively controlled when a proactive management approach is used.

Wheat foliar diseases

In general, wheat foliar diseases had minimal impact on wheat production during 2018. Septoria tritici blotch (STB) required management in the Western District, but did not progress under drier conditions in the Wimmera. Stripe rust and leaf rust appeared late in the 2018 season, but did not affect crop yield. There were no reports of stem rust in Victoria during 2018.

Rust in wheat

Widespread rain across Victoria in the early summer (December 2018) will support the growth of volunteer cereals that will act as a green bridge to carry rust inoculum over into the 2019 season. Rust is most severe in seasons following wet summers where there are large areas of uncontrolled cereal volunteers (green bridge).

Rust carryover can be reduced by removing volunteer cereals in paddocks by the end of February, thus providing a break in the life cycle of rusts from one season to the next. Removing volunteers also provides benefits for water storage, general management of weeds and other pests and diseases such as aphids and viruses.

Following a wet summer, it is important that increased attention is given to the management of cereal rusts. Where possible, avoid susceptible varieties to the three rusts (consult a current Cereal Disease Guide) and develop plans for rust management during 2019. At sowing, use of the fungicide flutriafol on fertiliser or fluquinconazole on seed has proven successful in delaying the onset of stripe rust epidemics in seasons where a significant green bridge risk existed.

Septoria tritici blotch

Septoria tritici blotch (STB) is currently the most important foliar disease of Victorian wheat crops. It is most severe in the high rainfall zone and widespread in the Wimmera, but did not develop to damaging levels in 2018 due to the dry spring. AgVic, with support from GRDC, assesses National Variety Trial (NVT) lines for their reaction to STB in the field at Hamilton to ensure new varieties have current Victorian relevant ratings.

An integrated approach that incorporates crop rotation (avoiding paddocks with infected wheat stubble), variety selection (avoid susceptible varieties) and in-crop fungicide application can provide effective suppression of STB. Identification of pathogen strains with partial resistance to common fungicides highlights the need to adopt an integrated control approach that is not solely reliant on fungicides.

Yellow leaf spot

Yellow leaf spot (YLS) is a common stubble borne foliar disease of wheat that is favoured by growing susceptible varieties and stubble retention practices. Previous studies by AgVic have demonstrated yield losses of up to 23%. Partial disease control which significantly reduces the level of yield loss in susceptible varieties is achieved with the application of a foliar fungicide (i.e. Prosaro®, (prothioconazole/tebuconazole)) at both stem elongation (Z31) and flag leaf emergence (Z39).

During 2017 and 2018, AgVic conducted field experiments near Horsham to compare fungicides and fungicide combinations for their ability to control YLS in comparison to a disease-free and an unsprayed control (Table 1). YLS infection was established by applying 1kg of infected wheat stubble to each plot. Disease severity, measured as percentage leaf area affected (%LAA), was assessed multiple times between mid-tillering (Z25) and mid anthesis (Z65). In 2018, no assessments were done post mid ear emergence (Z55) due to dry conditions. Grain yield and quality were also measured from harvest samples.

The effect of fungicide treatments on YLS severity during an average rainfall season in 2017 (393mm total) and a below average season in 2018 (204mm total) are shown in Table 2. Overall, no fungicide provided suppression comparable to the low disease treatment in either season, demonstrating that fungicides should not be

Table 1. Fungicide products applied at Z31 + Z39 (except Uniform® applied to fertiliser), active ingredients, rate and application method, and controls tested for suppression of YLS at Horsham during 2017 and 2018.

Treatment	Application	Rate of application (g ai/ha)	Example trade names
No Fungicide	-	-	Nil
Disease free	Multiple foliar fungicide	63/63	Low disease
Azoxystrobin/metalaxyl-M	Fertiliser	129/50	Uniform®
Azoxystrobin/cyproconazole	Foliar	160/64	Amistar® Xtra, Titan Azoxystrobin Extra®
Propiconazole	Foliar	125	Tilt®, Bumper®
Tebuconazole	Foliar	125	Orius®
Prothioconazole/tebuconazole	Foliar	63/63	Prosaro®
Azoxystrobin/epoxiconazole	Foliar	63/63	Radial®
Tebuconazole/azoxystrobin	Foliar	126/76	Veritas®

relied on for complete suppression of YLS. Of the fungicide products, propiconazole (e.g. Bumper®) and the prothioconazole/tebuconazole combination (Prosaro®) provided the greatest disease suppression in 2017. During 2018, propiconazole (e.g. Bumper®), and combinations of azoxystrobin/epoxiconazole (Radial®) and tebuconazole/azoxystrobin (Veritas®) provided significant suppression of YLS, comparable to the prothioconazole/tebuconazole combination (Prosaro®).

There were significant improvements to grain yield and quality following fungicide application during 2017 (Table 3), but not 2018 (data not shown). During 2017, propiconazole (e.g. Bumper®) and the prothioconazole/tebuconazole combination (Prosaro®) provided significant grain yield improvements over the nil control and the greatest grain quality improvements, comparable to the low disease control. This demonstrated that there were benefits to timely fungicide application with some products during a favourable season. Other

Table 2. Percentage leaf area affected by YLS in wheat variety Phantom⫽ on two occasions and AUDPC following different fungicide treatments at Horsham during 2017 and 2018.

	2017			2018		
	Disease severity (%)		AUDPC [A]	Disease severity (%)		AUDPC
Treatments	Z32	Z65		Z34	Z39	
Disease free	1.2 ^{a}	27.5 ^{a}	803 ^{a}	5.8 ^{a}	14.7 ^{a}	537 ^{a}
Propiconazole	13.0 ^{b}	29.3 ^{ab}	1594 ^{b}	15.3 ^{bc}	24.5 ^{cd}	989 ^{bc}
Prothioconazole/tebuconazole	16.7 ^{bc}	27.8 ^{a}	1742 ^{bc}	13.0 ^{b}	17.8 ^{ab}	833 ^{b}
Tebucoanzole/azoxystrobin	21.0 ^{cde}	32.7 ^{abc}	2035 ^{cd}	17.7 ^{bcde}	22.0 ^{bc}	1024 ^{bcd}
Azoxystrobin/cyproconazole	21.2 ^{cde}	34.2 ^{bcd}	2108 ^{cde}	21.2 ^{def}	26.2 ^{cde}	1234 ^{de}
Azoxystrobin/epoxiconazole	20.2 ^{bcd}	36.2 ^{cde}	2161 ^{cdef}	16.3 ^{bcd}	20.3 ^{abc}	954 ^{bc}
Azoxystrobin/metalaxyl-M	31.0 ^{f}	34.2 ^{bcd}	2491 ^{ef}	22.7 ^{efg}	25.3 ^{cde}	1228 ^{de}
Tebuconazole	24.5 ^{def}	38.5 ^{de}	2314 ^{def}	20.0 ^{cdef}	23.0 ^{bc}	1103 ^{cd}
No Fungicide	28.2 ^{ef}	40.3 ^{e}	2556 ^{f}	27.7 ^{g}	29.7 ^{de}	1458 ^{f}
P value	<.001	<.001	<.001	<0.001	<0.001	<0.001
LSD	7.82	5.53	439.7	5.22	6.44	224.2

Values that do not share the same letter in lowercase superscript are significantly different from each other and can be compared within columns only.

[A] AUDPC = Area under disease progress curve, denoting the cumulative disease severity over the growing season.

Table 3. Grain yield and loss plus grain quality of wheat variety Phantom⫽ in response to fungicide treatments to control YLS at Horsham during 2017.

	Grain yield		Grain quality	
Treatments	(t/ha)	Loss (%)	Screenings (%) [A]	Retention (%) [B]
Disease free	6.0 ^{a}	-	9 ^{a}	73 ^{a}
Propiconazole	5.8 ^{abc}	5 $^{n.s}$	10 ^{ab}	71 ^{abc}
Prothioconazole/tebuconazole	5.7 ^{abcd}	5 $^{n.s}$	9 ^{a}	73 ^{a}
Tebucoanzole/azoxystrobin	5.6 ^{bcde}	7	10 ^{bc}	70 ^{abcd}
Azoxystrobin/cyproconazole	5.5 ^{cde}	8	10 ^{bc}	70 ^{bcd}
Azoxystrobin/epoxiconazole	5.5 ^{cdef}	9	11 ^{bc}	68 ^{cd}
Azoxystrobin/metalaxyl-M	5.3 ^{def}	12	11 ^{c}	69 ^{bcd}
Tebuconazole	5.2 ^{ef}	14	11 ^{c}	67 ^{de}
Nil	5.2 ^{ef}	13	13 ^{d}	64 ^{ef}
P value	<.001		<.001	<.001
LSD	0.40		1.39	3.13

General analysis of variance with Fishers protected LSD used for analysis.

Letters in lowercase superscript can be compared within columns only.

n.s = non-significant differences from low disease control.

[A] Screenings = % of grain less than 2.2 mm wide. [B] Retention = % of grain greater than 2.5mm wide.

fungicides products did not provide significant yield improvements, but did provide improvements to grain quality, compared to the nil treatment.

The findings from this study were comparable to previous studies that showed that foliar fungicide application at Z31 and Z39 can provide significant improvements to grain yield and quality during seasons favourable to the development of YLS, where yields are average or greater. However, fungicides did not provide economic benefit during dry seasons. Where possible, use variety and paddock selection to minimise risk from YLS as this will be more effective.

Barley foliar disease management

Foliar diseases had little impact on barley crops in Victoria during 2018 due to the dry conditions. Spot form (SFNB) and net form of net blotch (NFNB) and scald were at low levels while leaf rust and powdery mildew were generally absent.

Net form of net blotch

Net form of net blotch (NFNB) is becoming an important foliar disease of barley due to the cultivation of susceptible varieties such as RGT Planet$^{\phi}$ and in some regions, Fairview$^{\phi}$ and Oxford$^{\phi}$. Field experiments at Horsham during 2017 showed grain yield losses of up to 22% (2t/ha), as well as grain quality losses in a high yielding season (approx. 8 t/ha) with good spring rainfall.

Field experiments conducted near Horsham (Wimmera) and Birchip (Mallee) during 2018 determined grain yield and quality loss in three barley varieties with different levels of resistance to NFNB and one very susceptible old breeding line, VB9613. Two treatments were applied: 1) No disease - fungicide treatment which had Systiva® applied to seed and foliar applied Prosaro® at stem elongation (Z31) and flag emergence (Z39) to determine grain yield and quality potential, and 2) Disease treatment, which had no fungicide application and 1kg of NFNB infected barley stubble added, to determine loss.

The Horsham trial was in a paddock with good sub-soil moisture, supporting grain yields of approximately 4.5t/ha, despite growing season rainfall being well below average. Scald infection was present in Fathom$^{\phi}$, Commander$^{\phi}$ and RGT Planet$^{\phi}$, which may have affected grain yield slightly. Up to 24% of leaf area was affected by NFNB in the very susceptible line VB9613. This resulted in a 12% reduction in grain yield (Table 4) and losses in grain plumpness and weight, demonstrating the importance of not growing very susceptible varieties as they can have losses during any season with good yield potential. NFNB developed late in the season in the susceptible to very susceptible (SVS) rated RGT Planet$^{\phi}$, but did not cause grain yield loss and only caused minor grain quality loss. This contrasted with the Horsham site during 2017, where RGT Planet$^{\phi}$ had 22% grain yield loss and significant grain quality losses. This highlights that seasonal conditions are important to disease development and that NFNB is unlikely to be an issue during dry seasons except if a very susceptible variety (VS) is grown.

Fathom$^{\phi}$ (moderately resistant to moderately susceptible (MRMS)) and Commander$^{\phi}$ (moderately susceptible (MS)) had little or no NFNB infection and no losses to grain yield or quality, showing that MS or better rated varieties can be sufficient to avoid loss due to NFNB in low disease pressure seasons.

The Birchip site had less than 5% of leaf area affected by NFNB (data not shown) and grain yield was less than 0.7t/ha in all varieties and treatments (data not shown), indicating that water was the main limiting factor to yield. This demonstrated the importance of reviewing disease management plans during the season and not unnecessarily applying fungicides in such a dry season.

Red leather leaf of oats

Red leather leaf is a common stubble and seed-borne foliar disease of oats caused by the fungus *Spermospora avanae*. To date, there has been little

Table 4. NFNB severity, grain yield and quality loss of three barley varieties and one VS rated breeding line at Horsham during 2018.

	NFNB Severity (%) 18/10 (Z85)	Grain yield loss (t/ha)^{A}	Grain quality loss (%)^{A}		
			Retention (>2.2 mm)	Screenings (<2.2 mm)	Weight (g)
Fathom$^{\phi}$ (MRMS)	0.2	0.3 (7%)^{ns}	0	0	0
Commander$^{\phi}$ (MS)	0.8	0.2 (4%)^{ns}	1ns	0	0
RGT Planet$^{\phi}$ (SVS)	5.0	0.1 (2%)^{ns}	1*	0	2^{ns}
VB9613 (VS)	23.8	0.5 (12%)*	7*	1*	5*

**=Significant difference between the fungicide and disease treatments at 0.05. ns = Not significant.*

research to determine its impact on oat production or identify effective control strategies. AgVic conducted separate variety yield loss and fungicide experiments near Horsham during 2018 to help develop management strategies.

The yield loss experiment consisted of four milling grade varieties (Table 5) with different resistance ratings to red leather leaf, with six replicates each of two treatments: 1) Disease free - three fungicide applications to minimise disease, and 2) Disease - no fungicide and 1kg of red leather leaf infected oat stubble applied to determine loss.

Despite the low rainfall during 2018, the oats yielded 3-4t/ha with up to 18% red leather leaf infection by season's end. Kowari$^{(b)}$ and Bannister$^{(b)}$ both had significant grain yield loss in infected plots (Table 5). Kowari$^{(b)}$ also lost grain quality, which is a potential concern for milling oat growers. No grain yield or quality loss was measured for Williams$^{(b)}$ or Mitika$^{(b)}$, most likely due to crop maturity in relation to disease development.

These findings demonstrate that red leather leaf caused grain yield and quality loss in milling oats, even during a dry season. Losses were variable between varieties and are likely to be greater during wetter seasons that favour disease development later in the season.

Fungicides

To evaluate fungicide strategies for the management of red leather leaf in oats, three fungicide applications timings (Z25, Z31 and Z39) were compared with an untreated control in the susceptible oat variety Mitika$^{(b)}$. Disease severity was assessed six times (27 July, 6 and 23 August, 5 and 11 September and 2 October) during the growing season and grain yield and quality measured. There was no significant effect of fungicide on grain yield or quality, so this data has not been presented.

Red leather leaf symptoms were first observed during mid-July which developed rapidly during late August and early September (Figure 1) in response to wet weather. There was little disease development during the spring months due to dry conditions. Red leather leaf suppression varied between foliar fungicide timings with application at tillering (Z25) providing the best suppression (Figure 1) and application at stem elongation (Z31) was the next most effective. This was due to fungicide application coinciding with the onset of early disease development in 2018. Foliar fungicide at flag leaf emergence (Z39) was less effective, due to the application being after the majority of disease had already developed.

Red leather leaf develops rapidly, given the right conditions. As a result, multiple fungicide applications may be required. Further studies are required to provide more robust management recommendations to oat growers.

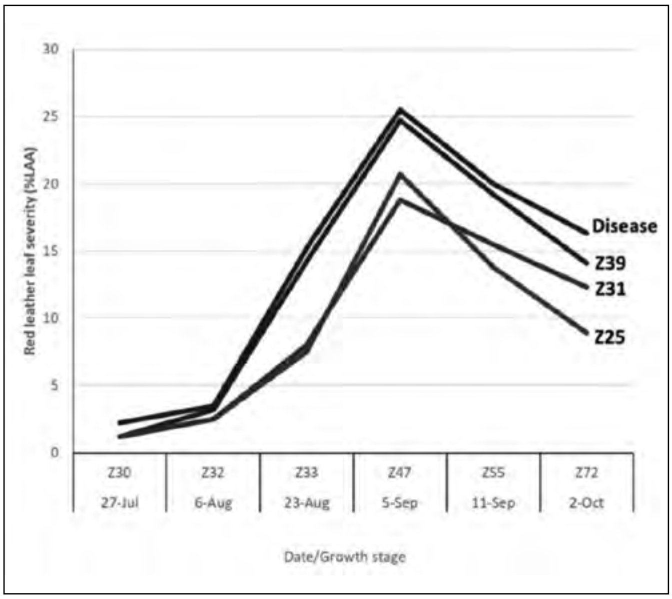

Figure 1. Red leather leaf development in susceptible oat variety Mitika$^{(b)}$ in response to application of foliar fungicide, propiconazole (125 g ai/ha) at different growth stages in comparison to a no fungicide, disease treatment.

Table 5. Red leather leaf severity, grain yield and quality loss of four milling oat varieties at Horsham during 2018.

	Red leather leaf severity (%LAA)^{A} 2 Oct (Z72)		Grain yield		Grain quality loss (%)^{B}		
					Retention (>2.5mm)	Screenings (<2.2mm)	Grain weight
Variety	Dis.	Fung.	t/ha	Loss			
Kowari$^{(b)}$ (MRMS)	17.8	12.7	3.0	0.3 (10%)* ^{B}	9*	4*	2*
Bannister$^{(b)}$ (MS)	13.3	6.9	4.0	0.5 (12%)*	1^{ns}	2^{ns}	1^{ns}
Williams$^{(b)}$ (MS)	9.4	11.5	3.5	0	0	0^{ns}	0
Mitika$^{(b)}$ (S)	16.1	12.6	3.0	0	1^{ns}	0^{ns}	2^{ns}

^{A} *%LAA = percentage of leaf area affected.*

^{B} **=Significant difference between the fungicide and disease treatments at 0.05. ns = Not significant.*

Soilborne diseases

Yield losses caused by root diseases often go unrecognised as symptoms are below ground and even if their effects become apparent, there are no in-crop management solutions available. A PREDICTA® B test taken before planting provides an effective way to detect paddocks at risk of root diseases and enables management strategies to be implemented.

Recent economic studies demonstrated annual average yield losses of 7% and 1% due to crown rot and root lesion nematodes, respectively, across Victoria and South Australia (SA). Within individual situations, however, field trials during 2018 in Victoria demonstrated yield losses from crown rot of 42% and 65% in bread and durum wheat crops, respectively (Table 6), demonstrating how damaging this disease can be.

Crown rot

Crown rot is now possibly the most important disease affecting wheat crops in Victoria and nationally. A recent study of 1502 PREDICTA® test results from across Victoria and SA (2015-2017) found that 36% of paddocks tested had a medium or high level of crown rot inoculum prior to sowing. Annual average yield losses across all wheat crops in Victoria and SA were estimated to be 6.6% with losses up to 10% in seasons conducive to crown rot. Field trials conducted by AgVic have demonstrated that in paddocks where crown rot is present, yield losses greater than 30% can occur.

The extent of yield loss caused by crown rot is related to the level of inoculum present in the paddock at planting, the seasonal conditions and variety susceptibility (Table 6). Hence, growers can use a PREDICTA® B test to establish the level of risk present in a paddock prior to sowing and implement appropriate management strategies if necessary.

Seasonal conditions have a large influence on the yield loss caused by a given level of crown rot infection (Table 6). For example, during the wet season of 2016, the medium crown rot inoculum levels caused no yield loss, but during the driest season (2018) the same level of inoculum caused a 35% reduction in grain yield in the susceptible variety Cobra⦹.

Cereals vary in their extent of yield loss in the presence of crown rot. As shown in Table 6, during 2015 at the high inoculum level, yield loss in the bread wheat Emu Rock⦹ (MS) was 12%, while in the bread wheat Cobra⦹ (S) was 35% and the durum wheat WID802 (VS) was 63%. This clearly shows the benefit of avoiding highly susceptible varieties in paddocks with medium to high levels of crown rot inoculum.

In paddocks with high levels of crown rot, it is best to avoid growing cereals. Previous work has shown that cereals increased inoculum levels, while

Table 6. Effect of seasonal conditions, increasing crown rot inoculum levels at planting and varietal susceptibility on yield loss with yield potential and growing season (April to October) rainfall at Horsham during the years 2015 to 2018.

Year	Yield Loss (%)			Yield Potential (t/ha)	GSR (mm) Apr-Oct
	Crown Rot Level (g/m row)				
	Low (0.25)	Medium (1.0)	High (2.0)		
Bread Wheat, cv. Emu Rock⦹ (MS to crown rot)					
2015	0	15	12	3.15	142
2016	0	0	0	6.55	374
2017	0	0	0	4.44	303
2018	0	0	0	2.53	187
Bread Wheat, cv. Cobra⦹ (S to crown rot)					
2015	18	29	35	3.14	142
2016	0	0	0	7.24	374
2017	0	9	17	4.12	303
2018	0	35	42	2.36	187
Durum Wheat, cv. WID802 (VS to crown rot)					
2015	19	50	63	3.10	142
2016	0	0	0	7.69	374
2017	0	12	25	4.32	303
2018	0	22	65	2.52	187

broadleaf break crops (e.g. canola and pulses) and fallow decreased inoculum levels of crown rot. In general, a two-year break from cereals is required to reduce medium to high inoculum levels to a low level. A three-year break may be required following the dry season of 2018 due to the decreased decomposition of cereal stubble.

Rhizoctonia root rot

The dry 2018 season will have favoured the build-up of *Rhizoctonia solani* AG8 levels within paddocks. Significant summer rainfall will decrease inoculum levels if volunteer cereals and summer weeds (green bridge) are effectively controlled. The impact of rhizoctonia root rot on crops sown in 2019 will be reduced if the season breaks early and crops establish in warmer soil. Rhizoctonia is most damaging when root growth is restricted either by cold soils, compaction layers or lack of moisture. Crops that establish well can still be affected in mid-winter when soil temperatures drop below 10°C at which point Rhizoctonia can attack the crown roots causing uneven growth and reduced tiller number, rather than classic bare patch symptoms.

If growing cereals in 2019, a PREDICTA® B test can be used to identify paddocks at risk. If Rhizoctonia is present at high levels, control summer weeds and autumn green bridge and consider rotating to a non-cereal crop. If a cereal is to be grown, wheat is more tolerant than barley and early sowing in the seeding window with banding of nitrogen (N) below the seed to facilitate rapid root growth can also limit early impacts. Ensure good crop nutrition, with particular attention to trace elements, and increase seeding rates to reduce impact of lost tillers from Rhizoctonia damage to crown roots.

Consider fungicide seed treatments to protect the roots. Rainfall is needed to move fungicides into the root zone as roots outside the fungicide zone are not protected. Seed treatments tend to protect the seminal roots, whereas liquid streaming Uniform® above and below the seed can protect crown and seminal roots and tends to produce larger yield responses in above average rainfall seasons.

Root lesion nematodes

The root lesion nematodes (RLN), *Pratylenchus neglectus* and *P. thornei* are widespread in Victorian cropping paddocks. A recent study of 1,965 PREDICTA® B test results from across Victoria and SA (2013-2017) found that RLNs were present in 92% of paddocks with approx. 10% of paddocks having a medium or high test result. This report estimated the annual average yield loss across all wheat crops in Victoria and SA to be 1% with losses up to 2% in seasons conducive to losses from RLNs. Field trials conducted by AgVic and SARDI have demonstrated that in paddocks where RLNs are present, yield losses greater than 10% can occur.

Using data collected from many field trials conducted in Victoria and SA, the PREDICTA® B risk categories were updated for RLNs (Table 7). These revised risk categories reflect that yield losses due to RLNs do not occur in all seasons and our improved understanding of the extent of yield losses that they cause.

Table 7. Revised *P. thornei* and *P. neglectus* PREDICTA® B risk categories for Victoria and SA for seasons that range in their conduciveness for yield loss in intolerant varieties.

Risk Category	RLN /g soil	Seasonal Conditions and Frequency[A]		
		Conducive 40%	Intermediate 30%	Non-conducive 30%
		Yield Loss %		
Pratylenchus thornei				
BDL[B]	<0.1	0	0	0
Low	0.1-14	0-5	0-2	0
Medium	15-60	5-20	2-10	0
High	>60	20-40	10-20	0
Pratylenchus neglectus				
BDL	<0.1	0	0	0
Low	0.1-24	0-5	0-2	0
Medium	25-100	5-20	2-10	0
High	>100	20-40	10-20	0

[A] *Conducive and non-conducive season are those where yield loss does and does not occur, respectively, due to the nematodes. The historical frequency of these occurrences is provided as percentages. The conditions that favour yield loss are not understood.*

[B] *BDL, below detection level.*

To keep nematode densities below yield limiting thresholds, it is important to grow varieties with a MR/MS or better resistance rating. If susceptible varieties are grown, it is important they are rotated with resistant crops or varieties and nematode densities monitored using a pre-sowing PREDICTA® B test. If medium to high nematode densities are present, consider growing resistant crops or varieties. Consult current Cereal and Pulse Disease Guides for the latest RLN resistance ratings as it is important to check the resistance rating of varieties due to varietal variation within crops for resistance/susceptibility to RLN species.

Bunts and smuts

Seed treatments provide cheap and effective control of bunt and smut diseases. Seed should be treated every year as bunt and smut can increase rapidly, resulting in unsaleable grain. Good coverage of seed is essential and clean seed should be sourced if a seed lot is infected. Fertiliser treatments do not control bunt and smuts, so seed treatments are still required.

Conclusion

In the absence of proactive disease control, yield losses due to diseases can be greater than 20%. It is, therefore, important that plans are developed to effectively manage wheat diseases this season.

Useful resources

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

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Sustaining our herbicide options into the future

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GRDC project codes: UA00158, 9175880

Keywords

- herbicide resistance, cross-resistance, pre-emergent herbicides, 2,4-D.

Take home messages

- Resistance to pre-emergent herbicides in annual ryegrass is increasing and the resistance patterns are complex.
- Mixtures of pre-emergent herbicides can help manage resistant annual ryegrass populations when coupled with seed set control tactics.
- Resistance to 2,4-D in broadleaf weeds is increasing. Low level resistance is easy to control, but high-level resistance requires additional practices.

Resistance to pre-emergent herbicides

The increasing incidence of resistance to post-emergent herbicides in annual ryegrass has meant a much greater dependence on pre-emergent herbicides for control of this weed. This has the unwanted consequence of selecting for resistance to pre-emergent herbicides. In recent years, resistance to pre-emergent herbicides has been increasing in annual ryegrass populations. Resistance to trifluralin is widespread in South Australia (SA) and western Victoria. The extent of resistance to trifluralin is increasing in NSW.

More recently, failures of Avadex Xtra® (triallate - Group J), Boxer Gold® (prosulfocarb – Group J + S-metolachlor - Group K) and Butisan® (metazachlor – Group K) to control annual ryegrass have been reported from the field. The problem is that some of these populations have resistance to numerous pre-emergent herbicides. Several of these populations have moderate levels of resistance to the Group J herbicides and some cross-resistance to the Group K herbicides. We tested six different resistant populations from SA and NSW. The levels of resistance to triallate and prosulfocarb were similar in these populations, but there were varying levels of resistance to the Group K herbicides metazachlor and pyroxasulfone (Figure 1).

Options for controlling annual ryegrass resistant to the pre-emergent herbicides

Two field trials were conducted at Arthurton and Paskeville, SA, in wheat in 2018 to explore opportunities for managing resistance to pre-emergent herbicides. Both sites had weed populations with high resistance to trifluralin, moderate resistance to the Group J herbicides and low resistance to the Group K herbicides. Growing conditions during 2018 were challenging with below average rainfall between April to July, resulting in lower than normal activation of pre-emergent herbicides.

In the field trials, trifluralin was relatively ineffective at reducing annual ryegrass at both sites and did not reduce annual ryegrass spike production, consistent with the high level of resistance to trifluralin present (Table 2). Triallate (Avadex Xtra®) alone reduced weed density at Arthurton, but not at Paskeville. Prosulfocarb, as either Arcade® or

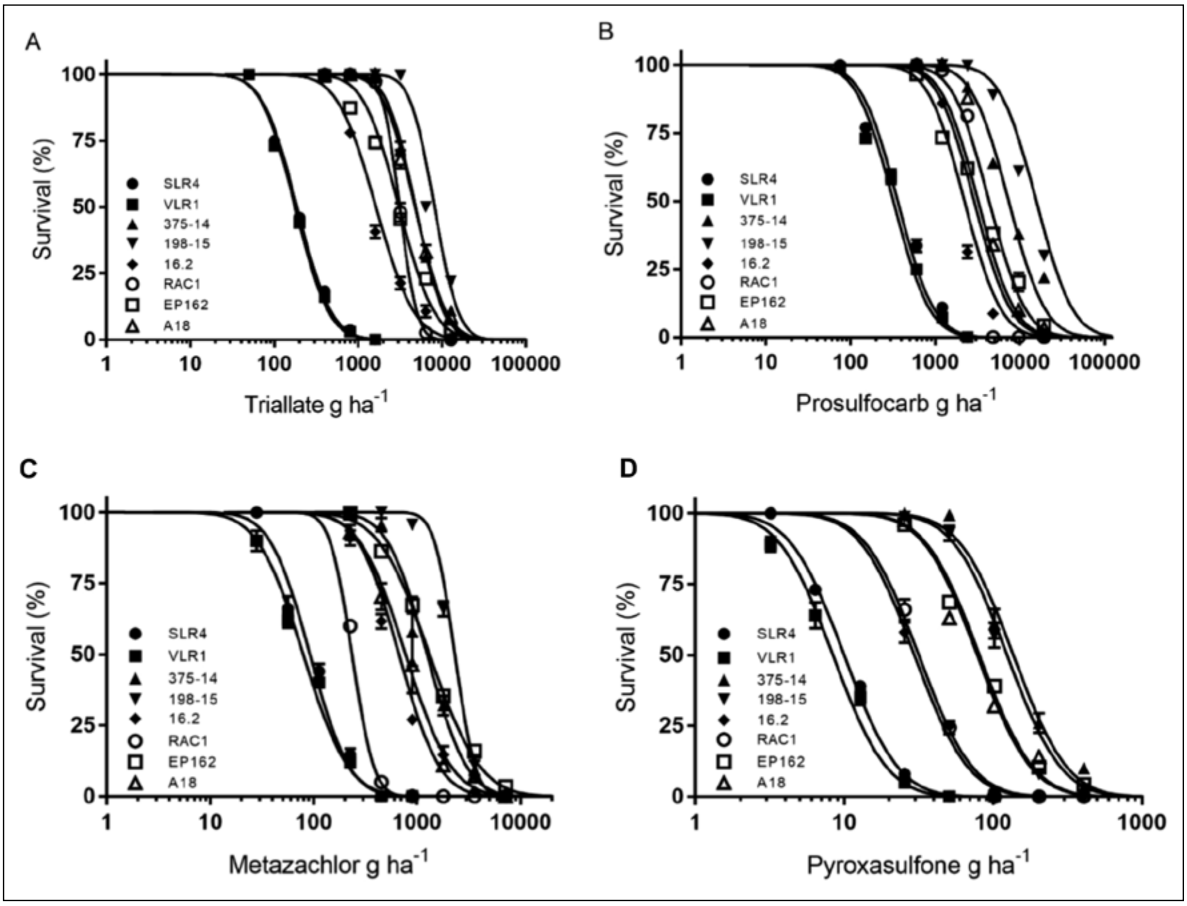

Figure 1. Response of two susceptible (SLR4 and VLR1) and six resistant annual ryegrass populations to various pre-emergent herbicides. (A) Triallate, (B) Prosulfocarb, (C) Metazachlor and (D) Pyroxasulfone.

Table 1. Control of herbicide resistant annual ryegrass with pre-emergent herbicide options at Arthurton and Paskeville in 2018. All herbicides were applied incorporated by sowing (IBS) prior to sowing. Weed density was determined eight weeks after sowing (WAS) and spike density at 18 WAS. Values with different letters in each column were significantly different.

Treatments	Rate (g a.i./ha)	Weed density (plants/m^2)		Spike density (spikes/m^2)	
		Paskeville	Arthurton	Paskeville	Arthurton
Untreated		688 f	518 i	514 g	294 f
Triallate	1500	609 f	191 f	318 f	223 d
Trifluralin	1200	832 g	388 h	507 g	295 f
Trifluralin + triallate	1200 + 1500	601 ef	282 g	339 f	279 f
Prosulfocarb	2400	105 a	119 bc	190 de	256 e
Prosulfocarb + S-metolachlor	2000 + 300	160 b	136 cd	159 bc	213 d
Pyroxasulfone	100	510 e	171 e	204 e	90 a
Prosulfocarb + S-metolachlor + triallate	2000 + 300 + 1500	262 d	173 e	168 cd	168 c
Prosulfocarb + triallate	2400 + 1500	259 cd	136 cd	107 a	178 c
Pyroxasulfone + triallate	100 + 1500	162 b	143 d	131 ab	128 ab
Pyroxasulfone + prosulfocarb + S-metolachlor	100 + 2000 + 300	106 a	102 a	165 cd	85 a

Boxer Gold®, provided higher levels of control and reduced annual ryegrass seed set. Pyroxasulfone (Sakura®) was less effective at reducing annual ryegrass numbers, particularly at Paskeville. This was probably the result of the dry seasonal conditions, as this herbicide requires more moisture to activate. Sakura® tended to be better at reducing annual ryegrass seed set.

Despite resistance to all of the herbicides used being present at the two sites, mixtures of pre-emergent herbicides were more effective at controlling annual ryegrass and reducing seed set (Table 1) than using single herbicides alone. Mixtures of pre-emergent herbicides can be useful where annual ryegrass populations are high or where conditions for pre-emergent herbicides to work are poor. These trials show that where moderate or low resistance to pre-emergent herbicides is present, mixtures can also help control resistant populations.

Resistance to herbicides in broadleaf weeds

Another problem that is increasing in prominence is resistance to 2,4-D in broadleaf weeds. With increasing resistance to Group B herbicides in broadleaf weeds, 2,4-D and the other Group I herbicides have been used more extensively for the management of troublesome broadleaf weeds in cereal crops and fallows. This extra selection pressure is resulting in resistance to Group I herbicides.

The major weeds of concern are wild radish, Indian hedge mustard and common sowthistle. Wild radish with resistance to Group I herbicides is present in cropping regions of NSW, Victoria, Tasmania and SA. Resistant Indian hedge mustard mostly occurs in SA with a few isolated populations in Victoria. Resistant sowthistle is also mostly occurring in SA with isolated populations in Victoria and NSW.

Resistance to the Group I herbicides appears to come in at least two forms that are probably related to different resistance mechanisms. There is a high-level resistance form, seen commonly in Indian hedge mustard and in some wild radish populations (Figure 2), and a low-level resistance form, seen in sowthistle and most wild radish populations. The low-level resistant individuals typically show strong symptoms of stem and leaf twisting and swelling, but the plants do not die and start to re-grow after 14 days or so. The high-level resistant individuals show no, or slight symptoms of the herbicide and recover within a few days to look normal.

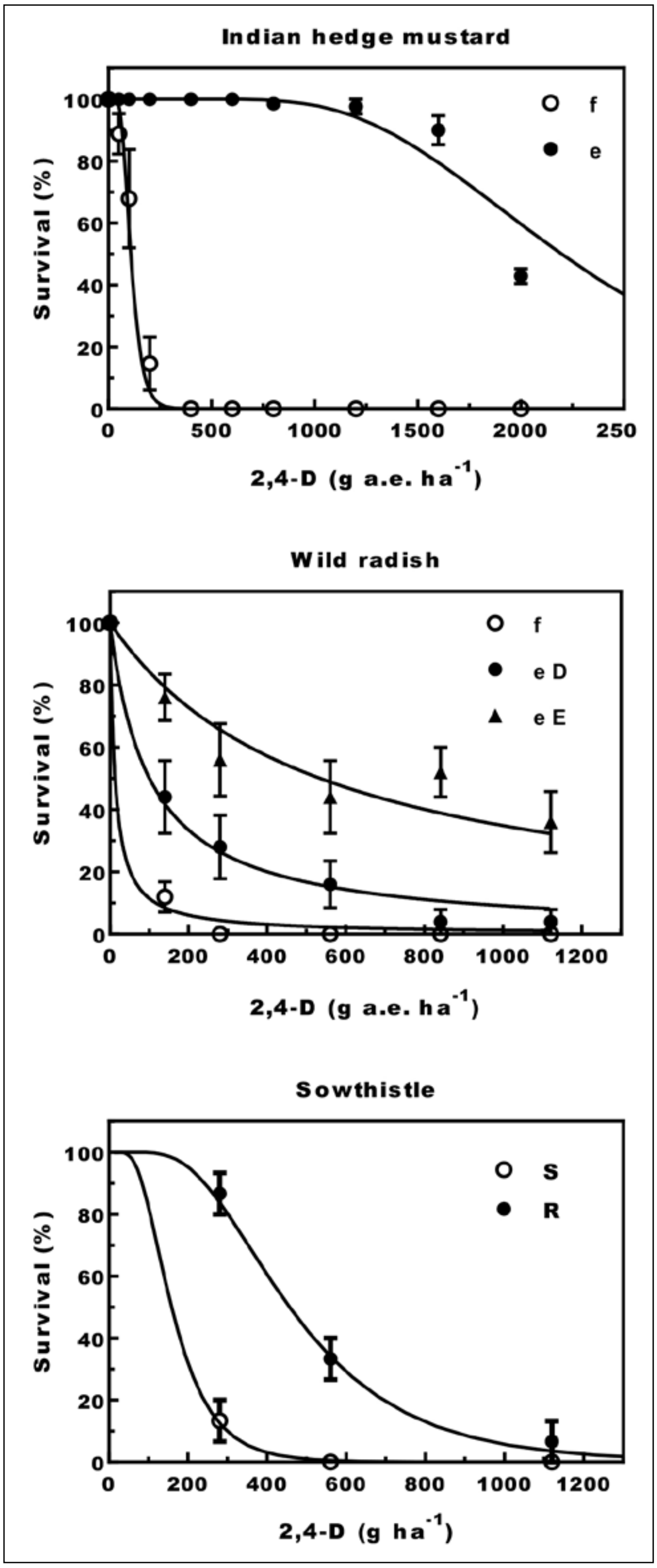

Figure 2. Response to 2,4-D of susceptible (S) and resistant (R) populations of Indian hedge mustard with high level resistance to 2,4-D (top), wild radish with high level and low-level resistance (middle), and sowthistle with low level resistance (bottom).

These different forms of resistance can have consequences for management with herbicides. Where the level of resistance is low, mixtures of 2,4-D with other herbicides coupled with crop competition can provide effective control. Where the level of resistance is high, other practices will have to be used. There are alternative mode of action herbicides from Groups H and G that can be effective in mixtures on these species. Harvest weed seed management strategies can work for wild radish and Indian hedge mustard, but will not be very effective for sowthistle. Wild radish being an outcrossing species can accumulate additional resistance mechanisms and may become more resistant to 2,4-D over time. For wild radish management, a two-spray strategy of a contact herbicide early post-emergence (e.g. Velocity® or Talinor®) followed by a more systemic product (e.g. Flight® or Triathlon®) typically works well.

Useful resources

http://sciences.adelaide.edu.au/agriculture-food-wine/system/files/docs/2016-wild-radish.pdf

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Working towards resilient adviser-grower client relationships in the grains industry

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Keywords

- agronomy, adviser, resilience, high performance, decision support, role clarity.

Take home messages

- Be clear in your role.
- Be thorough in your advising and avoid giving instant answers when the situation is complex.
- Be mindful of taking on another person's stress.
- Accept that not all growers will make the decision you want them to.
- Set boundaries to allow recovery time.

Background and context

Advisers are an integral part of the farm team. So much so that they can become quasi management. This works well for some, but the model can be tested in years when management decisions a re complex and there is no obvious answer for a scenario.

2018 was one of those years, and in fact, most years have periods of complex decision making. In a lot of regions in Victoria, the 2018 issue which required complex decision making was handling droughted and/or frosted crops and reviewing the hay option to capitalise on the opportunity presented by the east coast fodder shortage, a situation similar to the period between 2006 to 2008.

In other years, it has been nitrogen (N) decision making (2011, 2016 come to mind) or disease management in unfamiliar crops like the recent Botrytis grey mould outbreak in Mallee lentils or further back in 2000 in the Wimmera.

Advisers were leant on heavily by their clients in 2018 to assess the likely cereal and grain yield outcomes and to estimate the potential for making hay. A straightforward process you might say, however, nothing could be further from the truth.

Except in specialist hay districts, such as Elmore in northern Victoria and parts of the Mid North in SA, growers first and foremost tell me that they like to grow grain. For many, the prospect of surrendering a crop to hay feels like failure even if the financial outcome can be as good as, or better than, the budgeted grain outcome.

Many growers do not own hay making machinery or have experience in hay production. Even adept hay makers find it difficult to cut extra hectares of hay if they already have a large program, as they are fully aware of the logistical nightmare posed by a large hay program and the risk of weather damage during curing time.

Add to that is the uncertainty of the market — if large areas are cut, will the price plunge? Will hay buyers honour verbal agreements and pay up? The bitter taste of bad debtors for hay still lingers even a decade after the millennial drought.

Inevitably, in difficult years the stress is transferred from grower to adviser and on the flip-side, in favourable years, advisers feel the joy of delivering good advice that leads to excellent financial outcomes for the grower.

This paper attempts to answer the following question:

How best do advisers help their clients work towards or maintain a high performing business and at the same time foster a resilient client adviser relationship while maintaining their own wellbeing and professional sense of satisfaction?

What does a resilient client adviser relationship look like?

My view of a resilient working relationship is an arrangement that serves both the personal and business wellbeing of both parties to enable an enduring and sustainable relationship.

A useful definition of resilience offered by McEwen (2016) at an individual level is:

'An individual's capacity to manage the everyday stress of work and remain healthy, rebound and learn from unexpected setbacks and prepare for future challenges proactively'.

This applies to both advisers and growers. A key component of striving for resilience is proactively preparing for challenges.

McEwen's research-based model for building a good overall level of resilience is to invest in seven components described in Figure 1 and Table 1. Developing such capabilities across the whole seven components allows wellbeing and productivity to co-exist over a long period of time.

What does this mean for advisers?

The following practical strategies are offered to proactively manage the client relationship in order to build your own resilience and that of the clients and farm businesses you are working with. These guidelines were developed from several years of experience, both as an adviser for 12 years in Western Victoria and as a client for three years while employed as commercial manager of 10 farms across 80,000ha in four states. Previous roles in research and education have also contributed to the perspective shared in this paper.

1. Be clear in your role

Resilient client-adviser relationships are more likely to occur when both the adviser and client clearly understand the adviser's role in assisting the farm business. This does not happen by accident and requires clear communication from both parties. In the case of the adviser, it may involve the adviser's supervisor or employer, depending on the career stage of the adviser. A regular check-in, at least annually, with clients about roles and expectations, is one way of avoiding misunderstandings.

Farm businesses have a higher chance of sustained success when the farm management personnel are in control of the decision making and the adviser supports that decision making process by providing informed and evidence based information considering the individual farm situation.

This is illustrated in the findings of a recent GRDC project RDP00013 (2016) where high performing farm businesses exhibited the trait of owning the responsibility of decision making within the farm business. As part of the decision-making process, high performing growers had internal 'rules of thumb' that they considered in conjunction with professional advice and recommendations. 'Rules of thumb' used to guide decision making, either consciously or subconsciously, are generally based on intuition, previous experience and pre-existing knowledge (Long 2013).

In the hay versus grain scenario, an adviser will have the highest level of impact and add the most value by:

- Tracking down the required technical information to update knowledge.
- Making objective assessments (or teach the grower how to make the assessments).
- Working through the economic numbers of grain versus hay for a range of possible outcomes with the grower.
- Talking through the logistics and risks.
- Making a recommendation for the grower to consider.

Ideally the grower can then make and own the final decision.

Despite sometimes being pressured to do so, it is not the adviser's responsibility to make the final decision when it is a line-ball scenario. That responsibility sits with the grower, as the grower must be comfortable in accepting the risks and uncertainty associated with that decision. This is thoroughly described in the GRDC funded publication 'Farm Decision Making' authored by Nicholson et al. (2015) (https://grdc.com.au/resources-and-publications/all-publications/publications/2016/04/farm-decision-making)

2. Be thorough in your role as an adviser and avoid giving instant answers when the situation is complex

The stakes are large when making major in-field recommendations to support grower decisions, especially complex or complicated ones. The task for the adviser is to support often powerful and season defining decision making worth six figures or more to the bottom line. Suggested approaches include combining:

- Visual observation.
- Objective assessment.
- Data and scenario analysis.
- Working through the issues in partnership with the client.

Document the discussion and calculations used to guide the grower's decision. This can be a great learning experience for both client and adviser. Should the post-decision outcome not be as expected, the thorough process and documentation can be referred back to.

In uncertain and stressful times, it is human nature to look to blame. Sticking to a process that includes good practice and documentation protects the adviser from unwarranted blame.

Many growers, especially those with many years of experience are intuitive and are more comfortable with gut-feel decision making, especially when the issue is time sensitive, but in some cases, relying on gut-feel alone can be very risky.

Advisers can feel pressured to provide an instant answer, but the risks of providing an uninformed answer can be very high. Process and data driven decision making is the most responsible and professional approach. This process which requires paddock observation, objective measurement, calculations, discussion then recommendation, is sometimes perceived by the grower to take too long.

Despite this conundrum, data driven decision making, if generated in a timely manner, can complement intuition and gut-feel. The combination of the two can be very powerful and reduces the risk of gut-feel being derailed by stress. Nicholson et al. (2015) provide extremely useful practical advice on advising and decision making.

Figure 1. The seven components of resilience (McEwen 2016).

Table 1. Practical strategies for working towards resilience at work (McEwan 2016).

S1	S2	S3	S4	and present	S6	S7
Living authentically	Finding your calling	Maintain perspective	Managing stress	S5 Interacting	Staying healthy	Building networks
• Making the most of your strengths • Aligning your work with your values • Emotional regulation • Mood management	• Finding purpose and meaning in what you do • Feeling connected	• Perspective on setbacks • Solution focused problem solving • Avoiding thinking traps • Positive energy and optimism (but not blind hope) • Response to and management of negativity • Adaptability	• Caring for oneself at work and at home • Passive and deliberate relaxation • De-stressing and debriefing techniques • Time management and prioritisation • Workload negotiation • Work life blend • Being mindful	co-operatively • Seeking feedback • Seeking support • Offering support	• How to change habits • Healthy eating • Exercise • Better sleep	• Identify network gaps • Developing access to all levels of support required

3. Be mindful of taking on another person's stress

A useful skill when providing advice in pressure situations is to be able to listen to other's angst, without absorbing too much of that angst for too long. This can be hard for empathic and compassionate people and requires substantial self-management.

In the heat of the season, it is busy and demanding and sometimes there are no simple answers. It is a very natural response to ruminate over the advice you have provided and worry excessively. While empathy comes hand in hand with a good client adviser relationship, the client is best served when your decision making is based on logic rather than emotion.

Practical tips to manage your personal stress include staying healthy by getting adequate sleep, eating well, exercising and scheduling fun and relaxation.

Failing to look after yourself will impact on your personal wellbeing and on the quality of service you can provide your clients. The resilience at work scale (McEwen 2016) is one practical model that provides guidance for a holistic approach to staying well and achieving at work. (Table 1).

4. Accept that not all growers will make the decision you want them to

When uncertainty and stress are rife, our brain goes into flight or fight mode and tends toward emotionally driven decision making rather than rational decision making (Bradberry 2015).

The grower's decision may also be influenced by business or personal factors that you are not privy to. Despite your diligent, well informed and rational advice, there will inevitably be growers whose decisions may be contrary to your judgement and advice.

In that case, document your advice in writing, have the conversation, then leave it there. At the end of the day, it is their farm, not yours and you cannot control their decision making or their actions.

Nicholson et al. (2015) described some key factors that can increase the odds of client buy in:

- Involving the grower in the recommendation process so they understand and take ownership of your recommendations.
- Listen and consider their values, goals and motivations so that the advice is tailored to their business.
- Consider the emotional and financial risks involved.

5. Set boundaries to allow recovery time

'Stress is not the problem, the problem is lack of recovery' is a phrase used by Mark McKeon, a high-performance coach and regular speaker at GRDC events (McKeon 2011, McKeon 2018).

Living and working in small communities means you may be socialising with your clients. This is tricky as there is little escape when everyone wants to 'talk shop' at the pub or at footy. To serve your clients well, you need to be able to relax and recover by doing enjoyable things on weekends without the pressure of being in work mode 24-7. Most clients are generally respectful when boundaries around private time are set.

Simple strategies like turning your phone off after dinner and on the weekends will give you time and space to reset for another solid week of paddock checking and client problem solving.

Conclusion

Advising and problem solving for growers is a satsifying professional experience and extremely important, but it can be difficult in some seasons. Tips to minimise the impact of difficult advisory times include:

- Be clear in your role.
- Be thorough in your advising and avoid giving instant answers when the situation is complex.
- Be mindful of taking on another person's stress.
- Accept that not all growers will make the decision you want them to.
- Set boundaries to allow recovery time.

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Hyper Yielding Cereal project – is there relevance to the mainland high rainfall zone (HRZ)?

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[1]FAR Australia; [2]Southern Farming Systems (SFS).

GRDC project code: FAR 00003

Keywords

- feed wheat, feed barley, cultivars, early sowing (April), phenology, spring wheat, winter wheat, dry matter, soil fertility.

Take home messages

- Research results from the GRDC Hyper Yielding Cereals (HYC) project have set new benchmarks for the yield performance of irrigated feed wheat with plot yields in excess of 15t/ha in 2016 and in excess of 12t/ha in 2017.
- Higher final harvest dry matter is essential for higher grain yields. Crop canopies producing 30t/ha-35t/ha dry matter at harvest have produced plot yields of 15t/ha – 17t/ha in research plots, using feed grain germplasm.
- Initial screening (50 wheat and 11 barley cultivars/lines) have shown that there are four cultivar characteristics essential for April sowing in the Tasmanian HRZ;
  - The right 'time clock' or phenology is important so that the key development period of stem elongation coincides with the best environmental conditions to maximise growth and yield potential.
  - For sowing prior to ANZAC day (April 25) the research has shown that winter wheat cultivars provide much safer options for maximising yield than spring wheat cultivars.
  - Disease resistance particularly to Septoria tritici blotch (STB), leaf rust and scald.
  - Good standing power is essential for achieving yields over 8t/ha.
- Research from 2018, with mid-April sowing in south-east (SE) South Australia (Millicent), has shown that results achieved in the HYC project are relevant to the longer season mainland HRZ in south-eastern Australia.
- HYC research on feed grain germplasm in Tasmania has shown that the same cultivars are outperforming the current commercial controls grown in mid-April in SE South Australia.
- These wheat cultivars were RGT Accroc⁽ᴾ⁾, Annapurna⁽ᴾ⁾, RGT Calabro⁽ᴾ⁾, AGTW0002 and DS Bennett⁽ᴾ⁾.
- With the barley research, despite three contrasting seasons, the same three cultivars topped the yield rankings these were RGT Planet⁽ᴾ⁾, RGT Conquest and the faster developing cultivar Rosalind⁽ᴾ⁾.

Background

Despite a more suitable climate for grain production than the mainland and much higher yield potential, the average (predominantly dryland) yield of red grain feed wheat in Tasmania is still approximately 5t/ha. While this has increased relatively more than other states in the last 20 years (Source: ABARES) it is still felt to be well below the potential. The HYC project supported by GRDC and led by FAR Australia in collaboration with Southern Farming Systems (SFS) aims to make Tasmania less reliant on grain supplied from mainland Australia through increased productivity of feed grain wheat and barley. Through the collaboration of international, national, local expertise and breeders, the five-year project is working to close the gap between actual and potential yields, as well as using links with end users to promote the value of trading quality feed grains

Research

The irrigated Hyper Yielding Research Centre at Hagley in Tasmania has, over the last three years, used over 1000 experimental research plots each year to identify new cereal lines and agronomy strategies that could lift feed grain productivity in the Tasmanian HRZ. The concept of the research has been to explore whether the April sowing window can be used to maximise biomass and yield potential without giving rise to large increases to input costs.

In 2016, the first-year research results from the HYC project set new benchmarks for the yield performance of feed wheat with plot yields in excess of 15t/ha. The soft finish and high rainfall experienced were in stark contrast to 2017 when low rainfall, higher temperatures and late frosts affected the grain fill period and reduced maximum yields to 12t/ha – 13t/ha. In many ways the contrast of the 2016 and 2017 seasons has been useful in determining which new cultivars/lines perform well in both seasons. In 2018/19 at the time of going to press, wheat remained to be harvested but barley was producing yields in excess of 10t/ha for the third year in succession.

High harvest dry matters essential for higher grain yields

In order to generate higher yielding cereals, it has been essential to generate high harvest dry matters. This has been clearly observed in HYC research with some of the more promising cultivars producing the higher dry matter contents. The final harvest dry matters in 2016 HYC research for the highest yielding cultivars/lines were approximately 30t/ha – 35t/ha dry matter and showed significantly higher grain yields than the control cultivars Manning⍉, SQP Revenue⍉ and Beaufort⍉ (Figure 1). In addition to higher dry matter the same cultivars had better standing power and exhibited better resistance to STB and leaf rust.

High fertility essential for higher yields

High yield potential is strongly linked to higher fertility, where the extra nitrogen (N) required to realise higher potential is provided by the soil not by additional fertiliser. Analysis of HYC yields and grain proteins suggest that large quantities of N, exceeding applied N fertiliser, were removed from the soil to produce high yields. In 2016 yields of 14t/

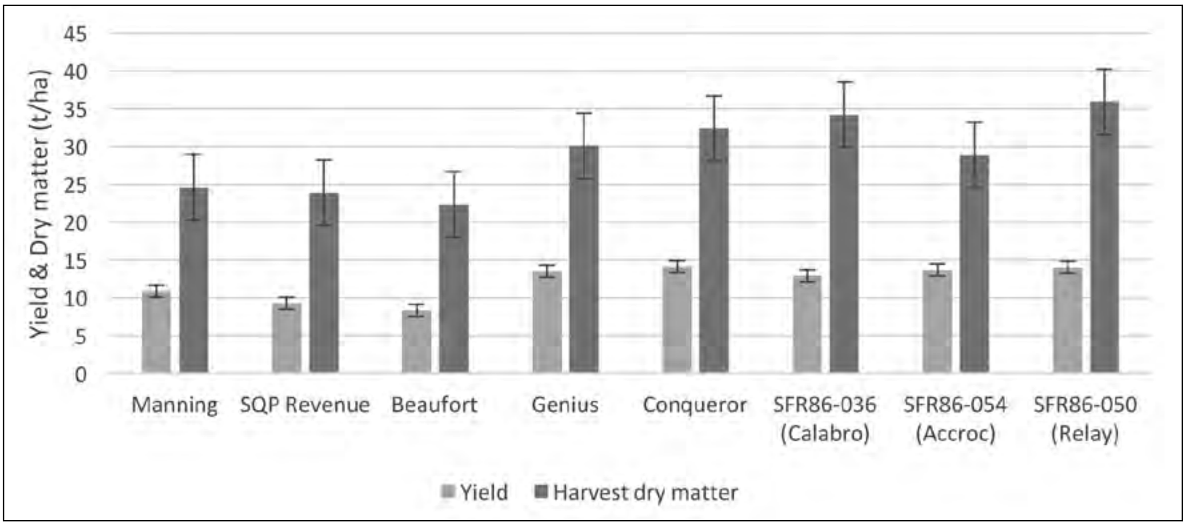

Figure 1. Influence of cultivar/line on grain yield and dry matter (t/ha) at harvest versus commercial controls sown 6 April – HYC Research 2016/17 season.

ha – 17t/ha were achieved with no more than 220kg N/ha fertiliser applied, yet N offtakes in the grain alone indicated the removal of approximately 258kg N/ha – 336kg N/ha for specific cultivars and sowing dates.

In the UK, recent analysis of independent NIAB TAG trials show similar findings to the HYC research over the last two years. Results from a large series of wheat trials indicated that high yield potential usually comes from higher fertility, where the extra N required to realise that potential is provided by the soil, such that the total applied N needn't be significantly higher than for crops with lower yield potential. The analysis of trials on wheat from the UK put forward 'that for every tonne of N fertilised grain/ha, two thirds of a tonne comes from the yield without N'. This was put forward to explain 'why the additional amounts of N required for very high yields in field trials is less than would logically be expected' (NIAB TAG 2018). Clearly the fertility of farming systems and soil organic matters are lower in Tasmania than the UK, however from the Tasmanian results the fertility of the whole farming system is a key component to achieving higher yields.

Is there any relevance of the HYC research to the mainland HRZ?

With far less emphasis on breeding for yield in HRZ regions of Australia, does the research on germplasm and agronomic strategies in Tasmania have any relevance to the mainland? 2018 results from the SA Crop Technology Centre at Millicent run by FAR Australia in collaboration with SARDI and funded by Landmark and the wider industry would suggest the answer is yes.

Mid-April sowing (18 April) suggested that winter wheat cultivars were more suitable to secure the yield potential of this sowing date than spring wheats which developed too quickly (Table 1). The sowing date was too early for the spring wheat cultivars resulting in significant frosting, particularly where cultivars were grown ungrazed (high and standard management).

There was a significant interaction between cultivar and management with spring wheat cultivars benefitting from simulated grazing and the winter wheats showing a yield penalty from grazing. With less frosting in spring the wheat cultivars, under simulated grazing, retarded the development resulting in a partial escape from some of the frosting effects with late flowering. In addition, cultivars identified as high yielding in Tasmanian HYC trials have topped the 2018 Crop Technology Centre results. These wheat cultivars were RGT Accroc, Annapurna, RGT Calabro, AGTW0002 and DS Bennett⦸.

High input management (five fungicides (seed treatment and four foliar sprays) and 200kg N/ha of applied N) did not significantly increase grain yields over the standard management approach based

Table 1. Grain yield (t/ha) under three management levels, 2018 Crop Technology Centre, Millicent, SA.

	Management Level						
Cultivar	High Input Yield t/ha		Standard Input Yield t/ha		'Grazed' Input t/ha		Mean
Manning⦸ (Winter control)	9.23	efg	9.33	efg	8.36	h	8.97
Beaufort⦸ (Spring control)	7.83	hi	7.53	i	8.04	hi	7.80
DS Pascal⦸ (Spring)	5.27	l	6.02	jk	6.43	j	5.91
Annapurna (Winter)	10.61	a	10.61	a	9.12	fg	10.11
Conqueror (Winter)	9.13	fg	9.05	g	9.25	efg	9.14
RGT Accroc (Winter)	10.49	ab	10.52	ab	9.27	efg	10.09
RGT Calabro (Winter)	10.23	abc	10.05	a-d	8.36	h	9.55
AGTW0002 (Winter)	9.53	d-g	10.44	ab	9.67	c-f	9.88
Trojan⦸ (Spring)	5.49	kl	5.59	kl	6.23	j	5.77
DS Bennett⦸ (Winter)	10.01	bcd	9.81	cde	9.58	d-g	9.80
LSD Cultivar p = 0.05	0.33 t/ha	P val	<0.001				
LSD Management p=0.05	0.88 t/ha	P val	0.450				
LSD Cultivar x Man. P=0.05	0.57 t/ha	P val	<0.001				

Winter – winter wheat, Spring – spring wheat, 'Grazed' Management – simulated grazing with mechanical defoliation.

Yield figures followed by different letters are considered to be statistically different (p=0.05), for example a yield of 9.33 efg is considered statistically different to 8.36 h but not to a yield of 9.13 fg.

Plot yields: To compensate for edge effect a full row width (22.5cm) has been added to either side of the plot area (equal to plot centre to plot centre measurement).

Table 2. Approximate date of pseudo stem erect (GS30), mid flowering (GS65) under standard management, dry matter (DM) removed in simulated grazing (mechanical defoliation) management at GS30 and grain yield reduction associated with grazing, 2018 Crop Technology Centre, Millicent, SA

Phenology (GS30 and GS65), Dry matter removal (GS 30) and yield decrease with grazing				
Cultivar	Date GS30	Date GS65	DM * Kg/ha GS30	Yield reduction (t/ha)
Manning⁽ᵇ⁾ (Winter control)	21 Aug	7 Nov	2195	0.97
Beaufort⁽ᵇ⁾ (Spring control)	27 Jun	2 Oct	337	+0.51
DS Pascalv (Spring)	27 Jun	5 Oct	261	+0.41
Annapurna (Winter)	21 Aug	24 Oct	2054	1.49
Conqueror (Winter)	9 Aug	12 Nov	1200	+0.20
RGT Accroc (Winter)	13 Aug	24 Oct	1475	1.25
RGT Calabro (Winter)	28 Aug	30 Oct	2197	1.69
AGTW0002 (Winter)	1 Aug	18 Oct	954	0.77
Trojan⁽ᵇ⁾ (Spring)	27 Jun	25 Sep	322	+0.64
DS Bennett⁽ᵇ⁾ (Winter)	1 Aug	18 Oct	1045	0.23

** Provisional data means presented with no statistical analysis in the express results*

on three foliar fungicides and a 120N total. Higher yielding cultivars were associated with higher test weights and larger grain size (data not shown).

Simulated grazing showed a considerable range of dry matter offtakes dependent on the date at which the cultivar reached growth stage (GS)30 (start of stem elongation). With later developing winter wheat cultivars that reached GS30 in late August, dry matter offtakes exceeded 2000kg/ha. However, these cultivars gave greater grain yield reductions as a result of simulated grazing (Table 2). With slightly faster developing winter wheat cultivars such DS Bennett⁽ᵇ⁾, which reached GS30 in early August, the dry matter offtake associated with grazing gave only a slight yield reduction in grain yield but dry matter offtake closer to 1000 kg/ha.

In conclusion, the HYC research trials have identified new cultivars and techniques that have set new benchmarks for yield performance in feed wheat with plot yields in excess of 15t/ha and barley yields over 11t/ha. In addition, 2018 research at the SA Crop Technology Centre in Millicent has found that the same lines identified as high fliers in Tasmania have been performing well in the South Australian HRZ.

Come and view the HYC research at the main Hyper Yielding Cereal Project Field Day in Tasmania on Thursday November 14 2019!

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High rainfall zone agronomy to help close the yield gap

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This paper was under review at the time of publication of proceedings and can be found in full at https://grdc.com.au/resources-and-publications/grdc-update-papers

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Effects of waterlogging on wheat crops and texture-contrast soils in the high rainfall zone of Victoria

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GRDC project code: DAV00151

Keywords

- waterlogging, wheat, texture-contrast soils.

Take home messages

- At three sites in the high rainfall zone (HRZ) of Victoria, the reduction in wheat yield due to waterlogging ranged from nil to 38%, with a decline in total nitrogen (N) uptake from nil to 40%.
- The effect of waterlogging on the crop was influenced by several factors including the depth of waterlogging, the duration of waterlogging, the aeration conditions in the soil and the timing of waterlogging.
- The importance of the various factors varied among sites and further work is required to evaluate their influence in different situations.

Background

Waterlogging during winter is common across many parts of the HRZ of southern Australia, but the impact of this waterlogging on crop production is not well understood. Options for managing waterlogging are currently limited. Drainage (surface or subsurface) has been shown to be effective in some situations but ineffective in others, and has not been widely adopted by growers (DEDJTR 2015). Similarly, raised beds can significantly reduce yield losses from waterlogging in wet years in some, but not all situations (Acuña et al. 2011; Bakker et al. 2007; Riffkin and Evans 2003).

Field trials conducted in the 1980s near Hamilton, Victoria, suggested that wheat yield losses due to waterlogging could vary between nil and 78% (Acuña et al. 2011; Gardner and Flood 1993; MacEwan et al. 1992; McDonald and Gardner 1987), and a similarly wide range of yield loss in cereals has been reported from the HRZ of Western Australia (WA) (16%-85% (Setter 2000)).

Previous research has shown that the adverse effects of waterlogging are due primarily to reduced oxygen availability in the soil, with consequently reduced uptake of nutrients (particularly N) and reduced growth of the tops and roots of the plant (Elzenga and Van Veen 2010).

For the HRZ of south-eastern Australia, however, there is little information on the effects of waterlogging on soil and crops and the consequences for productivity across the region. This study aims to better understand how waterlogging affects soil conditions and crop growth (particularly relating to N).

Method

Field experiments were conducted in the HRZ of Victoria to investigate the effects of differing degrees of waterlogging on soil conditions and growth of the crop. The focus was on wheat on texture-contrast soils, which is the dominant soil type covering more than 70% of the zone (MacEwan et al. 2010). These soils are naturally prone to waterlogging after rainfall as water accumulates in the loamy topsoil because of slow drainage through the heavy clay subsoil, leading to the development of a 'perched water table' (Cox and McFarlane 1995; MacEwan et al. 1992). The soil can be defined as waterlogged if a water table is present, even if it is not visible at the surface.

In 2017, experimental sites were established at Hamilton, Glenthompson and Tatyoon. The Hamilton sites were on the Agriculture Victoria Research farm on raised beds and the Glenthompson and Tatyoon sites on commercial farms. All sites were sown to wheat (cv. Trojan⏀ at Hamilton and Tatyoon, Beaufort⏀ at Glenthompson) shortly before the experimental areas were set up.

At each site (paddock), three locations (approx. 20m x 20m) were selected that differed in their expected susceptibility to waterlogging (as judged by the landholders and project team). These locations were termed 'Dry', 'Medium' and 'Wet' and were positioned on the upper, middle and lower parts of the paddock, respectively. The central part of each location (approx. 8m x 12m) was reserved for experimental measurements and sampling. Irrigation was applied during winter to the Wet location at Hamilton (~100mm) and Tatyoon (~85mm) to ensure waterlogging. Total annual rainfall was 674mm at Hamilton, 595mm at Glenthompson, and 520mm at Tatyoon. The soils were of similar texture at all sites and locations, with the heavy clay subsoil at an average depth of 30cm.

At each location, instruments were installed to measure soil moisture content (neutron moisture meter and EnviroPro® probes), the height of the water table (piezometer tubes containing Odyssey® water level sensors) and crop root growth (CI-600 in-situ root imager). Soil aeration status (redox potential) was measured at the Wet locations (Paleo Terra redox probes). Soil chemical and physical properties were assessed at the start of the season from soil cores taken to 1.3m depth. The crop was sampled from quadrat cuts at key growth stages (booting, anthesis and maturity) for dry matter and N analysis.

Results

Crop growth and N uptake

Grain yield at Hamilton and Glenthompson was reduced in the Wet locations compared to the Medium and Dry locations, which were similar. Grain yield at Tatyoon did not differ significantly among the Dry, Medium and Wet locations (Figure 1). The yield reduction at Glenthompson (2.1t/ha, 38%) was primarily due to a reduced number of ears, while the yield reduction at Hamilton (1.7t/ha, 20%) was mainly due to reduced grains per ear (Table 1). Total plant N uptake at maturity was also lower at the Wet location than the Medium and Dry locations at Hamilton (14% reduction) and Glenthompson (40% reduction), but not at Tatyoon. Grain N percentage was lower in the Wet location at Glenthompson only (Table 1). These trends were also evident in total above ground crop biomass and total N uptake at the booting and anthesis stages (data not shown). Root length at maturity in the top 48cm of soil was lower at the Wet than at the Dry and Medium locations (by 15%, 47% and 13% at Hamilton, Glenthompson and Tatyoon, respectively).

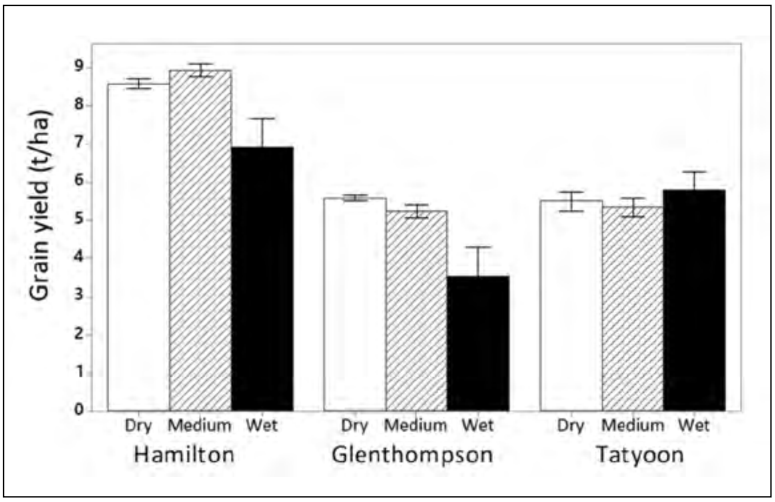

Figure 1. Wheat grain yield at the experimental sites. Bars show standard error.

Table 1. Wheat yield components at the experimental sites.

Site	Location	Ear number (m^2)	Grain number (m^2)	Grain number per ear	Grain N yield (t/ha)	Total plant N uptake (t/ha)	Grain protein content (%)
Hamilton	Dry	584	22,626	39	0.19	0.29	12.8
	Medium	647	23,883	37	0.19	0.29	12.7
	Wet	587	17,410	29	0.15	0.25	12.8
Glenthompson	Dry	349	17,054	49	0.13	0.16	13.8
	Medium	361	16,797	47	0.12	0.14	13.4
	Wet	226	11,228	49	0.08	0.09	12.4
Tatyoon	Dry	464	14,421	31	0.14	0.25	15.3
	Medium	475	13,866	30	0.14	0.22	15.0
	Wet	504	14,884	30	0.15	0.23	15.4

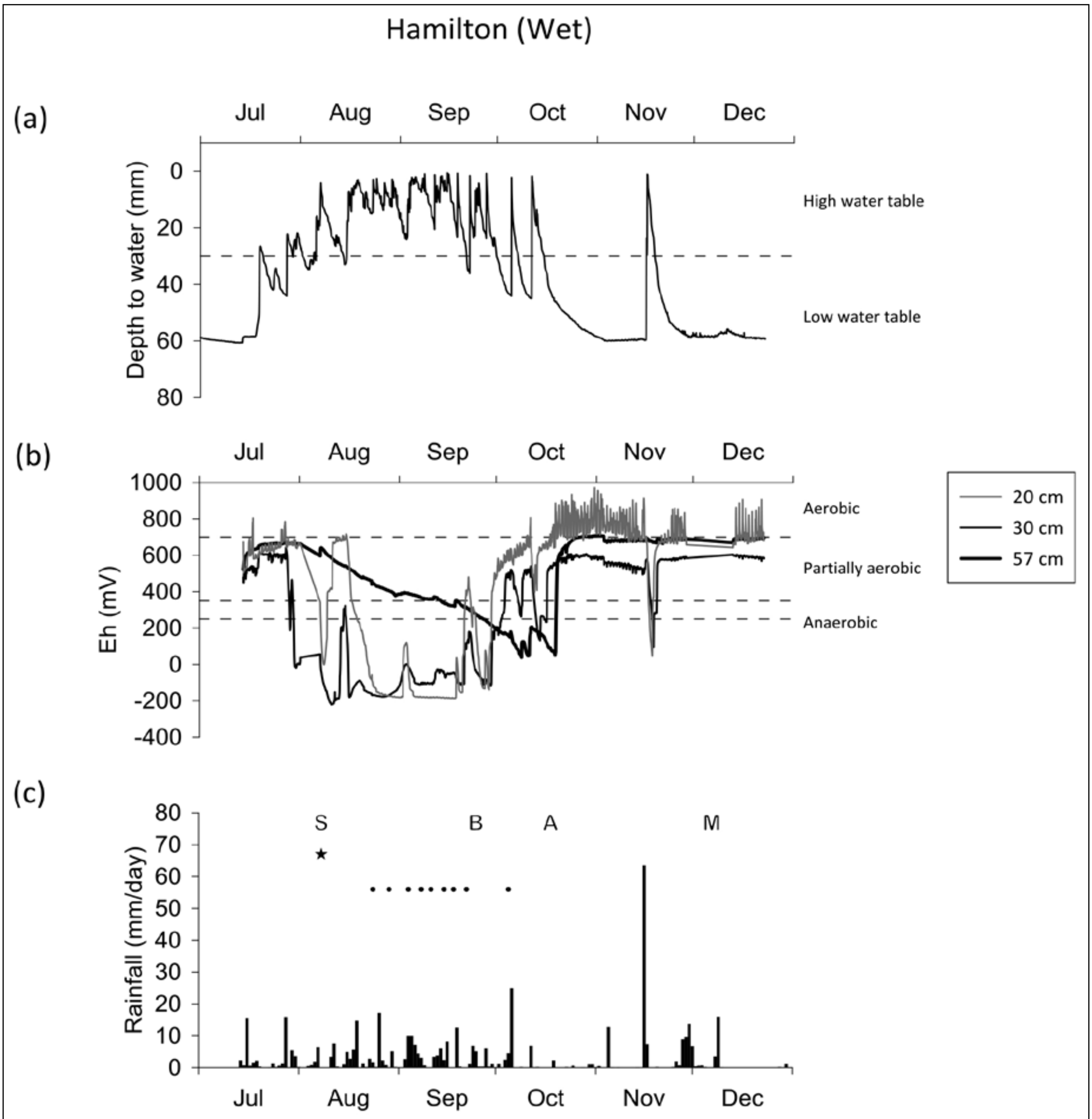

Figure 2. Depth of the water table (a), soil redox potential (b) and rainfall (c) at the Hamilton Wet location during the 2017 season. Markings represent stem elongation, S; booting, B; anthesis, A; maturity, M; fertiliser application, ★; and irrigation, ●.

Soil conditions

Soil moisture content was at or near saturation between June and the beginning of October over most of the 0-100cm depth at the Dry, Medium and Wet locations at Hamilton, Glenthompson and Tatyoon. All soils began to dry rapidly during October but, due to a large rainfall event in November, they remained close to saturation below the 40cm depth for the rest of the season (data not shown).

A perched water table was present between July and October, sometimes reaching the soil surface, at the Dry, Medium and Wet locations at Hamilton and Glenthompson and the Wet location at Tatyoon. A water table also developed at the Medium and Dry locations at Tatyoon but was much lower and of shorter duration. The general pattern was of a rapid rise in the water table following rainfall with a more gradual decline between rainfall events. The period of high-water table was mostly between the stem elongation and anthesis stages at Hamilton and Tatyoon, and between tillering and booting at Glenthompson. Rainfall and soil data from the Wet locations are shown in Figures 2(a,c), 3(a,c) and 4(a,c).

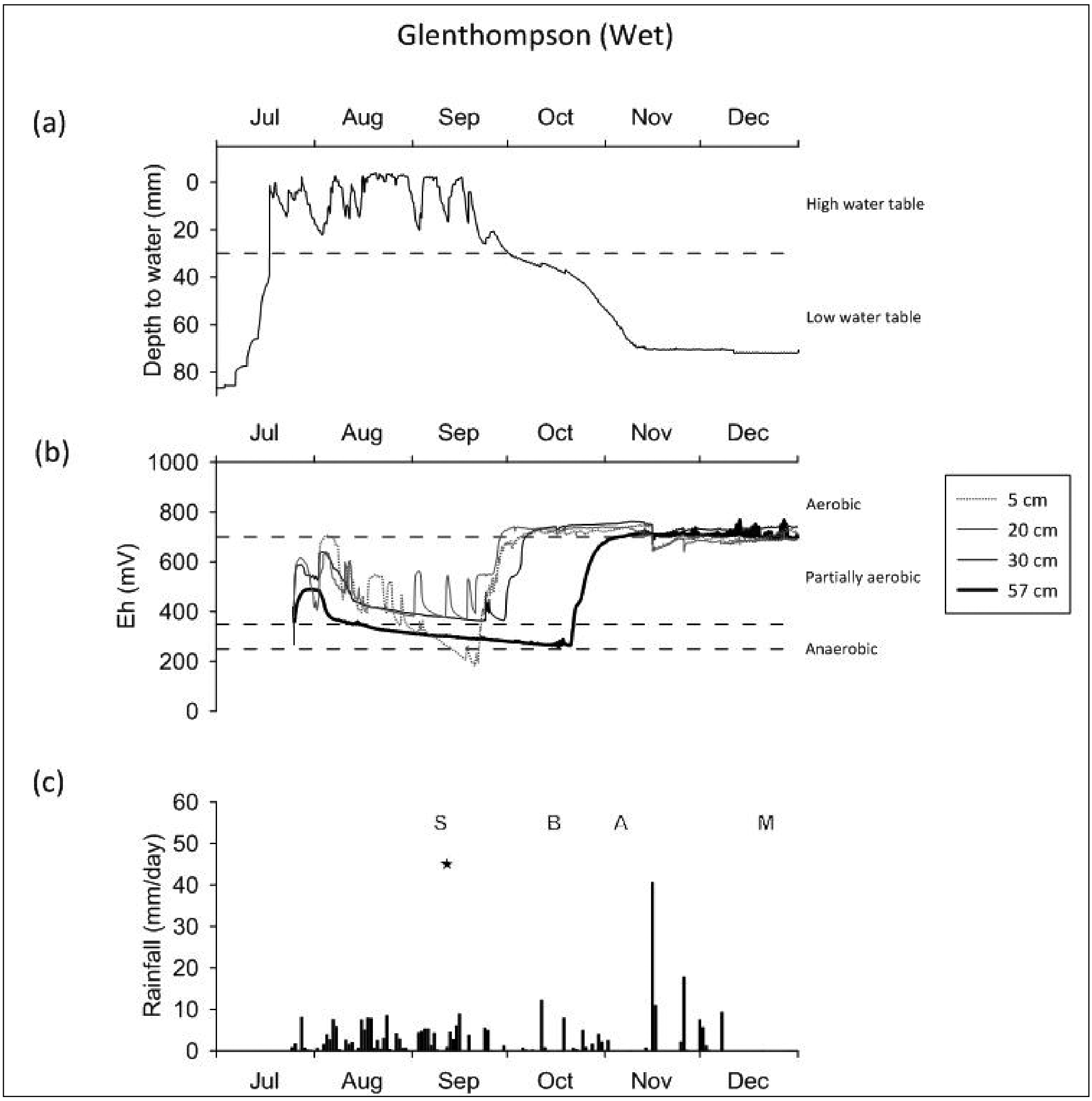

Figure 3. Depth of the water table (a), soil redox potential (b) and rainfall (c) at the Glenthompson Wet location during the 2017 season. Markings represent stem elongation, S; booting, B; anthesis, A; maturity, M; fertiliser application, ★; and irrigation, ●.

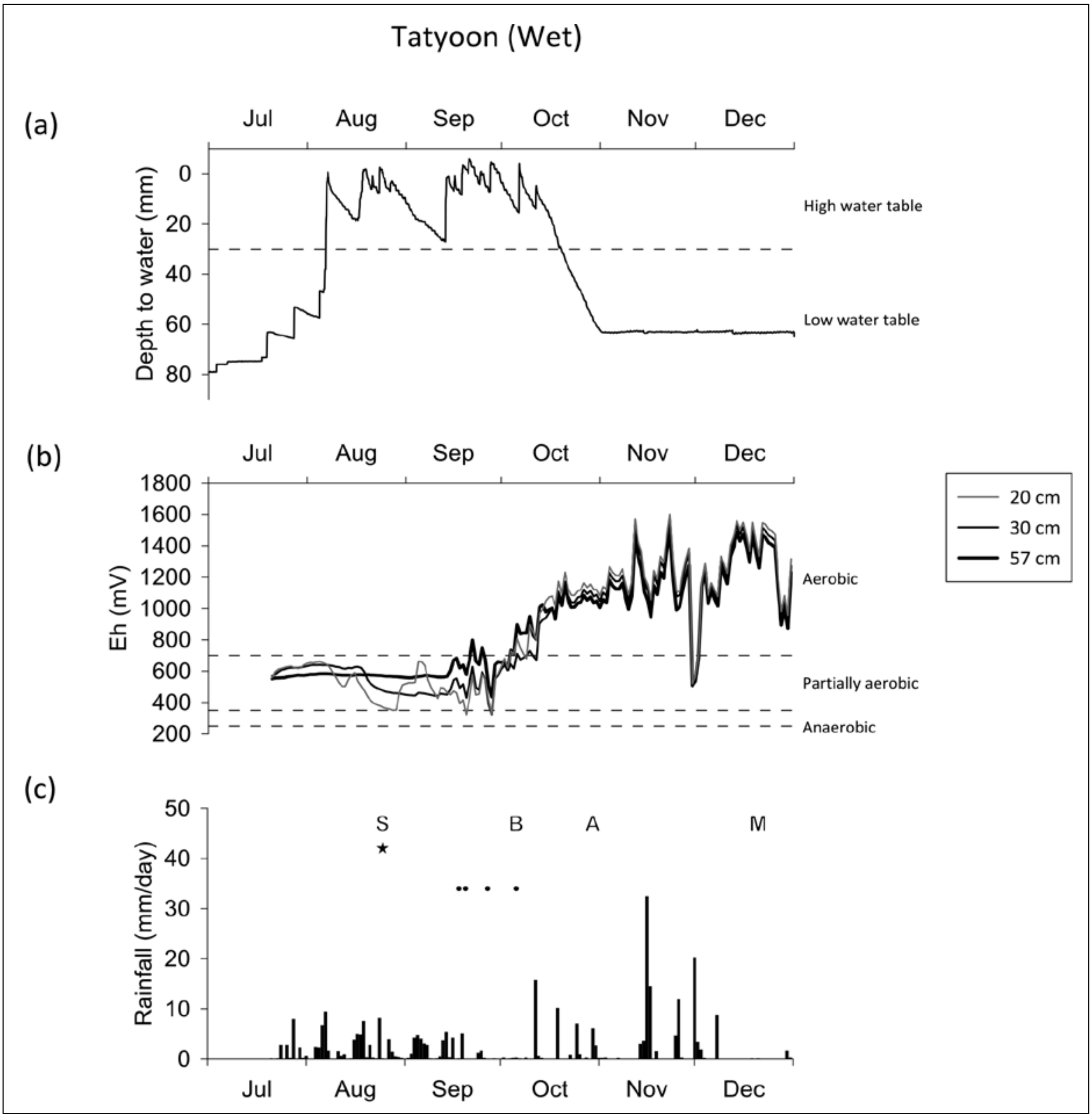

Figure 4. Depth of the water table (a), soil redox potential (b) and rainfall (c) at the Tatyoon Wet location during the 2017 season. Markings represent stem elongation, S; booting, B; anthesis, A;maturity, M; fertiliser application, ★; and irrigation, ●.

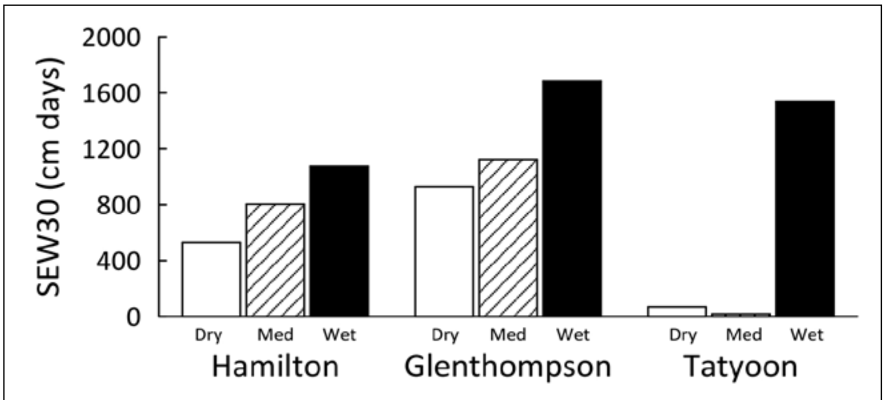

Figure 5. Sum of Excess Water index (SEW30) at the experimental sites indicating the accumulated depth and time of waterlogging in the top 30cm of soil over the 2017 season.

The depth of the water table and its duration over the season, both important factors for assessing the severity of waterlogging, can be combined in an index called the Sum of Excess Water in the top 30cm (SEW30)(Cox and McFarlane 1995). This is the total amount of waterlogging that occurs each day between the soil surface and 30cm depth over a given period. The SEW30 over the season (Figure 5) increased in the order Dry<Medium<Wet locations at Hamilton and Glenthompson, but there was no difference between the Dry and Medium at Tatyoon.

Redox potential, which represents the aeration status of the soil, reads >700mV in fully aerated (aerobic) conditions, 350-700mV in partially aerobic conditions, and <350 when oxygen is completely absent from the soil (anaerobic). Nitrogen loss due to denitrification is most likely to occur around 250-350mV. The redox potentials at the Wet locations are shown in Figures 2(b), 3(b) and 4(b).

At Hamilton, redox potential was in the partially aerobic zone when measurements began in July. With the formation of the water table, redox declined rapidly in the upper soil depths and slowly at the deeper (57cm) depth, into the anaerobic zone, where it stayed until the end of September. Redox began to rise again in October as the water table receded and was generally in the partially aerobic and aerobic zones after October, except for a short drop in aeration status after one heavy rainfall event in November.

At Glenthompson, the water table was already present when measurements started in July and redox potential was mostly in the partially aerobic zone. Again, redox potential generally declined till the end of September, though it did not become as strongly anaerobic as at Hamilton. As the water table receded, redox potential rose rapidly and by the end of October was generally in the aerobic zone, except for some declines in the surface 5cm due to late rainfall.

At Tatyoon, the redox potential was also in the partially aerobic zone in July but, unlike the other sites, it did not decline appreciably with the development of the water table. In fact, redox potential rose into the fully aerobic zone in early October, notwithstanding the presence of a high water table.

Discussion

The SEW30 index showed a large range in the amount of waterlogging at Hamilton, Glenthompson and Tatyoon, but the soil and crop responses to waterlogging differed at each site. The greatest impact of waterlogging was at the Glenthompson site, with an apparent yield loss of 38%. The Glenthompson Wet location had the longest duration of very high water tables, and the soil aeration status was quite hostile until the booting stage. These conditions are likely to have strongly impacted on the growth and functioning of the crop roots and shoots, including by reducing the uptake of nutrients, particularly N. Gaseous loss of N from the soil through denitrification may have further reduced the N supply to the crop. The waterlogging at Glenthompson began about one month earlier than at the other sites and waterlogging damage (reduced plant height and tillering) was clearly visible from the tillering stage. Thus, with early damage and prolonged waterlogging, the crop had little opportunity to recover until the booting stage.

At Hamilton, there was an apparent yield loss of 20% due to waterlogging, despite the presence of raised beds. The period of high water tables resulted in very hostile soil aeration conditions which are likely to have impaired crop growth and N uptake. Loss of N through denitrification is most likely to have occurred near the beginning and end of the waterlogging period, when the redox conditions were less extreme. Given that the soil aeration conditions at Hamilton were more unfavourable than at Glenthompson, it may seem surprising that there was less yield loss at Hamilton than at Glenthompson. However, crop damage may have been limited at Hamilton because waterlogging began relatively late, in early August, when the crop was more advanced (stem elongation stage) with well-developed roots and tillers — this may have helped it survive and recover from the hostile soil conditions.

At Tatyoon, the amount of waterlogging in the top 30cm of soil was intermediate between Glenthompson and Hamilton, yet there was no apparent effect of waterlogging on yield. Soil conditions were considerably less hostile at Tatyoon — the soil remained partially aerobic during the entire waterlogging period. This comparatively mild decline in redox under waterlogging at Tatyoon may be related to its lower soil organic carbon (C) content (1.3% C in the 0-20cm depth, compared to 2.0% C and 2.2% C at Glenthompson and Hamilton, respectively). The low C content would be associated with a lower demand for oxygen by microbes. In addition to the less extreme soil redox conditions, the late onset of waterlogging at Tatyoon (early August), when the crop was relatively advanced (stem elongation), is likely to have enabled better survival and recovery of the crop and minimised yield loss.

Differences in N availability may also have influenced the crop responses to waterlogging. Some loss of N though denitrification is likely to have occurred, particularly at Hamilton and Glenthompson. The timing of N fertiliser application also differed among the sites, with post-sowing applications in the early part of the waterlogging period at Hamilton (75kg urea) and Tatyoon (100kg urea), and applications before (70kg urea) and near the end (120kg urea) of the waterlogging period at Glenthompson. The potential role of N in how crops respond to waterlogging warrants further investigation. The effect of timing of N application is being investigated in another component of the DAV00151 project (not reported here).

It is possible that at Hamilton and Glenthompson, the apparent effects of waterlogging on crop yield were underestimated, as the Dry and Medium locations to which the Wet sites were compared were also waterlogged for part of the season. It was evident that these texture contrast soils can become significantly waterlogged without water being visible at the surface, so waterlogging may be a hidden constraint to production in some situations.

Conclusion

This study compared the response of wheat to a range of waterlogging conditions. Apparent yield declines due to waterlogging ranged from nil to 38% (with a decline in total N uptake from nil to 40%). The results suggest that the consequences of waterlogging on crop production are likely to depend on factors such as the depth of waterlogging (the height of the water table), the duration of waterlogging, the aeration (redox) conditions that develop in the soil under waterlogging, the timing of the waterlogging and other factors not identified here. Further study is required to establish the importance of the various factors and how they interact in different situations.

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Disentangling soil amelioration and plant nutrition effects of subsoil manuring on crop yield

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GRDC project codes: Grains Industry Research Scholarship GRS11004, TRE0002, SFS00019, CSP00111.

Keywords

- subsoil manuring, nitrogen, amelioration.

Take home messages

- Crop yield responses to subsoil manuring could be due to the nutrients contained in the poultry litter (i.e. improved soil fertility) or the amelioration of a (sub)soil constraint (e.g. soil structural improvements).
- To separate these effects and attribute yield responses correctly, experiments must have appropriate control treatments: a surface applied amendment control and a synthetic fertiliser nutrient control.
- Experiments were carried out across eight sites in Victoria and South Australia that were constrained by subsoils that were sodic, alkaline, boron toxic and/or low in organic matter.
- Evidence from 15 site x years suggests that an increased nutrient supply (particularly nitrogen (N)) drove the crop response to subsoil manuring under the conditions of this study.

Background

In the medium and high rainfall zones of south-eastern Australia, naturally dense clay subsoils are thought to limit dryland crop yields by restricting the movement of air and water and limiting root growth, especially those that have high levels of sodicity. Subsoil manuring is a technique that has been developed to increase yields on these soil types through deep incorporation of nutrient-rich organic matter. Significant and prolonged grain yield increases have been reported after subsoil manuring with 20t/ha of organic amendments such as lucerne pellets or poultry litter (Gill et al. 2008; Sale 2014).

However, it is unknown whether these yield increases are due to the amelioration of subsoil constraints (e.g. sodicity, alkalinity or boron toxicity), the nutrients supplied by the amendment, or some combination of both factors. Because of the large amounts of nutrients contained in amendments such as poultry litter, subsoil manuring can potentially have both an amelioration and fertilisation effect on crop yield. In order to separate these effects and attribute yield responses correctly, experiments require appropriate design with specific treatments.

Design of subsoil manuring experiments to correctly attribute yield responses

The complete set of treatments required to separate the nutrition and amelioration effects of subsoil manuring on crop yield is shown in Table 1.

The deep incorporation of organic amendments (i.e. subsoil manuring) needs to be compared to a surface-applied amendment control and a synthetic fertiliser control, where the same rate of total nutrients and same type of amendment is applied to both the subsoil and the soil surface. These treatments allow attribution of yield increases to either subsoil amelioration or mineral nutrition

Table 1. Tillage and amendment treatments needed to separate effects of subsoil manuring on yield due to increased nutrition or amelioration of a soil constraint (adapted from Celestina et al. 2019).

		Amendment treatment		
		No amendment	Organic amendment	Synthetic fertiliser
Tillage treatment	No tillage/surface broadcast	Full control	Surface applied control	Surface applied nutrient control
	Deep tillage for subsoil incorporation	Tillage control	Subsurface amendment ('subsoil manuring')	Deep nutrient control

by separating the carbon or biological effect of the amendment (e.g. an improvement in subsoil structure) from the fertiliser effect of the added nutrients. If subsoil manuring is ameliorating the physicochemical constraints in the subsoil then the deep placement of organic amendment should increase crop yields over and above those achieved with surface broadcast amendment or synthetic fertiliser placed on the surface or in the subsoil.

There are several difficulties with this comparison due to differences in the amounts and release rates of nutrients in the different amendments. The nutrient rates in the synthetic fertiliser treatment are matched to the total nutrient content of the chicken litter. Very high rates of fertiliser N, P & K are rapidly soluble and may have toxic effects on the crop; despite this, no symptoms of toxicity were reported in the experiments described below. In addition, applying the amendments to the soil surface or the subsoil will affect how quickly they are broken down and nutrients released. These factors will inevitably confound the results of these experiments to some degree, but the most appropriate design is the balanced two-way factorial experiment with ±deep tillage and ±amendments described in Table 1.

Methods

Eight field experiments were conducted on a range of soil types across the medium and high rainfall zones of south-eastern Australia between 2014 and 2016. The experiments, located at Westmere (Victoria) and Hart, Bute and Clare (South Australia), tested the treatments described in Table 1. Experiments compared the surface and deep placement of 20t/ha poultry litter and included an inorganic fertiliser treatment where macronutrient rates and placement were matched to total nutrient levels contained in the poultry litter (kg/ha: 594-634 N, 103-295 P, 266-406 K, 83-92 S). All sites received basal N, P and S at seeding and in-crop N every year.

The eight experimental sites used in this study covered four soil types and all had subsoil constraints that were thought to limit crop yields (Table 2). Every site, except for the Chromosol at Clare West, had moderate to high exchangeable sodium percentage (ESP) indicative of sodic, dispersive subsoils (ESP > 6%). Alkalinity and boron toxicity were present in the South Australian soils, and all eight sites had very low soil organic carbon below the topsoil layers.

A range of annual crops (canola, wheat, barley and lentil) were sown at the eight sites between 2014 and 2016 (Table 3). Seasonal conditions were dry across all sites in 2014 and 2015, with some significant heat events during 2015. The 2016 season was very wet but there was no waterlogging reported at any of the sites. The experiments at Clare East and West were destroyed by a bushfire in 2015.

Table 2. Description of soil types and subsoil constraints at the eight sites used in this study. ESP, exchangeable sodium percentage; SOC, soil organic carbon.

Site	Soil type	Description of constraints
Westmere	Sodosol	Duplex soil, gilgai microrelief, bleached A2 buckshot horizon. High ESP (15-26%) and low SOC below 25 cm.
Hart East	Calcarosol	Gradational clay loam. Moderate to high ESP (10-15%), high pH and low SOC below 30 cm.
Hart West	Calcarosol	Loam. High ESP (11-38%), pH and boron and low SOC below 30 cm.
Bute Northwest	Calcarosol	Transitional cracking clay. High ESP (24-42%), pH and boron and low SOC below 30 cm.
Bute Mid	Calcarosol	Loam. High pH and low SOC below 30 cm, high ESP (16-28%) and boron below 60 cm.
Bute Southeast	Vertosol	Grey cracking clay. High ESP (22-36%), pH and boron and low SOC below 30 cm.
Clare East	Vertosol	Black cracking clay. Low SOC below 30 cm, moderate ESP (8-12%) below 60 cm, moderate boron below 90 cm.
Clare West	Chromosol	Duplex loam over red clay. Low SOC below 60 cm.

Table 3. Crops sown and seasonal conditions at the eight sites used in this study. GSR, growing season rainfall.

Site	Year	Crop	Rainfall (mm)	
			GSR (Apr-Nov)	Annual (Jan-Dec)
Westmere	2014	Canola	304	368
	2015	Wheat	249	356
	2016	Barley	557	670
	Median		*315*	*502*
Hart East and West	2015	Wheat	332	414
	2016	Lentil	375	520
	Median		*310*	*422*
Bute Northeast, Mid and Southeast	2015	Wheat	243	309
	2016	Barley	458	696
	Median		*293*	*375*
Clare East and West	2015	Wheat	454	545
	2016	Wheat	788	978
	Median		*471*	*638*

Over 15 sites x years, subsoil manuring did not increase grain yields compared with any other treatments and there were no amendment × placement interactions on crop yield that would be indicative of amelioration of subsoil constraints.

The grain yields of amendments applied to the subsoil by deep ripping and those broadcast on the soil surface were the same (Figure 1). In other words, there was no benefit of deep placement of poultry litter or fertiliser over surface broadcasting the same amendment. Hence, it is likely that subsoil manuring was either not effective at overcoming any constraints present at these sites or the constraints were not evident in the seasons experienced.

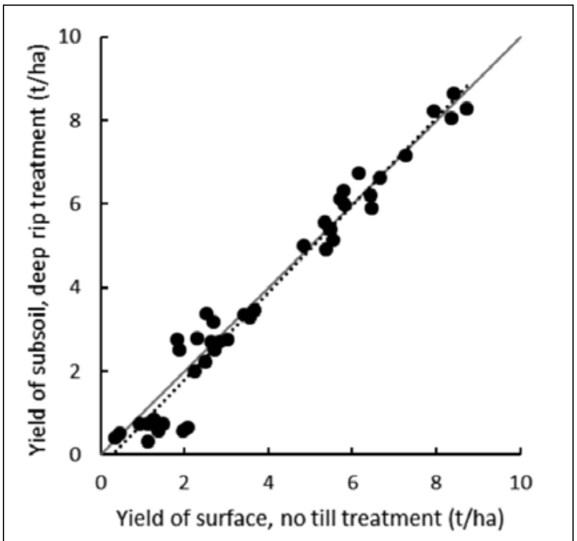

Figure 1. Relationship between grain yield of surface applied, no-till treatment and subsoil applied, deep ripped treatment. R^2 = 96% (adapted from Celestina et al. 2018).

Yields achieved with poultry litter and yields achieved with matched synthetic fertiliser were also equivalent (Figure 2), indicating that both amendments were similar in terms of their medium to longer term fertiliser effect on the crop. These results also suggest that the carbon or microbial component of the organic amendment does not have any advantage over chemical fertiliser in terms of improving crop yields.

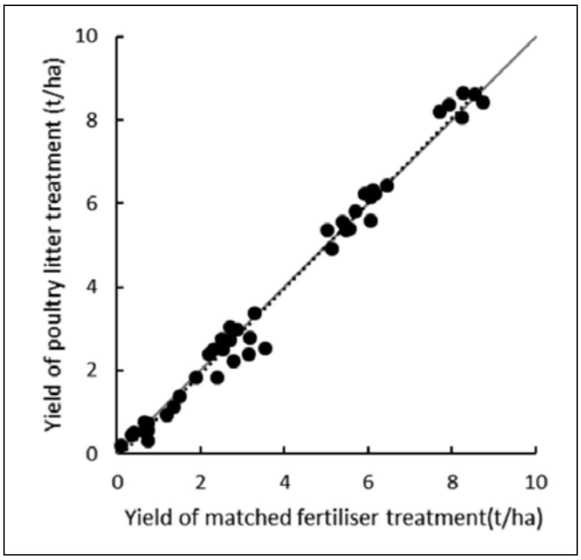

Figure 2. Relationship between grain yield of synthetic fertiliser treatment and poultry litter treatment. R^2 = 99% (adapted from Celestina et al. 2018).

Positive grain yield responses to the addition of 20t/ha poultry litter or equivalent synthetic fertiliser occurred only when grain protein levels were <10.6% (Figure 3), indicating that yield increases

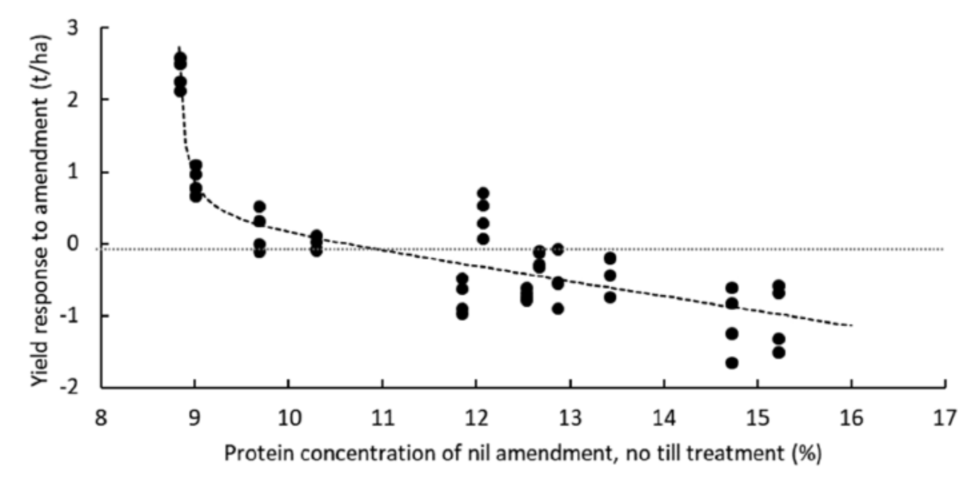

Figure 3. Difference in cereal yield between addition of amendment (poultry litter or matched fertiliser) and the full control of no till, no amendment, in relation to grain protein concentration of the full control. R^2 = 84% (adapted from Celestina et al. 2018).

were likely due to alleviation of N deficiency. Apart from one site year, at all sites where fertiliser was applied to ensure N was non-limiting, crop yields did not increase as a result of the application of any amendments. Haying off (i.e. noticeably reduced yield and increased grain protein) was frequently observed when N supplied by the poultry litter or fertiliser amendments exceeded the requirements of the crop. In addition, grain protein and canola oil responses indicated a substantial and long-lasting (2-3 years) N-fertiliser effect of both the poultry litter and synthetic fertiliser treatments.

Conclusion

Under the conditions of this study, differences in crop yield were attributed to nutrients (particularly N) in the amendment, and not amelioration of the subsoil. Yield responses to subsoil manuring across the eight field sites in this study were in accordance with crop yield responses to N fertiliser. Yield increases occurred in seasons with high water-limited yield potential and/or low soil mineral N and fertiliser N supply (such as at Clare East and West in 2016), and yield responses were negative or negligible in seasons with low water-limited yield potential and/or where supply of soil mineral and fertiliser N exceeded the water-limited demand of the crop (such as at Westmere in 2015).

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Capturing the potential value of frost damaged lentil seeds as a flour additive in baked products

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Keywords

- lentil, frost, protein, fibre.

Take home messages

- Damaged lentils retain high concentrations of protein and fibre.
- Dietary fibres can act as prebiotics which enhance digestive function.
- Flour produced from frost damaged lentils can be successfully incorporated into wheat-based food products adding value to the crop and providing many benefits as a novel food alternative for consumers.

Background

Grain producers have become more proficient at Lentil seeds are generally traded based on optimal quality traits relating to seed size, shape, colour and minimal defective seeds (McDonald, Panozzo, Salisbury, & Ford, 2016). Seed characteristics and yield are strongly influenced by environmental conditions such as heat stress (Delahunty, Nuttall, Nicolas, & Brand, 2015) and frost damage (Nuttall et al. 2018). However, such visual attributes which currently define price do not account for the proximal composition of the seed. In Australia, domestic pulse consumption is low compared to countries that have pulses as part of their culinary diets (Romagnolo & Selmin, 2017). The investigation into the use of pulse flour in composite specialty foods, including pasta products, breakfast cereals and snack foods, is gaining popularity in western countries (Dziki, Różyło, Gawlik-Dziki, & Świeca, 2014; Sparvoli et al. 2016; Tosh & Yada, 2010). It is also linked to improved functionality through micro and macro nutrient fortification (Rochfort & Panozzo, 2007; Takruri & Issa, 2013). To date, the utilisation of pulse flour infused products targets a niche market (Tiwari, Gowen, & McKenna, 2011).There are opportunities, however, for visually defective pulse seeds, but with acceptable composition, such as frost damaged lentils, to be used as a food additive, rather than being discarded for animal feed (Portman et al. 2018).

Method

Lentil seeds downgraded due to severe frost damage were obtained from AGT Foods, Horsham, Victoria. The seeds were air aspirated (KimSeed, Western Australia) to remove foreign matter and ground to flour using a cyclone mill fitted with a 0.5mm screen (Laboratory Mill 120; Perten Instruments, Huddinge, Sweden). Lentil flour was combined with commercially available soft wheat flour in ratios of 100% wheat, 75%-25% wheat-lentil, 50%-50% wheat-lentil, and 100% lentil. Wheat-lentil composite biscuits were baked in accordance with the method for baking quality cookie flour AACC 10-50.05 (AACC, 2000). The total % protein of the resulting composite biscuits was determined by the Dumas combustion method AACC 46-30.01 (AACC, 2000) using a Leco TruMac analyser (Leco Corp, MI, USA). The non-digestible fibre of composite wheat-lentil biscuits was determined by the neutral detergent fibre method (NDF)-ANKOM (ANKOM Technology, NY, USA). The colour of biscuits was measured using the Commission International de l'Eclairage tristimulus colour parameters (CIE) L*a*b* with a Chroma Meter CR-410 (Minolta Co., Osaka, Japan). The hardness of the biscuits was determined according to the American Institute of Baking (AIB) method for cookie hardness (Procedure, 2011) using a TA-XT2 Texture Analyzer (Stable Micro Systems, Surrey, UK).

Statistical analysis

All data were subjected to analysis of variance (ANOVA) with GenStat statistical analysis software 17th edition (VSN International, Hemel Hempstead, UK). Means were analysed for Fisher's Least Significant Difference (LSD) with a significance level of $\alpha = 0.05$. Results are expressed as mean values ± standard deviation. All analyses were conducted in triplicate.

Results and discussion

Effects of lentil flour on proximal protein and fibre composition

The proximal analyses for biscuits produced from varying composites of wheat and lentil flour are presented in Figure 1a. As was expected, the addition of lentil flour resulted in a significant increase of % protein in each composite sample ($P< 0.05$).

It was determined that the average total protein concentration of frost damaged lentil was 27.6% ± 0.5, which was similar to a non-frosted Northfield lentil which had an average protein concentration of 27.5 % ± 0.1. The proximal analysis of biscuits produced with composite flour showed that insoluble fibre (Figure 1b) also significantly increased with increasing concentration of lentils ($P< 0.05$).

Both protein and fibre concentration and quality are important considerations within novel food development (Asif, Rooney, Ali, & Riaz, 2013). The inclusion of lentil flour not only enhances the amount of protein present, but the quality of protein is substantially better having a more diverse amino acid profile (Boye, Zare, & Pletch, 2010; Portman et al. 2018). Furthermore, the increase of fibre shown in this experiment may have a functional benefit. Specifically, these fibres facilitate greater movement of material through the digestive system (Tosh & Yada, 2010). Insoluble fibres, including cellulose, hemicellulose and lignin, are fermented in the large intestine, resulting in the formation of short chain fatty acids (SCFAs). It has been proposed that SCFAs limit the effects of chronic inflammation, atherosclerosis and metabolic disorders (Ohira, Tsutsui, & Fujioka, 2017).

Effect of lentil flour on the sensory evaluation of biscuits

The colour and hardness of the biscuits were measured to assess the effect of lentil flour. These are shown in Figure 2. There was significantly visible darkening of the biscuit with the addition of 25% and 50% lentil ($P< 0.05$), but there were no significant differences for darkness when comparing the higher concentrations of 50% and 100% composite blends. This darkening effect is most likely caused by an increase in oligosaccharide sugars found in lentils, which participate in the Maillard reaction (Martins, Jongen, & Van Boekel, 2000; Tamanna & Mahmood, 2015; Žilić et al. 2013). Thus, the browning effect could potentially be reduced by varying the cooking time and temperature.

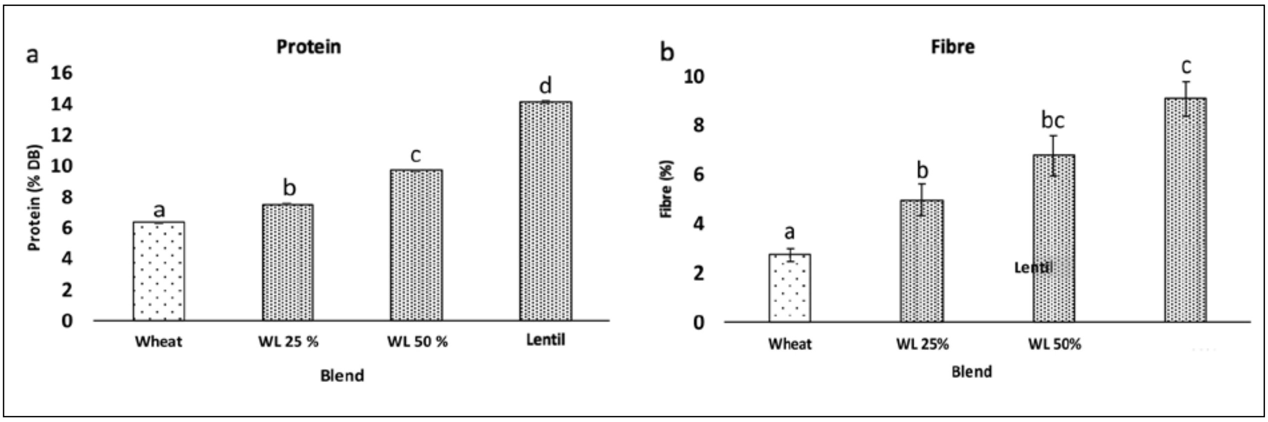

Figure 1a. Comparison of % protein and **Figure 1b** % fibre of lentil composite biscuits (WL). Letters that are the same are not significantly different ($P<0.05$).

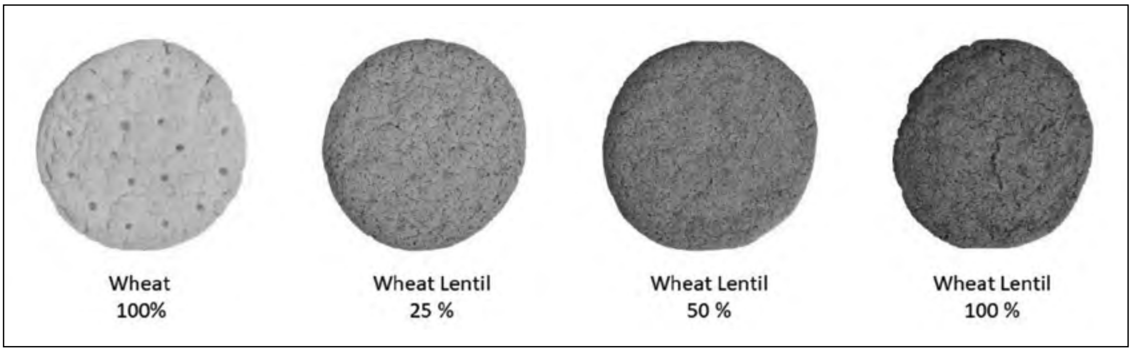

Figure 2. Examples of wheat-lentil biscuits made using lentil flour milled from frost damaged lentil seeds.

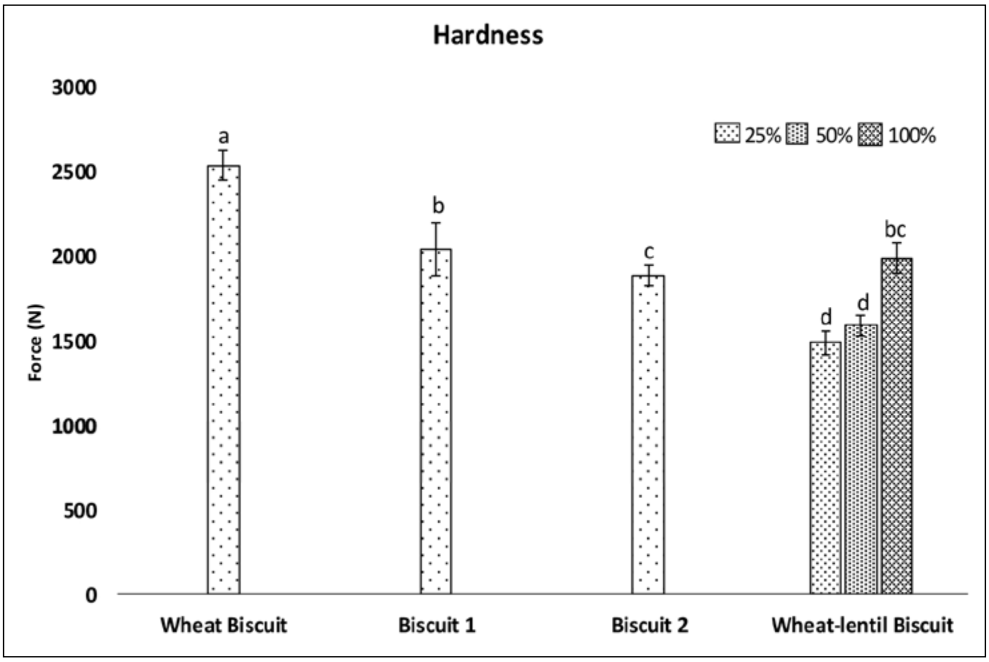

Figure 3. Biscuit hardness. Biscuit 1 and Biscuit 2 are commercial brands available in store. Letters that are the same are not significantly different (P<0.05).

Increasing the concentration of lentil flour also affected the firmness of the biscuits (Figure 3). Concentrations of 25% and 50% significantly reduced the firmness of the biscuit compared to the 100% wheat biscuit (P< 0.05), and this is probably due to a dilution effect that lentil flour has on wheat gluten (Portman et al. 2018). However, increased concentrations of lentil flour result in increased firmness which is most likely a result of a higher fibre content leading to a higher water absorption capacity. The hardness of the wheat-lentil composite biscuits was also compared with two similar style store bought biscuits (Biscuit 1 and Biscuit 2). Wheat-lentil composite biscuits were softer at the lower concentrations and comparable in hardness at the 100% level.

Conclusion

Frost damaged lentil seeds had a concentration of both protein and fibre comparable to non-frosted Northfield lentil seed. Wheat-lentil composite biscuits had superior levels of both protein and fibre when compared to wheat biscuits. Visually, wheat-lentil composite biscuits retained an acceptable quality in both colour and firmness when compared to similar commercially available biscuits. There are many benefits that can be gained from creating novel food products through the incorporation of pulse flours, such as the frost damaged lentil flour used in this experiment.

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Evidence and emotion - finding a new way forward for the grains industry

Richard Heath.

Australian Farm Institute.

Keywords

- social licence, community trust, right to farm.

Take home messages

- A lack of community trust in some farm practices is leading to the potential for disruptive change.
- Dispassionate facts are not competitive in many social licence debates.
- The grains industry must learn how to communicate what it does in a way that the community will relate to.

Introduction

A social licence is easier to define once lost than when it is in place. The live export industry is very familiar with the disruptive consequences of losing the social licence to operate, and understanding social licence has been critical for doing business in the forestry sector for decades. It is currently one of the most talked about issues in global agriculture, yet it remains an enigma to many in the Australian sector. The grains industry is not immune from the disruption of social licence induced change as the continuing discussion about the future of glyphosate demonstrates.

Social licence is notoriously difficult to quantify and virtually impossible to measure, which means it is often shunted into the 'too hard' basket. It must be earned rather than granted, and it can be extremely tricky to regain once lost. Although it seems trendy, it is not new. Society has always determined acceptable behaviour. What has changed recently perhaps is the range of activities that the concept of social licence is being applied to.

Many areas of agriculture once considered below the radar are increasingly subject to social licence in the way they are being regulated or influenced by market behaviour. High profile issues such as chemical use, animal agriculture and native vegetation management are but a few that have been, or are likely to be, impacted by significant regulatory change as a result of societal pressure — independent of economic, public safety or scientific imperatives.

Along with the range of issues affected, the speed and spread of change are significant factors in why social licence has recently become such a disruptive force for agriculture.

In satirically describing the operation of a fictional Social Licence Review Board (SLRB), The Australian columnist Bernard Salt said that: 'The key skill in being admitted to the SLRB is being able to see and nurture division that others cannot or will not see. This is perhaps the most threatening aspect of the way that social licence is being applied to agriculture: that division and opposition to farming practices can be created seemingly without cause and championed in a short space of time by a vast number of people with no investment in nor understanding of the practice. Through the speed and reach of social media-driven campaigns, practices which have been considered normal or acceptable for generations can suddenly be under threat.

While social licence can seem a very nebulous concept for growers to deal with, the impact of an industry losing its social licence is immediate and potentially terminal for the farm businesses involved.

It is no wonder then that social licence is a topic that is currently generating so much interest. For the grains industry, the future of glyphosate use regulation, the market's acceptance of corporate farming and genetic engineering technologies for plant breeding are all issues for which the unwritten social contract is under threat.

While forced practice change in these issues will not lead to the end of agriculture, it could however have the potential to shape a very different agricultural sector to what is known today.

Australian agriculture cannot afford to minimise the impact of social licence. It is applied to other sectors (such as coal seam gas, mining or banking), so it is naïve in the extreme to think that it will not be applied to the agricultural sector.

There are a number of ways that the likelihood of social licence induced change can be approached:

- It can be fought: This approach requires an intimate understanding of how to communicate effectively to justify current practice. Facts alone will not be enough. https://theconversation.com/why-facts-alone-dont-change-minds-in-our-big-public-debates-25094
- It can be guided: Industries that anticipate social licence issues have the ability to position themselves as drivers of change for good, rather than clinging to practices which have lost public support.
- It can be embraced: Change always provides opportunity and successfully anticipating new markets enabled by social licence induced change will provide opportunities for those willing to seek it out.

Whichever approach is taken (and it is likely that agriculture will move forward with a mixture of all three), it cannot be ignored. Agricultural industries that do not collaboratively and continuously renew their social licence will be prone to disruption well into the future.

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GRDC Grains Research Update BENDIGO

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BOOSTING PROFITABILITY – RESILIENT SOLUTIONS

PROGRAM DAY 2 - FEBRUARY 27th

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9.40 am	**Insects – tools for forecasting risks to enable proactive management (R)** - P205 ***James Maino,*** *cesar*	**Relative importance of different factors on WUE of wheat in western Victoria (R)** - P213 ***Roger Armstrong,*** *Agriculture Victoria*	**Understanding alphabet resistant annual ryegrass - where to from here (R)** - P223 ***Peter Boutsalis,*** *The University of Adelaide*	**Weed research - chaff lining weed persistance and site specific targeted tillage (R)** - P229 ***Mike Walsh,*** *The University of Sydney*
10.20 am	**MORNING TEA**			
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CONCURRENT SESSIONS (40 minutes including time for room change) (R = session to be repeated)

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1.30 pm **Pesticides and regualtory impacts - the road ahead** – P269 ***Gordon Cumming,*** *GRDC*

2.10 pm **Integrated weed management status - where to from here?** – P277 ***Peter Newman,*** *AHRI & Weedsmart*

2.50 pm **CLOSE AND EVALUATION**

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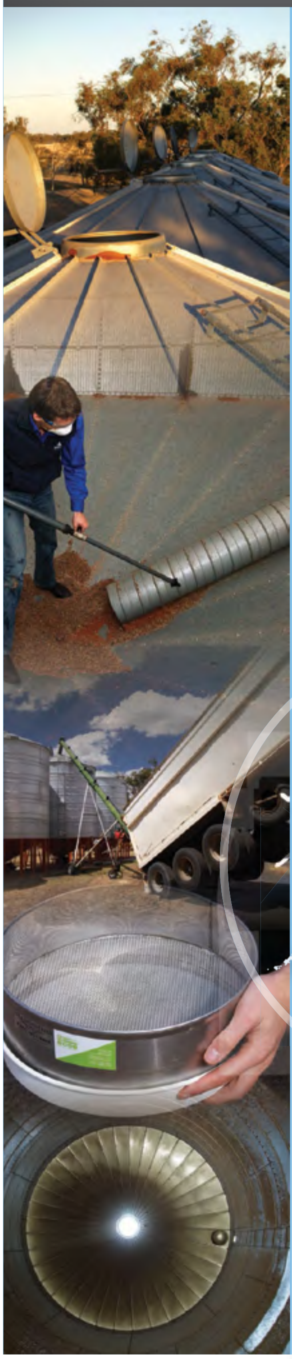

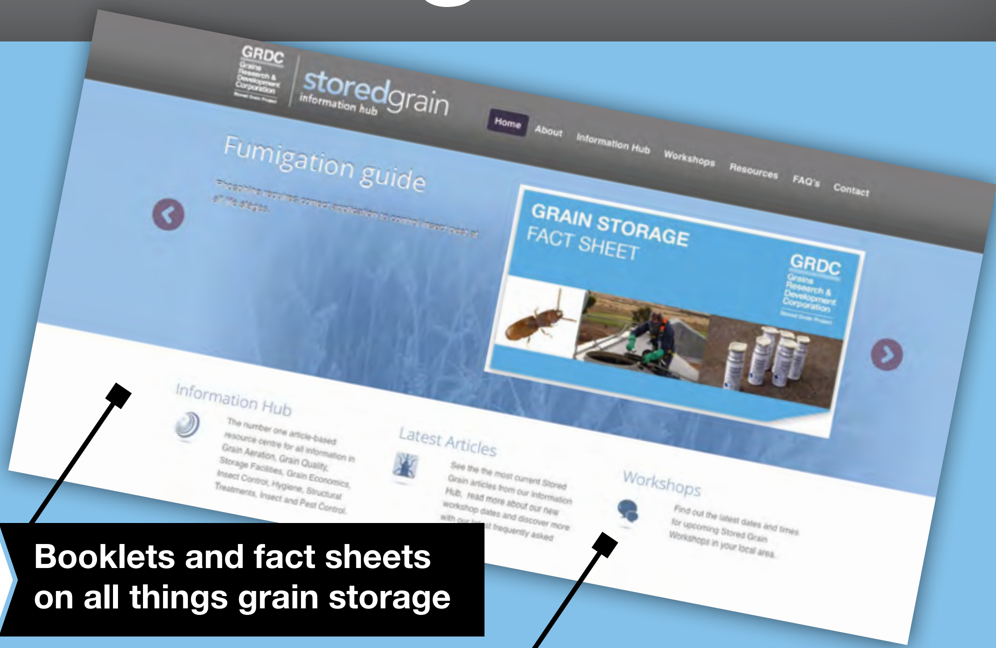

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Concurrent session Day 2

Canola – what disease is that and should I apply a fungicide?

Steve Marcroft[2], Susie Sprague[1], Angela van de Wouw[3], Andrew Ware[4] and Kurt Lindbeck[5].

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GRDC project codes: UM00051, CSP00187

Keywords

- canola, phenology, flowering time, fungicide, disease control.

Take home messages

- Disease symptoms on canola are caused by a variety of pathogens. Correct identification is critical to ensure appropriate control strategies are selected. Use the GRDC Back Pocket guide or Canola: the ute guide, for disease identification.
- Blackleg and sclerotinia stem rot most commonly cause significant yield loss. Whilst other diseases can be common and prevalent, the level of yield loss associated with other disease infection is either low or has not been quantified.
- Blackleg crown canker results from infection during early seedling growth. Prior to sowing, use the BlacklegCM decision support tool to identify high risk paddocks and explore management strategies to reduce yield loss.
- Blackleg upper canopy infection is the collective term for flower, peduncle, pod, main stem and branch infection, but does not include crown canker.
- Upper canopy infection can cause yield losses of up to 30%. Yield loss is reduced by selecting cultivars with effective major gene resistance and using crop management strategies to delay the commencement of flowering to later in the growing season, especially in high disease risk areas.
- Sclerotinia stem rot in high risk situations can be controlled by fungicide application at 30% bloom (14-20 flowers on main raceme).
- Foliar fungicide application for sclerotinia control (approximately 30% bloom) can reduce UCI if it is present and causing yield loss. Unfortunately, applications during flowering do not protect the pods from pod lesions. More work is required to determine robust foliar fungicide timings and economic returns.
- Blackleg pathogen populations with resistance to the triazole fungicides fluquinconazole, flutrial and a tebuconazole + priothioconazole mixture have been detected. No resistance was detected for new succinate dehydrogenase inhibitor (SDHI) and quinine-outside inhibitor (QoI) chemistries.

'Major' diseases – to spray or not to spray?

Sclerotinia

Sclerotinia is a disease that can cause substantial yield loss in some regions in some years. The decision to apply a fungicide is determined by the frequency of previous outbreaks on your farm. If sclerotinia has never been an issue then it is unlikely to occur in the future and fungicides are not warranted. If sclerotinia has occurred in the past, the following factors may help in deciding whether to apply a fungicide:

- **Spring rainfall:** Epidemics of sclerotinia stem rot generally occur in districts with reliable spring rainfall and long flowering periods for canola. Consider rainfall predictions for spring and canola crop growth stage.
- **Frequency of sclerotinia outbreaks:** Use the past frequency of sclerotinia stem rot outbreaks in the district as a guide to the likelihood of a current sclerotinia outbreak. Paddocks with a recent history of sclerotinia are a good indicator of potential risk, as well as adjacent paddocks. Also consider the frequency of canola in the paddock. Canola is a very good host for the disease and can quickly build up levels of soil-borne sclerotia.
- **Commencement of flowering:** The commencement of flowering can determine the severity of a sclerotinia outbreak. Spore release, petal infection and stem infection have a better chance of occurring when conditions are wet for extended periods, especially for more than 48 hours. Canola crops which flower earlier in winter, when conditions are cooler and wetter, are more prone to disease development in spring.
- **SclerotinaCM:** SclerotiniaCM has taken experimental data and expert knowledge to determine the probability of economic benefit of fungicide application to any canola crop in Australia. The app can be used in season at the decision-making time, it requires the agronomist to input individual paddock data, recent weather and expected weather and then produces a probability of return from fungicide application.

The most yield loss from sclerotinia occurs from early infection events. Early infection is likely to result in premature ripening of plants with little or no yield. Plants become susceptible to infection once flowering commences. Research in Australia and Canada has shown that an application of foliar fungicide around the 20 to 30% bloom stage (20% bloom is 14 to 16 flowers on the main stem, 30% bloom is approx. 20 flowers on the main stem) can be effective in significantly reducing the level of sclerotinia stem infection. Most registered products can be applied up to the 50% bloom (full bloom) stage.

The objective of the fungicide application is to prevent early infection of petals while ensuring that fungicide also penetrates into the lower crop canopy to protect potential infection sites (such as lower leaves, leaf axils and stems). Timing of fungicide application is critical. A foliar fungicide application is most effective when applied before an infection event (e.g. before a rain event during flowering). These fungicides are best applied as protectants.

In general, foliar fungicides offer a period of protection of up to three weeks. After this time, the protectant activity of the fungicide is reduced. In some crops, development of lateral branch infections later in the season may occur if conditions favourable for the disease continue. The greatest yield loss occurs when the main stem becomes infected, especially early. Lateral branch infection results is less yield loss. Use high water rates and fine droplet sizes for good canopy penetration and coverage.

Blackleg crown canker

Severe crown canker is most likely to develop when plants are infected during the early seedling stage. The fungus grows from the cotyledons and leaves asymptomatically through the vascular tissues to the crown, where it causes necrosis resulting in a crown canker at the base of the plant. Yield loss results from restricted water and nutrient uptake by the plant. Protection during the seedling stage is critical to reduce crown canker severity. The risk factors for development of blackleg crown canker are well understood in Australia and include intensity of canola production, blackleg resistance of the cultivar, stubble management and rainfall. A decision support tool, BlacklegCM, is available and should be used to assess the risk for blackleg crown canker prior to cultivar selection and sowing. Versions of BlacklegCM are available for iPad or android tablets. BlacklegCM does not work on iPhones. The tool is interactive, allowing growers and advisers to determine the blackleg risk for each paddock and consider the possible economic return of different management strategies. The tool also provides in-season support for the application of foliar fungicides.

Figure 1. Upper canopy infection includes blackleg infection of flowers, peduncles, pods, main stems and branches.

Blackleg upper canopy infection

Blackleg is able to infect all parts of the canola plant. Upper canopy infection (UCI) is a collective term that describes infection of flowers, peduncles, pods, upper main stem and branches (Figure 1). UCI has become increasingly prevalent over recent years and may be associated with earlier flowering crops because of earlier sowing of cultivars and more rapid phenological development during warmer autumns and winter. There is also evidence of delayed and prolonged release of blackleg spore release in stubble-retained systems and increased intensity of canola production. While the crown canker blackleg is well understood, the factors contributing to UCI and possible control strategies are currently under investigation. An outline of findings to date are presented below.

Blackleg UCI research results

In field experiments, UCI has caused up to 30% yield loss. The impact on yield varies depending on the timing of infection and plant part infected. Flower loss from infection of flowers or peduncles is unlikely to directly reduce yield as the plant is able to compensate by producing more flowers. However, the fungus can grow into the associated branch which can then affect seed set and grain filling in surrounding pods. Infection of pods or peduncles after pod formation can result in significant yield loss. Infected branches and upper main stems can affect all developing flowers and pods above the point of infection causing a reduction in pod and seed set as well as smaller seed. Severe infection can cause stems and branches to break off, premature ripening leading to shattering or difficulty in ascertaining correct windrow timing due to maturity differences between seed affected or unaffected by blackleg.

Entry of blackleg into the plant is via the stomatal openings. Physical damage to the plant by insects, hail or frost, facilitates entry of the pathogen causing severe disease. In NSW and Victoria in 2018, splitting of stems (probably related to frost damage) and hail damage resulted in sporadic severe UCI symptoms on main stems and pods.

It is now thought that UCI infections are also systemic, causing damage to the plant's vascular tissue similar to traditional blackleg crown infections.

Figure 2. Blackened branches caused by internal vascular damage; symptoms become visible post 100% seed colour change. These symptoms may not occur in crops that received the sclerotinia 30% bloom fungicide application.

The issue for growers is that external symptoms may appear insignificant, but internal vascular damage may cause significant yield losses. Preliminary results indicate this may be why fungicide applications on crops with few symptoms can still result in economic yield returns. Interestingly, researchers have noted that symptoms of internal vascular damage result in blackened stems post the windrowing growth stage i.e. post 100% seed colour change (see Figure 2).

Blackleg UCI control strategies

Genetic resistance

Effective major gene resistance prevents infection of all canola plant parts (cotyledons, leaves, stems, branches, flowers, pods). Effective major genes can thereby prevent both crown canker and blackleg UCIs. Unfortunately, most major genes present in current cultivars have been overcome by the blackleg pathogen across many canola producing regions. It is therefore crucial to know if major genes are effective or overcome in your growing region. The Blackleg Management Guide provides information that is relevant for control of blackleg crown canker.

Commencement of flowering

There is a strong relationship between the earlier onset of flowering and yield loss caused by UCI. Canola plants are particularly susceptible to stress during the early stages of flowering (Kirkegaard et al. 2018). Evidence from controlled environment and field experiments indicates that plants infected by blackleg on the upper main stems and branches during the early flowering period results in the greatest reduction of grain yield compared to crops that flower later or are infected at later growth stages. Yield loss can be due to a reduction in seed size, seeds/pod and/or pods/m2. Oil content can also be reduced. In most regions, mid-May to early August is the most conducive period for blackleg infection. By delaying the commencement of canola flowering to early August, growers may be able to avoid severe UCI infections.

Fungicides

If UCI occurs, it has been shown that sclerotinia fungicides will also reduce UCI severity and yield losses. Application of Prosaro®/Aviator® Xpro for sclerotinia control around 30% bloom can also provide protection from blackleg infection during early flowering. The 30% bloom spray may control flower, peduncle, stem and branch infections but is unlikely to provide pod protection. High levels of pod infection tend to occur in seasons with frequent late rainfall events (such as 2016) or where there is physical damage to the pods, e.g. hail (such as 2018).

'Minor' diseases – to spray or not to spray?

White leaf spot (Mycosphaerella capsellae)

White leaf spot (WLS) is a very common disease of canola that occurs on the leaves of seedlings but can spread up the canopy if wet conditions prevail. Infection reduces leaf area which may cause reduced biomass accumulation and consequently reduce yield. There is no evidence that there is any cultivar resistance to white leaf spot in Australian commercial canola cultivars. There is no data available on yield losses from WLS.

WLS is a sporadic stubble-borne disease so it is likely to be more prevalent and severe in areas with intensive canola production. The issue for advisers is that there is no knowledge on how to predict if WLS will occur as there has been no work carried out on epidemiology. Therefore, use past infestations as a reference and monitor crops at the 4-6 leaf stage prior to considering control options. If lesions are present and wet weather is forecast, it is likely that WLS will continue to flourish. If no (or few) lesions are present and the weather is forecast to be dry, it is highly unlikely that new leaves will become infected.

Interestingly, several experiments to assess fungicide efficacy for blackleg control have also produced excellent control of WLS. Both Prosaro® and Miravis® applied for blackleg control at 4-6 leaf growth stage have provided excellent control of WLS. Miravis® is registered for WLS control, whilst Prosaro® is not registered for WLS control. Other experiments show that Jockey®Stayer applied to the seed and flutriafol amended fertiliser for blackleg control may also provide some WLS control (Van de Wouw et al. 2016). Jockey®Stayer and flutriafol are not registered for WLS control. At this stage, when applying fungicide for blackleg control at the early vegetative stage, you may also achieve WLS control.

Powdery mildew (Erysiphe cruciferarum)

Powdery mildew may be becoming more prevalent or it may be 'frequency illusion', that is, once you start looking, you see it everywhere. Powdery mildew occurs typically post flowering and will affect all plant parts. It is a white powder covering the plant parts. There is limited data available regarding if powdery mildew causes any yield loss and very limited epidemiology data to determine which situations may increase the risk of the disease occurring. In northern NSW, this disease occurs regularly and is thought to reduce yield in some seasons. Powdery mildew on brassicas (including canola) is caused by the fungus *Erysiphe cruciferarum* and first appears as small whitish patches on the upper and lower surfaces of leaves. These spots consist of mycelia and conidia (spores), which allow the fungus to spread rapidly. The fungal patches spread under favourable conditions and form a dense white layer that resembles talcum powder. Disease outbreaks appear to be associated with dry conditions, moderate temperatures, low relative humidity and minimal rainfall. The fungus survives mainly on alternate brassica weed hosts but is also known to survive within old canola stubble.

There are no known commercial canola cultivars with resistance to powdery mildew. Overseas management of powdery mildew is achieved through application of foliar fungicides. In experiments in northern NSW, powdery mildew control with fungicides was not achieved. However, in Victoria in 2018, fungicide applications to control blackleg also controlled powdery mildew. In fact, it appears that in Victoria the blackleg fungicides are extremely efficient at powdery mildew control. In blackleg experiments, fungicide applications from 10 leaf to 50% bloom have all provided some control of powdery mildew. Control from early applications suggests that powdery mildew is present in the crop a long time before it is visible in the spring.

At this stage we do not know if or when powdery mildew will occur, we do not know what practices and how the climate or weather may influence disease severity. We also do not know if it causes any yield losses. If you are spraying during flowering for sclerotinia, you may also achieve control of powdery mildew.

Pathogens that do not require fungicide control

Downy mildew (Peronospora parasitica)

Downy mildew is often prevalent causing premature senescence of cotyledons and early true leaves. Generally, plants grow through the infection, although seedling vigour can be reduced. There is no knowledge on yield loss, but loss of vigour in canola seedlings is definitely not desirable. No fungicides are registered for downy mildew control in canola and there are no observations of control from blackleg fungicide seed treatments or foliar applications.

Alternaria

Alternaria occurs with prolonged wet weather, especially post-flowering. Alternaria pod spot can result in premature shattering resulting in yield losses. Seed retained and planted from infected crops may cause seedling blight as the disease is carried on the seed. It is recommended to only retain seed from crops unaffected by alternaria. Seed treated with fluquinconazole for blackleg control has also resulted in suppression of alternaria seedling blight. There are no fungicides registered for alternaria control in Australia and no observations that fungicides applied to control sclerotinia stem rot during flowering control alternaria pod spot. It is not known if flutriafol or SDHI seed treatments will control alternaria seedling blight.

Fungicide resistance

With the high use of fungicides comes the risk of fungicide resistance developing. We have recently screened 107 populations for resistance to all commercially available and soon to be released fungicides. The results from these screens show that 22% and 28% of populations have a high frequency of isolates resistant to the demethylation inhibitor (DMI) fungicides (fluquinconazole and flutriafol respectively), whilst only 7% of populations have a high frequency of resistance to the tebuconazole + priothioconazole mixture. No resistance was detected to any of the SDHI or QoI fungicides. We will continue to screen populations in 2019 and 2020 to monitor changes in the frequency of resistance to both the old DMI chemistries and the new SDHI and QoI chemistries.

The development of fungicide resistance to blackleg in Australia highlights the importance of fungicide use stewardship. Overseas experience informs us that the new SDHI fungicides are more likely to develop resistance than the current DMI fungicides.

Fungicide resistance screening sample submission

If you would like your 2018 canola (2019 stubble) screened for fungicide resistance, we will require 30 pieces of canola stubble from your 2018 paddock. Please email Angela Van de Wouw at angela@grainspathology.com.au for stubble collection protocol. We will provide you with fungicide resistance results for the current DMI blackleg fungicides and the new SDHIs. The service is free to growers and advisers. Costs are covered by an Australian Research Council (ARC)/industry investment.

Useful resources and references

BlacklegCM App for iPad and android tablets

www.grdc.com.au/resources-and-publications/all-publications/publications/2018/blackleg-management-guide

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

Van de Wouw et al. (2016) Australasian Plant Pathology 45: 415-423

Kirkegaard et al. (2018) Ten Tactics for Early-Sown Canola (https://grdc.com.au/resources-and-publications/groundcover/groundcover-133-march-april-2018/ten-tactics-for-early-sown-canola)

www.nvt.com.au

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Notes

Notes

Mice - status, baiting and forecast threat

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GRDC project codes: CSP1806-017RTX, CSP1804-012RTX, CSP1806-015RTX

Keywords

- mouse monitoring, crop damage, zinc phosphide.

Take home messages

- Mouse numbers are currently low across most regions of southern New South Wales, South Australia and northwest Victoria. At this stage, there is low potential for economic damage at sowing in 2019.
- Information about changes in mouse numbers in the lead up to the 2019 sowing can be accessed from the mouse monitoring updates published at https://www.feralscan.org.au/mousealert/pagecontent.aspx?page=mouse_news
- Growers should conduct their own monitoring to ensure they know what is happening in their paddocks in the lead up to sowing each autumn. This includes following the recommendations outlined in the GRDC GROWNOTES™, Tips and Tactics, Better Mouse Management page at https://grdc.com.au/resources-and-publications/all-publications/publications/2017/07/tips-and-tactics-better-mouse-management
- Timely application of mouse bait at the prescribed rate is paramount for reducing the impact that mice have on crops at sowing. Strategic use of bait is more effective than frequent use of bait.
- GRDC has invested in a suite of new projects aimed at understanding the way mice use zero and no-till cropping systems and developing new strategies to monitor and control mice.

Background

There are three distinct but related GRDC investment projects that aim to better understand the way mice use zero and no-till cropping systems. The outcomes of these projects will lead to a reduced impact of mice in cropping systems through the development of more effective monitoring systems and better strategies to control mice using existing technology.

1. Surveillance and forecasts for mouse outbreaks in Australian cropping systems

This project commenced in October 2012 and the GRDC has invested in five years of additional monitoring. The aim of the project is to monitor mouse populations across all grain growing regions and use predictive models to forecast mouse outbreaks. A key element of the project is to communicate the results of the monitoring and predictions to growers and industry to enhance awareness of increases in mouse activity.

A new component of this work is to develop and test the feasibility of a remote monitoring system for mice to detect changes in mouse activity throughout the year and at a spatial scale that is not possible using existing monitoring techniques.

Preliminary exploratory work has started to test prototype monitoring systems. Once a suitable system has been identified, laboratory trials will be run using arenas to determine how efficiently mouse activity is detected. If the results in the laboratory are favourable, the monitor will be tested in enclosures with known numbers of wild mice and then in field-based scenarios. This work will begin in 2019 with field-based testing planned to commence in 2020.

2. Bait substrate trials

In recent years, growers have reported poor efficacy of zinc phosphide. It is not clear what is driving the reduced effectiveness of baits, but in some instances, growers are reporting the need for multiple applications of bait to achieve the desired level of control.

Trials to determine what is driving the reduced efficacy of the bait and testing potential new bait substrates that might be more attractive to mice have commenced.

Experiment 1: Two choice grain preference

Experiment 1 is designed to test the willingness of house mice to switch food types when challenged with an alternative food type. This will determine if mice display a grain preference and identify leading bait substrate candidates. Mice were held on a background food type (barley, lentils or wheat) and then offered the choice of an alternative grain type (malt barley, durum wheat or lentils) for five nights. Mice displayed a strong preference towards cereal grains, with a slight preference towards malt barley (Table 1).

Experiment 2: Toxic bait take against different background grains

Experiment 2 is aimed at determining the acceptance of different toxic bait substrate by mice when challenged against different background food type. Mice were held on a background food type (lentils, barley or wheat) then offered an alternative of three types of zinc phosphide-coated grain for three consecutive nights as well as the background diet. Mice consumed toxic bait grains regardless of bait substrate type. However, background food type had a strong influence on the amount of toxic bait consumed (Table 2). Mice established on a wheat background consumed fewer toxic bait grains then mice on a lentil or barley background diet. Mice on a barley background diet showed a preference for malt barley.

Toxic bait aversion

Average toxic bait uptake was highest on the first night of exposure. Mice that did not die after consuming toxic grains showed a strong bait aversion (Table 3). By night three of the trial, bait mice stopped eating toxic grains.

Table 1. The average proportion consumed by mice (expressed as a percentage %) of alternate malt barley, durum wheat or lentils compared to the back ground food type, after being on a background of lentils, barley or wheat for 2 weeks (n=10). Mice displayed a significant preference for cereal grains over lentils.

Background food type	(n)	Malt barley	Durum	Lentils
Lentils	30	96	98	55
Barley	30	72	67	1
Wheat	30	53	22	4

Table 2. Average number of toxic bait grains consumed by mice (n=10) held on either lentil, barley or wheat background. Values represent estimates of fixed effects (individual mice as random effects). Mice did not show any significant preference for bait substrate type.

Background grain type	Barley	Husked malt barley	Unhusked malt barley
Lentils	5	5	6
Barley	1	3	4
Wheat	1	2	1

Table 3. Number (average) of toxic bait grains consumed by mice that did not die in the lentil (n=4), barley (n=14) and wheat (n=16) background food types over the three-night trial.

Background grain type	(n)	Night 1	Night 2	Night 3
Lentils	4	8	1	0
Barley	14	3	0.2	0
Wheat	16	2	0.1	0.1

Table 4. Amount of food and bait to be applied to each treatment group in the Enclosure study		
Treatment	Food quantity	Toxic Bait
Untreated Control	Maintenance diet (60 grains/m^2)	No bait
Treatment 1 (Low)	Maintenance diet (60 grains/m^2)	3 grains/m^2
Treatment 2 (Med)	Maintenance diet plus 90 grains/m^2	3 grains/m^2
Treatment 3 (High)	Maintenance diet plus 900 grains/m^2	3 grains/m^2

Experiment 3: Effect of alternative food quantity on bait effectiveness

This trial will be undertaken in large enclosures and is designed to examine the role of available alternative food on commercial zinc phosphide bait effectiveness. The effect of commercially available zinc phosphide bait will be measured using four groups of mice provided with different levels of available background cereal grains (Table 4).

Mouse ecology

This work will involve a series of experiments aimed at understanding how mice use zero and no-till cropping systems. Historically, mice lived on the margins of paddocks and moved into crops when conditions were favourable. Now with low levels of disturbance in paddocks, mice are building burrow networks in paddocks and living where resources are most plentiful.

This project will address five key topics:

1. Farming practices.
2. Managing refuge habitat.
3. Understanding mouse movements.
4. Mouse burrows.
5. Bait delivery.

Understanding the impacts that farming practices have on the distribution of resources in paddocks and how mice access these resources and use the associated habitat will assist in the development of new strategies to control mice.

Monitoring outcomes

Ongoing monitoring of mice across all cropping regions is critical to provide accurate predictions of future populations of mice and in turn provide accurate information to growers about changes in mouse populations.

In the autumn of 2018, mouse numbers in the Victorian Mallee were extremely high and while numbers on the Adelaide Plains were not as high, there was still cause for concern (Figure 1). In general, growers were well prepared for mice in the lead up to sowing and significant quantities of bait were spread prior to and during the sowing of the 2018 crop. The combination of an extremely dry summer, and a dry and cold autumn and winter, in conjunction with the distribution of large amounts of bait led to a decline in mouse numbers in late May-early June and since then mouse numbers have remained low.

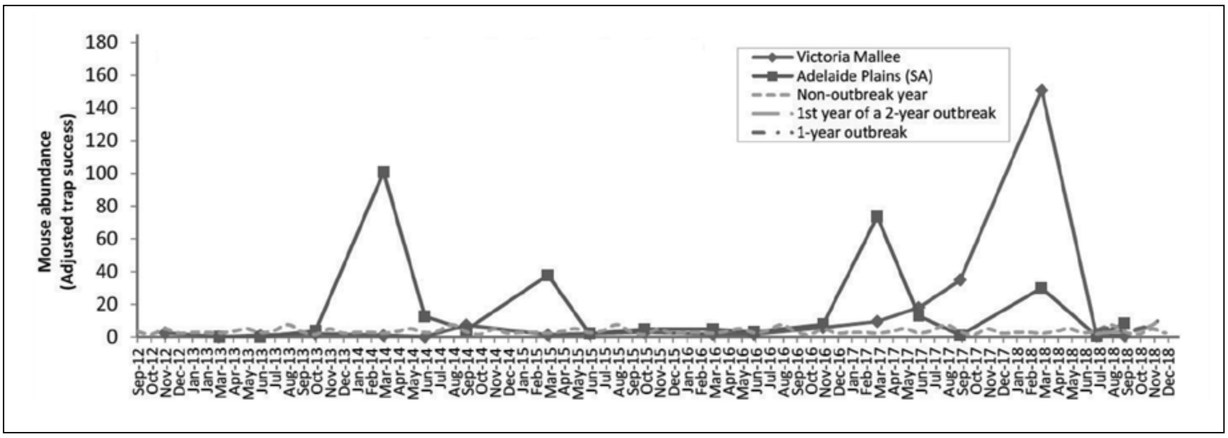

Figure 1. Current mouse population abundance at benchmark sites in Victoria and South Australia compared to outbreaks in the past.

Current research outcomes

The results from the bait substrate trial show that mice have a clear preference for cereals over lentils. While there appeared to be a slight preference for malted barley, there was no significant preference for any of the cereals.

When challenged with toxin on different cereal grains, mice were willing to eat the toxin regardless of the substrate, but background food significantly affected the number of toxic grains consumed. Mice that were on a background of lentils ate significantly more toxic grains than mice that were on cereal backgrounds.

Mice that ate a sub lethal dose of toxin on the first night showed bait aversion – they stopped taking toxic grains on nights two and three.

The next phase of this work aims to determine the effect of the amount of background food on the efficacy of zinc phosphide.

Future research

The results of the bait substrate experiments, in conjunction with the results of the work in the five key mouse ecology priority areas, will form the basis of a series of recommendations for improved mouse control strategies. The current approach to bait application is to spread bait on a broad scale across entire paddocks. To date, the majority of our understanding of mouse ecology and behaviour is based on work undertaken in conventional cropping systems. Better understanding of mouse ecology in zero and no till cropping systems could lead to more strategic application of bait, potentially reducing the quantity of bait spread or increasing the effectiveness of bait by targeting high activity zones in paddocks.

Acknowledgements

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Lime and liming – managing soil health

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GRDC project codes: SFS00026, DAN00206, 9176971

Keywords

- lime, soil acidity, soil pH.

Take home messages

- Liming to maintain good soil pH levels and avoiding yield losses is just as important as applying fertiliser for maximising yields.
- If growers let soil pH levels in the topsoil run-down (pH in $CaCl_2$ < 5.0) they are at risk of creating soil acidity issues at depth which are harder and more expensive to treat.
- In general, not enough lime has been applied frequently enough to address acidification occurring within the whole soil profile, so soil test to depth and calculate lime requirements for 0-10cm, 10-20cm and 20-30cm, not just the top 10cm of soil.

Background

Southern Farming Systems (SFS) was fortunate to be involved in a soil acidity project in both crops and pastures which started in 2014 under a GRDC and federal government investment in South West Victoria. Our understanding of soil acidity management from this work has been considerable regarding; lime responses, soil acidity increases in the 10-20cm layer, lime movement and lime quality. This work is set to be expanded in a new GRDC and NLP Smart Farms project across the high rainfall zone in Tasmania, Gippsland and in southern South Australia (SA). This paper reports on some of the SFS acidity research and related extension messages.

Importance of liming

Soil acidity affects major plant and soil functions

Soil acidification is unavoidable in productive farming systems, and acidity eventually eats away profits, affecting chemical, biological and physical functions within soils and plants. This makes it difficult to diagnose acidity based on crop symptoms. However, soil pH provides a good guide to which functions might be affected and the likely lime response as shown in Table 1.

Do not let soil pH run down

Our cars are serviced regularly so they run reliably and efficiently, and most people do not wait for their cars to break down and then have it fixed. The same applies to maintaining soils. If topsoil pH is allowed to run down to less than 5.0, which is common in grazing enterprises, significant production has probably been lost over the past 5-8 years and possibly not noticed. More importantly, by letting the soil acidity form in the top 10cm of soil, the acidity build-up results in leaching downwards of hydrogen ions and this allows soil acidity to increase at depths of 10cm to 20cm, where it becomes much more difficult and expensive to treat.

Lime is slowly soluble and often will not work straight away — it takes time to dissolve and move and so some ongoing yield losses will continue to be incurred. If a subsoil acidity problem exists, lime with no incorporation will take five years or more to fix the acidity profile beyond 10cm (depending upon soil type and rainfall), provided enough is applied to move downwards.

Table 1. Crop symptoms at different soil pH (measured in CaCl2).	
If the soil pH (CaCl2) is:	
More than 5.5	There will be no problems from soil acidity affecting crop growth and yield, and there could be net movement of lime beyond 10cm depth.
Less than 5.2	The effectiveness and numbers of rhizobia that fix nitrogen (N) on acid sensitive legumes (e.g. lucerne and pulses, but not narrow-leafed lupin) are reduced. Liming increases the persistence and effectiveness of these rhizobia, and the amount N fixed and grain produced of the sensitive legumes.
Less than 5.0	In addition to the effects above, there is a chance of molybdenum deficiency in legumes — check for local advice. Molybdenum is important in the synthesis of amino acids and proteins and a requirement for Rhizobium bacteria to fix atmospheric N.
Less than 4.8	In most soils, aluminium (Al) starts to precipitate from a harmless solid into a soluble form which is toxic to root growth. Aluminium tolerance among plant species varies. Reduced root growth means roots are unable to effectively explore soil for nutrients (particularly phosphorus and trace elements) and access stored subsoil water for growth or grain filling. Crop yield is reduced significantly. Reduction in root hairs occurs and so infection by rhizobia (nodulation of legumes) is severely affected.
Less than 4.5	The speed of N mineralisation processes (nitrification) slows significantly, resulting in decreased N supply. In most soils Al concentrations increase further and quickly become toxic to most pasture and crop species. There is a chance of molybdenum deficiency in cereals or canola, but check for local advice. The effectiveness of rhizobia in acid tolerant legumes, such as subclover, balansa and arrowleaf clover is reduced.
Less than 3.8	Soil can no longer buffer effectively against pH change and is overcome with acidity which breaks down clay minerals leaving only the sand component. Irreversible soil structural damage is done.

(Source: Table adapted from Fenton, 2003)

Maintaining good soil pH means yield responses to lime may not be immediately noticeable, but they will avoid ongoing acidification and yield declines. A soil pH increase will show that the lime is working, and regular soil monitoring is recommended, particularly at 10-20cm where there may be issues with subsurface acidity build-up.

Soil acidity eats away at yields

SFS replicated research trial data has been used to create lime response curves by calculating the percentage difference in yield of control un-limed plots compared to limed plots for wheat, barley canola and faba bean (see Figures 1-4). They show the yield reduction at different soil pH levels,

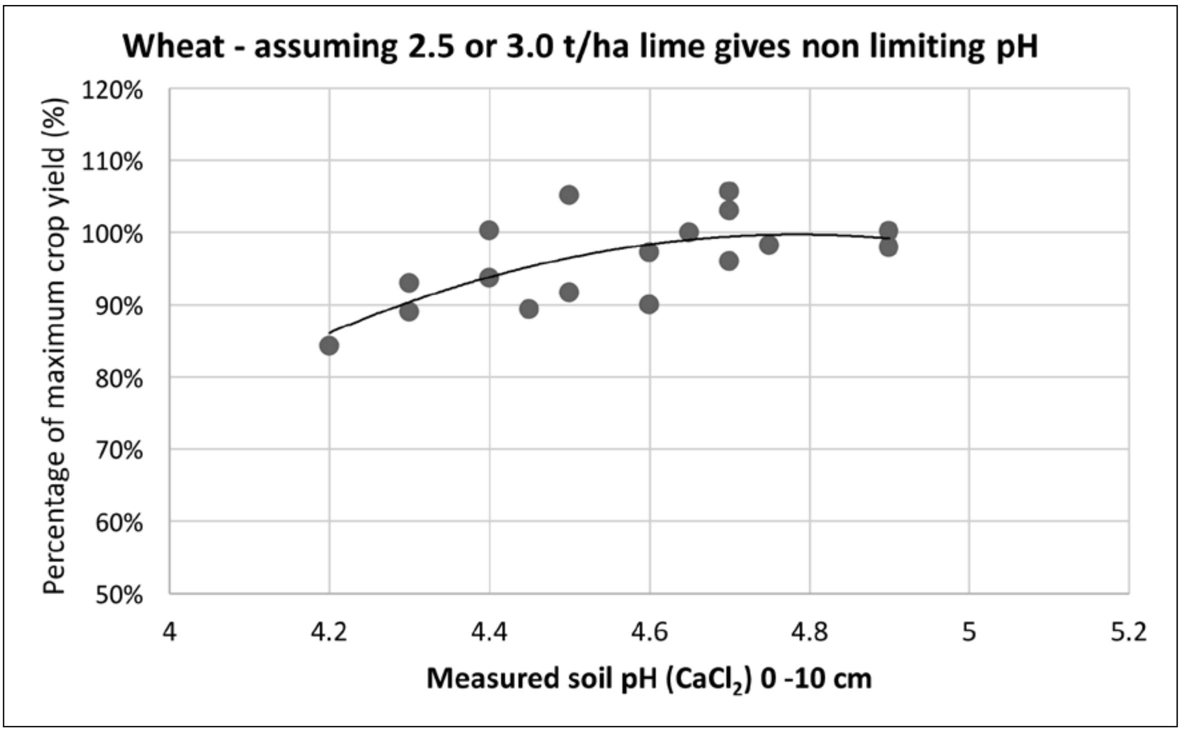

Figure 1. Wheat yield responses to different soil pH levels measured 2012-2018 (n=17).

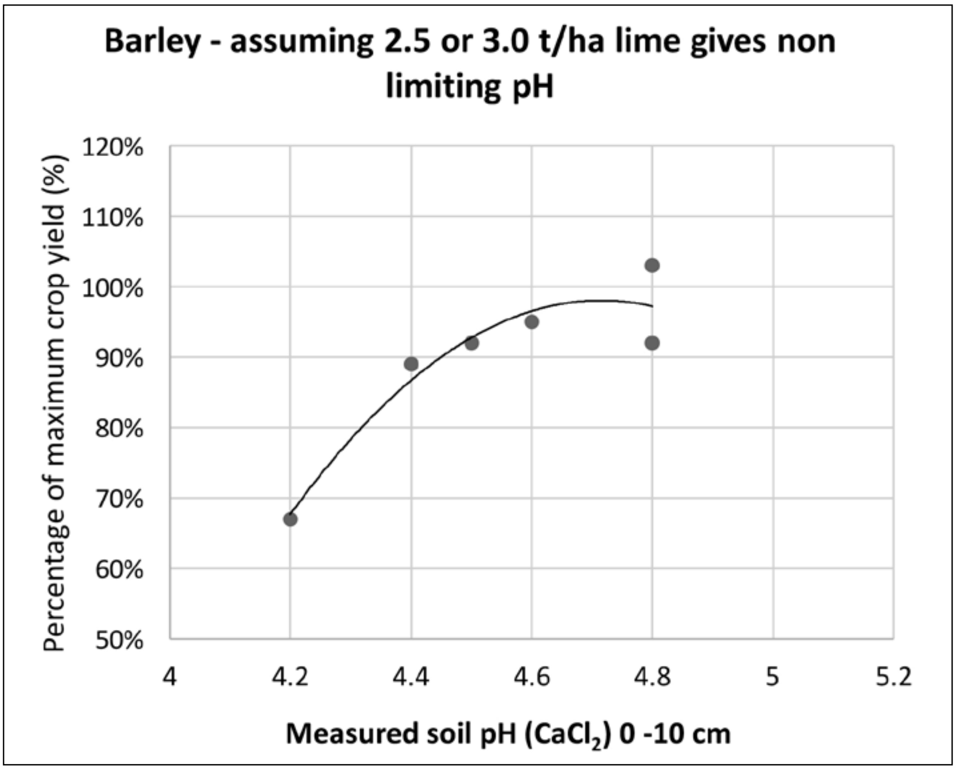

Figure 2. Barley yield responses to different soil pH levels measured 2014 to 2018 (n=6).

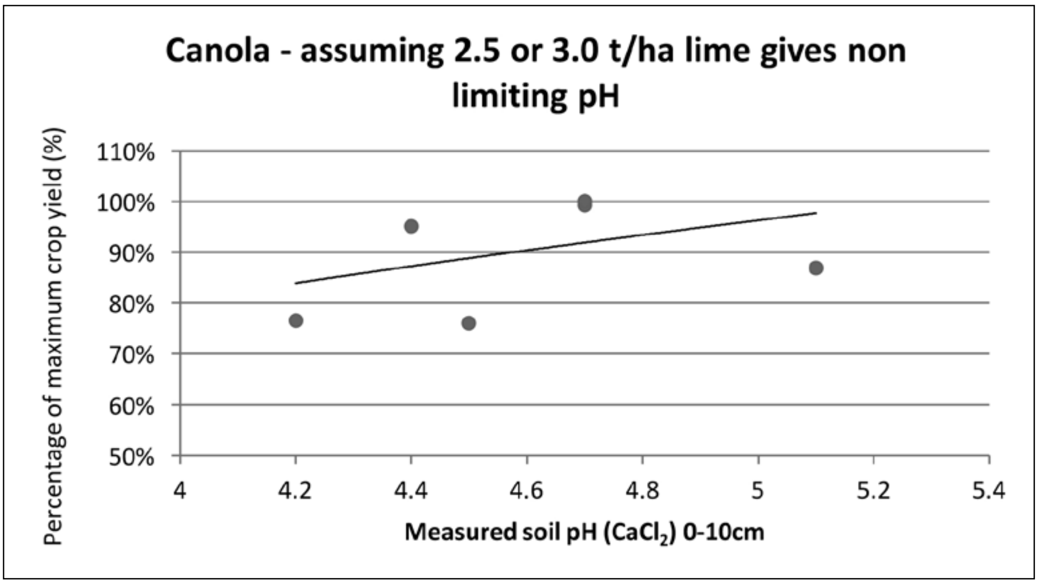

Figure 3. Canola yield responses to different soil pH levels measured 2012-2016 (n =7).

especially in barley. The responses are from surface applied South West soft rock lime [Neutralising Value (NV) 90%, Effective Neutralising Value (ENV) 63%] in 2014 with minimal tillage and incorporation. Most of the trial sites had acidity less than pH 4.5 in the top soil plus acidity issues down to 15cm or 20cm. The moderate rates of lime applied and without any significant incorporation did not correct subsurface acidity at the sites and this probably reduced yield beyond what was measured.

Lime responses are difficult to predict

The lime responses can be variable as they are influenced by many factors such as:

Subsoil acidity

A trial at Rokewood is investigating subsoil acidity further including incorporating lime and organic amendment (lucerne pellets) to depth (see Table 2). The pH at this site was 5.1 at 0-10cm, 4.1 at 10-

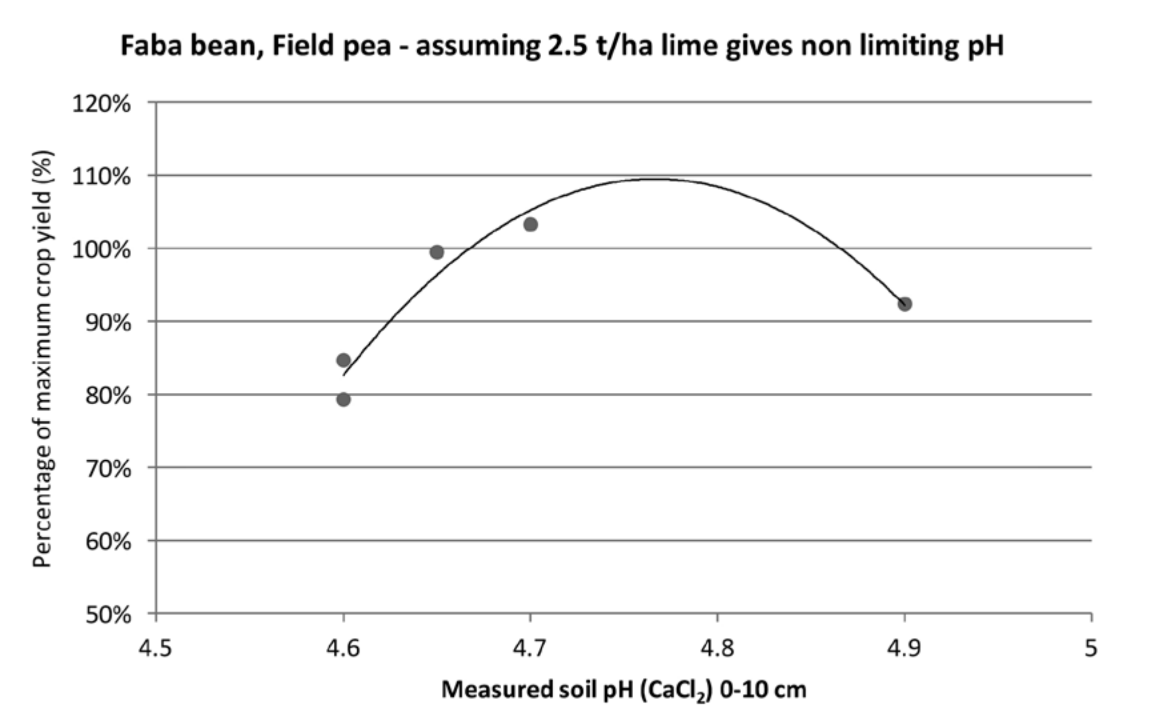

Figure 4. Faba bean and field pea yield responses to different soil pH levels measured 2014-2016 (n =5).

20cm and 4.7 at 20-30cm. Relatively acid tolerant lupins were planted in the first year, but nonetheless it was apparent that the subsoil acidity resulted in a 672kg/ha reduction in biomass and a 200 kg/ha yield loss (although yield difference was not significant). Interesting the best response was with deep placement of lucerne pellets, producing an extra 399kg/ha biomass and 360kg/ha yield. Approximately a 20% significant yield reduction in both wheat and barley was recorded at an acidity trial site near Cootamundra, NSW where the acidity constraint was at 10cm-30cm depth.

Season

Acidity and aluminium toxicity reduce root growth which reduces the plant's ability to extract soil moisture particularly in a dry finish to the season. However, if there is ample soil moisture and the crop's nutritional needs are met, there may not be a significant lime response.

Organic carbon

High soil organic carbon (organic C >2%) appears to influence lime response by reducing the impact of aluminium solubility and toxicity.

Table 2. Rokewood subsoil acidity trial. Lupin response to liming treatments applied in 2018.

Treatments	Treatment description	Lupin yield (t/ha)		Establishment counts (Plants/m^2)		Dry matter cuts at anthesis kg DM/ha	
Surface lime Incorporated	Surface liming 1.5t/ha incorporated into 0-10cm with offset discs to bring pH to 5.5.	1.24	b	8.63	a	4084	b
Deep rip only	Surface liming 1t/ha incorp. + deep rip. Ripped down to 30cm, tines 50cm apart.	1.36	b	6.73	b	4724	a
Deep lime	Surface liming 1t/ha incorp. + deep rip + deep lime. Deep lime 1.5t/ha placed between 8cm to 25cm (acid layer).	1.44	ab	9.07	a	4756	a
Lucerne pellet	Surface liming 1t/ha incorp. and lucerne pellets 7.5t/ha placed into acid band. (Rate based on providing the same amount of alkalinity). Contains 200kg to 300kg N/ha.	1.60	a	8.3	a	4983	a
LSD (P<0.05)		0.21		1.43		537	
CV (%)		7.46		8.72		5.8	

LSD- Least Significant Difference, CV – Coefficient of Variation

Other soil constraints

If there are other soil constraints to production present, then a lime response may not be seen. This has been apparent in pasture trials in Southern Victoria where nutrient deficiencies were seen to over-ride lime responses (Miller, 2016). Lime or fertiliser may not have shown significant differences when applied separately, but together they did. This indicates that lime is not a substitute for fertiliser — both are needed. Other potential constraints may include compaction, waterlogging, or sodicity.

Lime reaction

Growers or agronomists looking for obvious responses in the first season following lime applications may be disappointed. Among the trials of this project, there were only two with statistically significant lime responses in grain yield in the first year and that was when pH was low (pH 4.2 and 4.5) and acid sensitive crops were grown. Lime needs acidity moisture and time to dissolve. Incorporated superfine lime has taken up to 18 months to fully dissolve. Surface applied lime without incorporation is likely to drive up soil pH in the top 1cm to 6.0 or above where lime stops dissolving. Hence, the benefit of incorporation of some kind.

Acidification rates

If you are farming and removing plant and/or animal products from the paddock then you are acidifying the soil. Soil acidification is caused by a number of processes, for example, as roots take up cations they release hydrogen ions to maintain charge balance. Also, the cycling of nitrogen is particularly important, with the addition of urea or ammonium which is converted into nitrate and then leached beyond the rooting zone, leaving behind acidity. If the agricultural system was closed (i.e. products not removed and nitrate not leached), then acidification rates would be zero.

Analysis of trial results and monitoring of 100 un-limed paddocks mainly within the Corangamite catchment showed that the rate of acidification varies according to the farming system and soil type (Table 3). The measured pH changes varied from 0.05 and 0.18 units per year depending upon the production system. The decrease in soil pH at 10-20cm and at 20-30cm over the four-year period was also found to be highly significant ($p<0.05$). The equivalent amount of pure lime (i.e. 100% NV) required to neutralise the annual acidification rate has been calculated from the reductions in pH over a four-year period (2014 – 2018) and is expressed as kg lime/ha/year. It was estimated up to 755kg/ha of pure lime p.a. is required to neutralise acidity from hay production on loamy soils throughout the soil profile.

Table 3. Average annual acidification rate measured across Corangamite farming systems at different depths based on pH ($CaCl_2$) change over four years (2014 – 2018).

System	Average annual acidification rate of the soil layers (*Application of kg pure lime/ha/year to counteract acidity)		
	0-10cm	10-20cm	20-30cm
Cropping on clay loams	Average pH fall 0.05/year	Average pH fall 0.03/year	Average pH fall 0.03/year
	Lime equivalent 180	Lime equivalent 100	Lime equivalent 100
	(Range 85-430)		
Grazing on clay loams	Average pH fall 0.04/year	Average pH fall 0.01/year	Average pH fall 0.02/year
	Lime equivalent 138	Lime equivalent 45	Lime equivalent 50
	(Range 85-345)		
Hay cutting including lucerne on loams	Average pH fall 0.18/year	Average pH fall 0.09/year	Average pH fall 0.12/year
	Lime equivalent 350	Lime equivalent 175	Lime equivalent 230
	(Range 300-400)		

** Assuming 1 tonne of pure lime/ha lifts pH by 0.29 units in a clay loam and 0.5 in a loam.*

Table 4. Acidifying effects of various farm enterprises in >500mm rainfall zone. (adapted from Hollier, 1999).

System	kg of lime/ha/year to balance acidification
Continuous grain cropping including grain legume	200 to 300
Grazed pastures	100 to 200
Lucerne hay	200 to 700

Lime movement takes time

When lime dissolves it produces bicarbonate ions (alkalinity) which neutralises hydrogen ions (acidity). Bicarbonate ions move 1cm to 3cm per year, depending on soil pH buffering capacity and leaching rainfall. In South West Victoria, after three to four years of applying lime with minimal disturbance in crop and pastures, the bulk of pH change was at 0-5cm and little change below it, except on light textured soil types in high rainfall areas. In crop trials, the average pH change was 0.2 below 5cm, although no pH change was measured at two trials. Norton et al (2018) also reported that after 11 years there was no lime movement beyond 5cm in a permanent pasture research trial at Sutton, NSW. The millennial drought may have contributed to the lack of movement, as well as the high pH buffering capacity of this clay soil.

Given the same rate of acidification, light textured soils (sands) show greater rates of soil pH decline than heavy clays because they do not buffer against the pH change as much (i.e. sands have a low pH buffering capacity). While the drop in pH due to soil acidification is greater on sands than clays, the pH increase following lime application is also greater.

Lime movement occurs if pH is kept above 5.5

Very few of the recent SFS trials saw lime movement beyond 10cm because there was not enough time for it to move and because rates were not high enough to saturate the surface with alkalinity to allow it to leach. Any change in pH measured may have been through physical lime falling down cracks. A lime trial run by NSW DPI from 1992 to 2010 (18 years) is one of a number of trials that only found subsoil amelioration when soil pH in the topsoil was kept above 5.5 (Li, et al. 2019). Micro-fine lime was incorporated into the top 10cm and soil pH maintained above 5.5 for the trial duration to counteract acidification and leaching. After four years, lime had moved to 15cm, but advanced no further for another four years (2004), but in 2010, lime was detected at 25 and 30cm. Movement was about 1cm per year.

Variation across the paddock and down the profile

The average paddock pH can be misleading when trying to make decisions about liming. To make informed decisions about liming, it is good to know what you are dealing with. The use of pH mapping or using yield maps to identify low production zones and then taking exploratory cores within them both have merit. The Rokewood subsoil acidity site provides a good example of how soil acidity changes spatially and vertically down the soil profile. The Rokewood trial is 100 by 140m and the variation in soil pH is 2 units in the top 10cm (Table 5).

Doug Crawford, Ag Vic, describes four considerations in relation to variable rate liming once the variability in soil pH is known. These are:

- No pH issues and therefore there is no need to lime.
- Marginal soil pH but maintenance liming is needed which can be applied by a blanket rate.
- There are distinct pH zones which make variable rate useful.
- There is too much variability but generally low pH, therefore it makes sense to apply a blanket rate of lime.

Doug describes pH mapping as an insurance policy to make sure lime is applied to where it is needed most and hence, is as cost-effective as possible. Some argue that the money spent on pH mapping (approx. $65/ha) is better spent on additional lime. Having pH maps allows you to identify zones that can be monitored in future, especially if subsoil acidity is likely.

Variation in soil pH across paddocks is caused by management and soil type which makes it hard to predict. Some examples of variation are:

- Sheep stock camps (see McCaskill, 2009, who showed how sheep camps affected the establishment of lucerne at the Hamilton Evergraze Proof site).

Table 5. Average pH ($CaCl_2$) and Exchangeable Al results for the Rokewood trial site 19/12/2017.

Depth	Average Soil pH	Range of soil pH	Average Al% of exchangeable cations
0-10cm	5.11	4.1-6.1	2.75%
10-20cm	4.10	3.8-4.4	19.33%
20-30cm	4.71	4.1-5.5	3.41%
30-40cm	5.76	4.8-7.1	0.09%

- Lime spreading inaccuracies (see Burns and Norton, 2018, for examples of lime misses in faba bean).
- Burnt canola swaths increased soil pH by 0.3-0.8 of a pH ($CaCl_2$) unit, equivalent to about 1t/ha of lime in DAFWA investigations (Brennan, et al. 2003).
- Trees generally increase soil pH, but blue gums are an exception.
- High production areas tend to have more product removal resulting in more acidity.
- Cutting hay of half or parts of the paddock. Hay cutting is highly acidifying.

Developing a lime program

Once the distribution of soil acidity is spatially and vertically understood, decisions can be made about where to lime, what rates are needed and how to apply the lime. Most growers and advisers only consider the 0-10cm soil. Lime rates are rarely estimated based on treating acidity at all soil depths — 0-10cm, 10-20cm and 20-30 cm, which is why subsoil acidity develops.

Lime rates are determined by knowledge of the pH buffering capacity, which is chiefly influenced by the amount of organic carbon and then clay content. Below is a commonly used method for lime rate estimation which is available through Soil acidity monitoring tools (DPI, 2005) and appears in OptLime and Soil Amelioration calculators from WA. It calculates the amount of lime required to reach a target pH but to maintain it.

The target soil pH for the 0-10cm is 5.5 to 6.0, if aiming to achieve lime movement or growing acid sensitive pulses, and pH 4.8 deeper in the soil to avoid Al toxicity.

Step 1. Pure lime requirement (t/ha) = (Target pH – Current pH) ÷ Conversion factor

Divide the desired pH change by a conversion factor for different soil types:

0.26 for clay,

0.37 for clay loam,

0.47 for sandy clay loam,

0.57 for sandy loam and

0.67 for sand.

Step 2. Adjustment for organic matter (OM) - If the soil OM% is above 2%, then add an extra 0.4t/ha.

Note OM% = organic carbon% x 1.7. Greater than 2% OM content is likely in most pastures or crop pasture rotations.

Note the calculation is for pure lime which has 100% NV and so lime rates will require adjustment depending on the NV% of the lime to be used.

Also, these calculations need repeating for each 10cm soil layer as shown in the example in Table 6. The 10-20cm and the 20-30cm layer will be unlikely to contain OM content below 2% so step 2 can be ignored.

Lime calculation rates for amelioration of acidity are estimates only and so it is important to monitor soil pH change after three or five years so that rates can be adjusted.

Too much lime?

Topdressing large amounts of lime without incorporation may cause micronutrient deficiencies (e.g. copper, zinc, boron and manganese) if these elements are already marginal, especially on poorly buffered sands. High rates of pure lime (NV 100%) are thought to be in excess of 2t/ha for a sand, 3t/ha for a sandy loam or 4t/ha for a loam or clay loam soil. While these deficiencies can be overcome by the application of appropriate granular fertiliser or foliar sprays, if high rates of lime are required, it is best to split applications over a period of three or four years or incorporate the lime with a tine or disc implement.

Choosing a lime

Choosing a lime should be based on the most cost-effective product. Transport costs can be high so often, the cheapest lime is from the pits located closest to the farm. The price of lime tends to reflect the level of processing. However, you need to know how effective the product is at neutralising acidity.

Table 6. The calculations of approximate lime rate required at the Rokewood sub soil acidity trial.

Depth	Average Soil pH	Target	pH changed required	Soil type	Organic C%	Lime requirement (t/ha)
0-10cm	5.11	5.8	0.7	Sandy loam	0.8	1.2
10-20cm	4.10	4.8	0.7	Sandy loam	0.5	1.2
20-30cm	4.71	4.8	0.1	Clay	0.6	0.3
Total pure lime requirement for soil pH recovery						**2.8**

The typical costs of lime spread are about $40 to $50/t depending upon the quality and transport distance.

- Purchase cost $18 to $30/t for Victorian Ag lime.
- Cartage rate 10 cents/km.
- Spreading $8/t.
- Variable rate spreading, extra $2/ha.

Most agricultural limestones are calcium carbonate and can be described as hard rock limes or soft rock limes. Explosives are needed to extract hard rock limes and need to be processed very finely so they react quickly in the soil, which add to the expense. Most of the limes in Victoria are soft rock excavated, crushed and then particles screened to less than 2mm. One of the best quality limes is from near Goulburn, NSW, which is 99% purity and ball milled so that 70% of particles are less than 0.01mm, costing approx. $39/t. However, if it must be transported 600km, it is not cost effective.

Purity, particle size and solubility

The main factors determining lime quality include purity (i.e. neutralising value NV) particle size distribution and solubility (Scott et al. 1992). Pure calcium carbonate (or pure limestone) has an NV of 100%. The higher the NV, the purer the product. Lime products sold in Victoria commonly have an NV of 80 to 90%. Some products can exceed 100% if containing appreciable amounts of magnesium carbonate and/or burnt lime.

The finer a lime product is, the greater the surface area for the neutralising chemical reactions to occur. Therefore, a finer lime will reduce soil acidity more quickly than a coarser lime. The rate of lime dissolution is also affected by its solubility. Lime is regarded as being relatively insoluble, although this varies amongst different types. NSW DPI compared the pH change of different lime types with the same average particle sizes and found that soft limes created 20% greater pH change compared to a hard calcitic lime over a period of six to 12 months due to differences in solubility (Conyers et al. 1995). Dolomites contain less soluble magnesium carbonate, and created 15% less pH change compared to hard limes. There are no standard tests for lime solubility.

Effective Neutralising Value (ENV)

ENV is a calculation that allows for comparison of different liming materials by accounting for both the neutralising value of the lime and particle size. An ENV of a lime product is calculated based on the sum of its percentage of particle sizes (fine <0.3mm, medium >0.3mm to 0.85mm and coarse >0.85mm) which are discounted according to their potential reactiveness. Particle sizes of 5mm are thought to take about 20 years to dissolve. This indicated a flaw in the ENV quality assessment as there is a vast quality difference in limes with particle sizes 1mm to 2mm and those with greater than 5mm which is currently not accounted for.

The Victorian Lime Producers Association (VLPA) members annually report NV and particle sizes greater than 1mm, which is made available on their website. A good quality lime from Victoria will have close to 50% of its particle sizes less than 0.3mm and very little above 0.85mm and with good screening practices should contain no more than 5% above 1mm. Having up to date information on particle size distribution is important, even for soft rock limes. Independent tests are available from laboratories such as Agrifood Technology, CSBP or Apal. There are several calculators available to help compare limes based on their NV% or ENV, such as Lime Cheque, available off the Ag Excellence Alliance website (https://agex.org.au/project/soil-acidity/).

Pelleted limes and liquid limes

There has been interest in the use of pellets containing super fine lime (20 to 40 µm) for ameliorating soil acidity, however, the costs of these products are about $260/t in bulk. Researchers in WA have reported that the lime pellets used in their trials acted like a good quality lime, and that it did not move horizontally in soils as was hoped, only vertically. There is interest in using these products in air seeders to place prilled lime into acidic layers at 10-20cm at rates of 500kg/ha for two or three years and possibly in different orientations to maximise soil coverage.

Liquid lime sources are generally micro-fine calcium carbonate in suspension. In trials conducted by the Woady Yaloak catchment group, recommended rates of liquid limes were shown to be ineffective at creating pH change in comparison to standard rates of agricultural limes. Even though liquid limes have high NV the recommended rates are insufficient to correct soil acidification rates. It has been suggested that a liquid lime solution might wash through the soil macro-pores and may correct acidity at depth, but this has not been demonstrated in field trials.

Table 7. Costs of soil acidity at the Bellarine trial site where soil pH was 4.2 (0-10cm), 4.4 (10-20cm) and 4.9 (20-30cm) and lime applied at 3t/ha.					
Year	Crop	Average yield of limed plots (t/ha)	Yield reduction compared to lime 3t/ha	$Price/t of grain	$ Calculated cost of acidity
2014	Barley	3.0	1.0	$278	$275
2015	Canola	1.7	0.4	$531	$228
2016	Wheat	7.3	1.2	$200	$230
Total costs of acidity for 3 years					$734/ha

Profitability of liming

The profitability of liming is generally straightforward because many of the crops are acid sensitive, such as barley and pulses, and liming costs are often recouped within short time frames (see Li et al. 2010). Certainly, at one SFS trial, acidity cost was calculated to be $734/ha over the three-year period and liming (approx. $150/ha spread) paid for itself after the first year (see Table 7). This trial provides a good example of how liming can avoid yield losses from acidification.

Timing of lime application

Lime can be applied any time. Lime is normally applied in summer or early autumn to fit the farming schedule. Spring liming of pastures is beneficial to a following cropping rotation as there is time for the lime to start neutralising acidity, particularly if there is summer rainfall. The 'Liming acidic soils for legumes' project advises that applying liming preferably two years before a sensitive crop such as pulses.

The factors which affect the time of liming are:

- Paddock trafficability.
- The need to apply lime six weeks prior to sowing to avoid inducing any micronutrient issues.
- Accessing lime, and ability to back-load lime after grain delivery to reduce transport costs.
- Wind erosion risks where the fine component of lime is lost from bare surfaces.

Growers in high rainfall zones often look to spread lime prior to burning stubble. Lime effectiveness is not adversely affected by burning. Agricultural limes are treated at 900°C in kilns to create burnt lime which makes it faster acting, for use in the building and horticultural industries. A hot stubble burn might reach 500°C at most. However, agronomists raise some concerns with spreading lime before burning stubble which need to be considered. These include:

- Spreading lime over heavy stubble may not give even coverage compared to spreading on bare paddocks. This may be a visual perception issue as the lime cannot be as easily seen amongst the stubble or could be valid if the spreading height was too low.
- Stubble does not seem to burn as well if lime is spread. This may be a factor if the lime was moist and covered stubble.

Applying lime into paddocks with some stubble cover or prior to burning is likely to reduce losses from wind erosion. Timing application to coincide with rainfall or heavy dews can help wash the lime off any stubble and start to dissolve the lime.

Conclusion

Acidification occurs in all farming systems where plant or animal products are removed, and liming will be necessary to neutralise it or else significant losses in yields will occur

Acidification is not just confined to the top 10cm of soil and the emerging issue of acidity at 10-20cm indicates that our liming practices (rates, frequencies and lack of incorporation) have been insufficient at addressing it. Therefore attention to the subsurface and subsoil through monitoring, the maintenance of good soil pH and generally incorporation of lime in low rainfall (<500 mm) or heavy clay soils is vital for protecting the soil asset.

Useful resources

http://www.sfs.org.au/SoilAcidityLimeResponse

https://agex.org.au/project/soil-acidity/

https://grdc.com.au/legumes-in-acidic-soils

https://www.agric.wa.gov.au/soil-acidity/soil-acidity-frequently-asked-questions-faqs

http://vlpa.asn.au/w/product-specification/

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Sowing into stubble — impacts of row spacing, yellow leaf spot and stubble height on crop development

Nick Poole, Tracey Wylie and Michael Straight.

FAR Australia.

GRDC project codes: RP100007, RP100009

Keywords

- no-till, stubble height, row spacing, yellow leaf spot, dry matter, phenology.

Take home messages

- Research results from the GRDC Stubbles Initiative and the preceding GRDC Water Use Efficiency (WUE) project have discovered several management challenges in a no-till environment where stubble loads often exceed 8t/ha.
- Triazole fungicides give relatively poor control (25%-50%) of yellow leaf spot, *Pyrenophora tritici-repentis*, in a wheat-on-wheat scenario, whereas variety choice and cultural practice can give up to 90% disease control.
- In comparison to the row spacing research in the GRDC WUE project (sown in late May/June), where yield decreased as row spacing increased, wheat sown in mid-April showed no negative effects of wider row spacing.
- Increasing row spacing in mid-April sown wheat had little effect on crop structure but did in some cases decrease dry matter (DM) production.
- Long stubble can have a negative effect on tiller number, DM and light interception of wheat, and in some cases cause a decrease in final grain yield.
- An increase of up to 50% photosynthetically active radiation (PAR) has been recorded in the winter months when stubble height was decreased from 42cm to 12cm.

Background

It is widely accepted that as rainfall increases across agroecological regions, the amount of full stubble retention practised in the farming system decreases. This is often because growers perceive that growing high yielding crops in stubble retained systems is more difficult than growing them in paddocks where the previous crop residue has been removed (mainly through burning). It is also true to say that much agronomic knowledge has been gleaned from trials that have not been carried out under modern no-till stubble retained (NTSR) systems, leaving a potential knowledge gap. This GRDC supported, locally specific research sought to maintain profitability of NTSR systems in medium-high rainfall environments. The project also built on findings from the previous GRDC supported WUE project.

Research

The research component of the GRDC supported project 'Maintaining profitable farming systems with retained stubble in the Riverine Plains region' was comprised of a series of large and small plot trials. The first of these trials was established during 2014.

Using large scale trials (focus farms), the research team evaluated the impact of a single-year, one-off change in stubble management. The results of these trials helped to determine if periodic active management of stubble in an NTSR system increases the sustainability and profitability of the system across the rotation. As different stubble management approaches are likely to perform better under different seasonal conditions, the four years of trials (2014-2017) have provided information on crop performance under a range of seasonal climatic conditions.

The focus farm trials were located at Henty and Coreen, New South Wales (NSW), and Yarrawonga and Dookie, Victoria. The rotation position was maintained by moving the trial sites around the farm to maintain either a wheat-on-wheat or wheat on canola stubble position.

Yellow leaf spot *(Pyrenophora tritici-repentis)*

Yellow leaf spot (YLS), caused by the fungal pathogen *Pyrenophora tritici-repentis* has been the principal disease, causing green leaf loss, with the most severe infection noted during 2016. Six research trials run over four years using susceptible and moderately susceptible wheat varieties, investigated this disease in a wheat-on-wheat situation.

The influence of fungicide treatment against this disease was consistent over the four years of research. Using either Prosaro® (210 g ai/L tebuconazole + 210 g ai/l prothioconazole) or Tilt® (250 g ai/L propiconazole) applied at the end of tillering/early stem elongation (GS23-33)#, disease control rarely exceeded 50% and ranged from 25 to 50% (Figure 1). This level of disease control is poor, relative to traditional control levels observed with fungicides against other diseases such as stripe rust. Despite this, there were small, but consistent, yield benefits across the four years (maximum response to fungicide during 2013 was 0.25t/ha, during 2014 was 0.21t/ha, during 2015 was 0.4t/ha and during 2016 was 0.17t/ha). These small yield

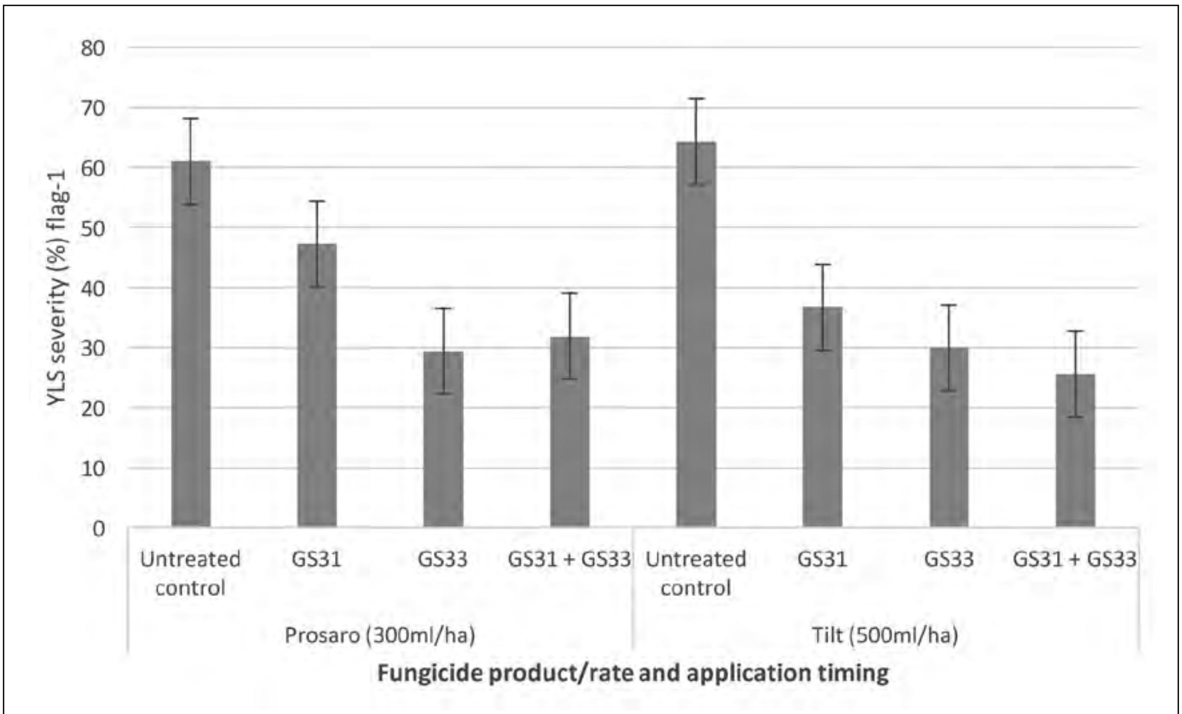

Figure 1. Interaction between fungicide application timing and fungicide product on YLS severity (flag-1), assessed at start of flowering (GS61), 14 October 2016

**error bars are a measure of LSD*

effects were seen in response to two applications of fungicide and later spray timings during stem elongation, or third node (GS33).

#application earlier than label recommendation of 70% flag leaf emergence and early flowering

Foliar fungicides applied at early stem elongation (GS31) during 2014-2016 gave poor disease control and were rarely, if ever, economic. Across all four years, even though the rotation position and variety have favoured the disease, the yields of the trials was still in the 2-4t/ha range. The early infection of YLS up to GS30 (start of stem elongation) was better controlled with stubble management practices, such as burning, rather than with foliar fungicides. It was also noticeable that in the large block stubble management trials, a switch to the more resistant variety Corack⁽ᵗʰ⁾ gave good control of YLS, such that differences in YLS control as a result of stubble management treatment was not observed.

Row spacing

Early sown row spacing trials (mid-April) at Yarrawonga ran for three years in different paddocks in the same rotation position after canola. In both 2014 and 2015, the narrow row spaced crops produced more DM, but showed no differences in grain yields (Figure 2). With higher rainfall and higher yields overall in 2016, wider row spacing (37.5cm) produced lower yields (0.34-0.43t/ha less) than the 22.5cm and 30cm row spacing.

In previous work carried out by Riverine Plains Inc. and the Foundation for Arable Research (FAR) Australia, the influence of row spacing on grain yields was shown to be affected by the overall yield potential of the season. This research showed comparable yields across row spacing under lower yielding scenarios and an advantage to narrower rows under higher yields. At a yield potential of 3.0-6.0t/ha, there was no difference in yield between 22.5cm and 30cm row spacing when wheat crops were sown in mid-April. Wheat crops sown on a 37.5cm row spacing at the same time show no yield disadvantage, provided grain yields are less than 3.5t/ha. In a dryer warmer finish to the season, a higher harvest index in the wider rows helped to compensate any yield penalty as more grain is produced from the final DM.

Results in early sown crops differ from the results generated in later sown crops (late May/early June) studied as part of the WUE project, where the 22.5cm spacing produced more DM than the 30cm spacing, which led to a higher yield. With mid-April sowing, the results demonstrated that there was no difference in yield between row spacing of 22.5cm or 30cm.

Stubble height

During the four seasons (2014–2017), one of the most consistent effects of the stubble management treatments in NTSR systems was the influence of stubble length on DM production. There was a

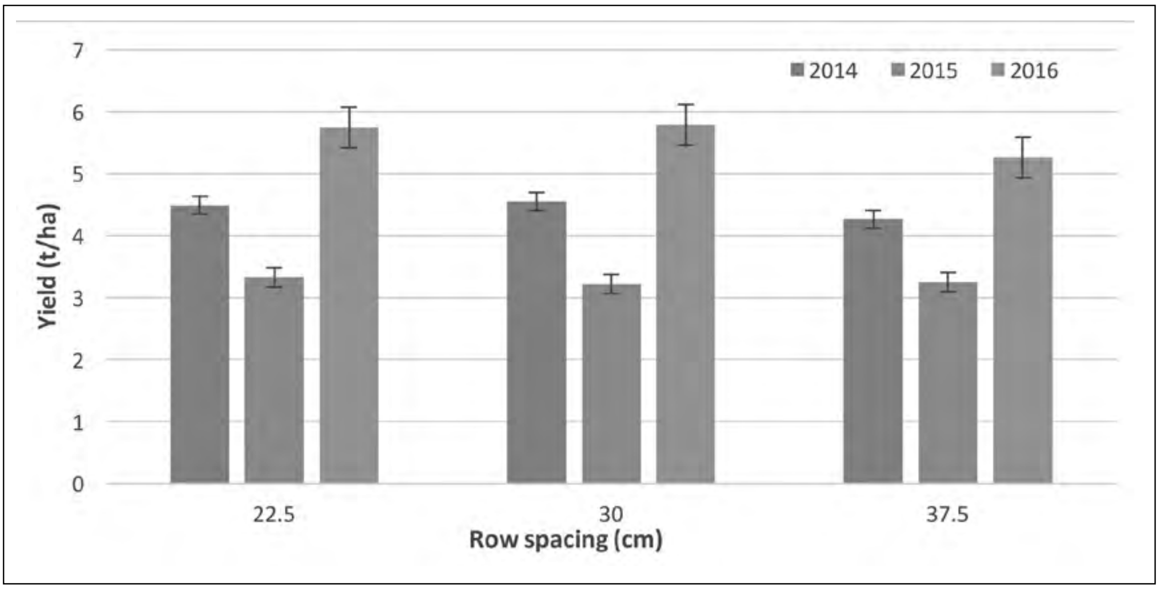

Figure 2. Influence of row spacing on grain yield in early sown wheat following canola (average of four varieties) in 2014, 2015 and 2016 (Yarrawonga, Victoria).

**error bars are a measure of LSD*

consistent reduction in tillering and DM production in longer stubble, although the effect on final grain yield was inconsistent. In 2014 at Dookie, a reduction in stubble height of 25cm significantly increased grain yield by 0.7t/ha, the largest yield effect observed in the stubble management project in the Riverine Plains. In part, this appears to be linked with nitrogen (N) availability and temperature, but these factors did not completely explain the increase in yield. In 2016 for the first time, the research team looked at differences in light interception by the growing crop canopy — more accurately described as photosynthetically active radiation (PAR). During the winter month of June 2017, the influence of the different stubble management treatments on PAR was assessed.

At Yarrawonga, results revealed reductions in PAR of approx. 50% in long stubble NTSR compared with short stubble NTSR when measurements were made at 3pm in the afternoon. However, there was no difference in PAR when treatments were compared at 12 midday (Figure 3). Although the PAR will be influenced by the sun's zenith (high point

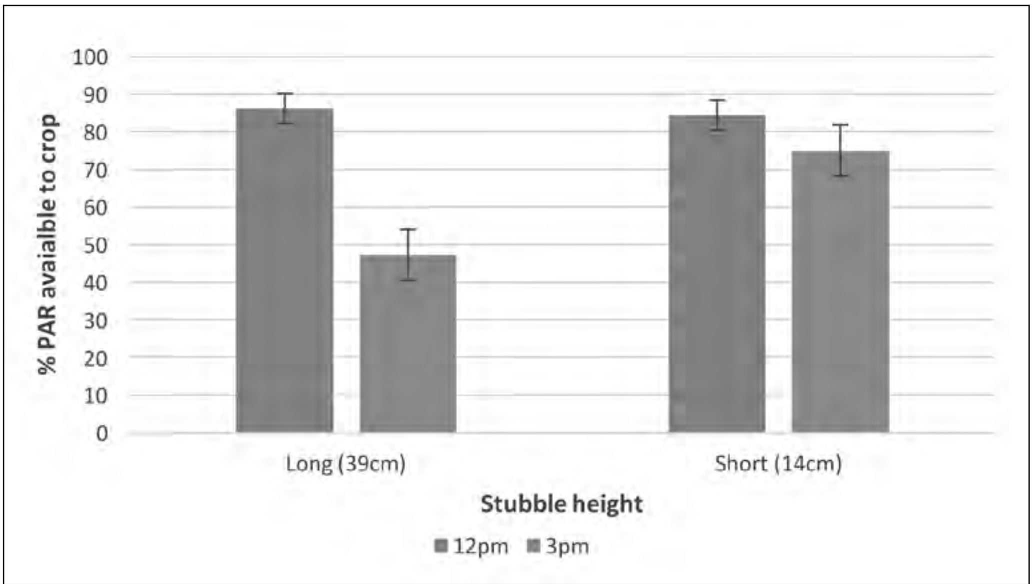

Figure 3. Influence of stubble treatment on availability of PAR at 12pm on 20 June 2017 (GS22) and 3pm on 28 June 2016 (GS23) at the Yarrawonga trial site.
**error bars are a measure of LSD*

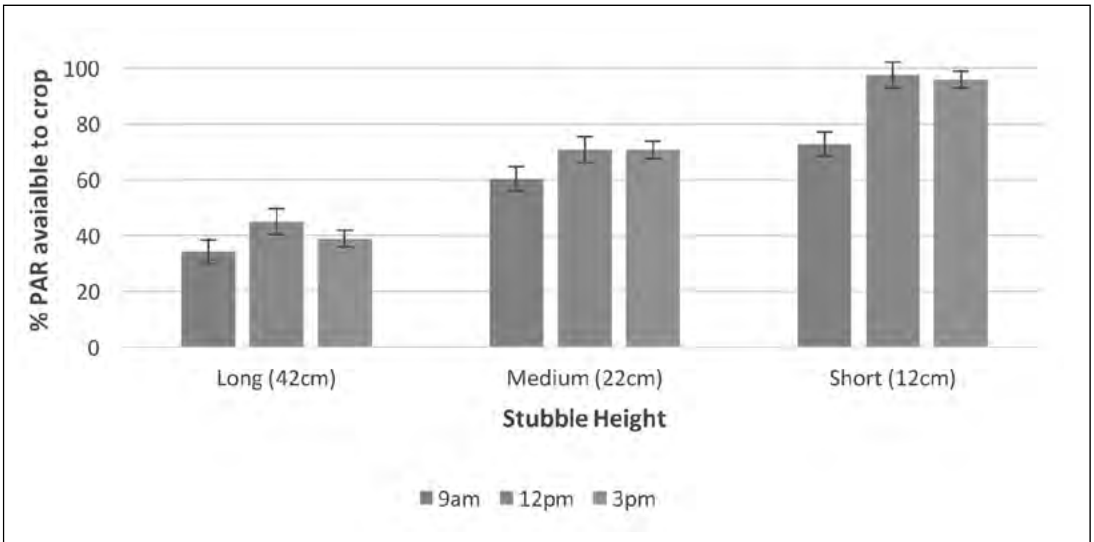

Figure 4. Influence of stubble height on availability of PAR at 9am on 6 June 2017, 12pm on 13 June 2017 and 3pm on 19 June 2017 at Rennie, NSW.
**error bars are a measure of LSD*

in the sky) and row direction, the results clearly show that the ability of the crop to capture available sunlight is a key difference between crops sown into long or short stubble, and could be the major factor why there was reduced tillering and a lag in DM production associated with long stubble.

A trial at Rennie (NSW) was established in 2017 to understand the interactions of stubble height with temperature and PAR. The assessments of available PAR indicated that stubble height had a very significant influence on the % light intercepted by the crop. Crop in the long stubble (42cm) received more than half the PAR compared to short stubble (12cm) (Figure 4). The orientation of stubble rows was east-west and the differences were similar irrespective of whether comparisons were made at 9am, 12 noon or 3pm.

Conclusion

In conclusion, the GRDC Stubbles Initiative research trials in the Riverine Plains region have enabled growers to better understand and mitigate the management issues around crop development in a no-till system. Effects of disease, in this case YLS, in tight wheat no-till rotations can be mitigated by an integrated approach using cultural methods, by removing/reducing stubble, selecting resistant varieties and applying fungicide when necessary at the start of stem elongation. When planting wheat in mid-April, row spacing in the 22.5-37.5cm range has less effect on final grain yield. In a no-till system, wider rows allow for better trash flow in high stubble loads at sowing time. Stubble height of the previous crop has a profound effect on crop development, especially early in the growth stage. Longer stubble (>30cm) reduced tiller numbers and DM over four years of research, due to shading and significantly reduced grain yield, in one trial, when compared to short stubble (<15cm).

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The research undertaken as part of the project ‘Maintaining profitable farming systems with retained stubble in the Riverine Plains region’ was made possible by the significant contributions of growers through both trial co-operation and the support of the GRDC. FAR Australia would like to thank them for their continued support.

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Insects – tools for forecasting risks to enable proactive management

James Maino[1,2], Garry McDonald[1,2] and Paul Umina[1,2].

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GRDC project codes: UM00057, 9176535, DAQ00201, 9176191

Keywords

- prediction, resistance, economic thresholds, Russian wheat aphid, pest development.

Take home messages

- Forecasting tools for crop pests and beneficials increase confidence in when intervention is or is not needed.
- Risk factors associated with the continued spread of redlegged earth mite (RLEM) resistance (besides high pesticide usage) include high winter rainfall, low summer rainfall, low temperature variability (e.g. coastal) and a longer growing season. Growers and advisers can access a resistance testing service at no charge.
- Other grains pests predicted to be at high risk of resistance evolution include oat aphid, Lucerne flea, cabbage aphid and cowpea aphid. Special attention should be paid to these pests in the field, and in particular, their response to chemical applications.
- Preliminary data collection and forecasting of Russian wheat aphid (RWA) damage potential highlight the importance of minimising early season colonisation events, while later stage colonisation is associated with lower risk of yield loss. Forecasting will be crucial for estimating impacts under novel conditions.
- Increased certainty about pest risks (and mitigating factors e.g. beneficial insect presence) can be achieved through better forecasting and monitoring methods and will be vital in transitioning to more proactive, sustainable and cost-effective pest management.

Background

Better pest management decisions are limited by the industry's ability to monitor and forecast pest risk. However, pest forecasting tools are increasingly available to help growers plan their pest monitoring and management programs. For example, growers often use the simple *Etiella* day-degree model to help predict the timing of possible emergence of adult *Etiella* moths near lentils, and time their management accordingly. This ultimately increases the longevity of control options and creates enduring farm profitability.

Pest control practices can often be quite 'reactive' because adverse outcomes, such as resistance, are difficult to predict. Forecasting tools, through their improved ability to predict risks, will increase certainty about pest outcomes and help to prioritise monitoring, which together lead to more proactive management. This ultimately results in more effective and sustainable pest management strategies.

While there has been strong progress in recent years, many forecasting tools are still in development. This paper provides an overview of some recently completed, ongoing and future research on forecasting tools. Practical management advice is provided wherever possible, but another aim is to increase awareness of the opportunities for improving pest management in this rapidly developing field.

Completed research

Predicting resistance distributions: Where is resistance in redlegged earth mites most likely to appear?

While resistance in RLEM (*Halotydeus destructor*) has been detected in Western Australia (WA) as far back as 2006 (Umina 2007), resistance has only recently emerged in eastern Australia (Maino et al. 2018a). The recent appearance of resistance in RLEM in near-coastal regions in South Australia (SA) was predicted in 2016 using a model that identified the biological and cultural processes driving resistance evolution in WA and from this, inferred areas of high risk in other parts of Australia (Maino et al. 2018b). Risk factors included particular climatic conditions, in addition to more widely acknowledged risk associated with high pesticide usage. This was presented at the Australian Annual Resistance Meeting (2016) as a map of resistance risks in Australia (Figure 1) when resistance had not yet been detected in eastern Australia. This forecasting tool has helped to identify regions or properties where there is a higher risk of resistance evolution, and based on this, focused resistance surveillance activities on these areas. Genetic studies have since revealed the range of resistance is expanding through both the spread of existing resistant populations, as well as independent evolution of new resistant populations, highlighting the importance of farm biosecurity and minimising selection pressure by reducing insecticide usage.

Recommended action includes additional attention when monitoring responses of RLEM populations to pesticides in regions with high winter rainfall, low summer rainfall and longer growing season, and where there has been historically high pesticide usage (Maino et al. 2018b). In such areas, the use of pesticides when RLEM populations are present should be carefully considered, and if applied, the efficacy should be routinely monitored. Populations that are suspected to be resistant should be reported to **cesar** who can provide resistance testing at no cost to growers through GRDC support. The earlier resistance is detected, the more options there are for management.

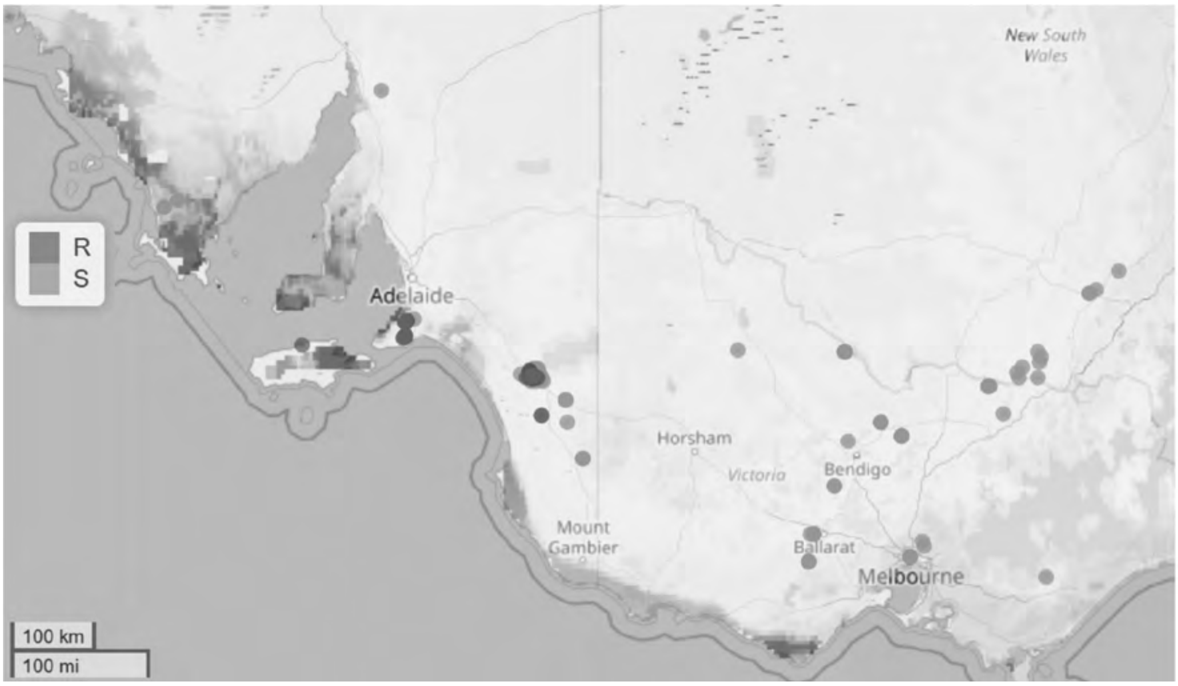

Figure 1. Predicted pyrethroid resistance risk in RLEM (higher risk indicated by darker shading) with observed resistance (dark circles) and susceptible sites (light circles) overlaid. The prediction was generated in 2016 based on patterns of resistance observed in WA (Maino et al. 2018b). Since then, resistance has emerged in eastern Australia near locations predicted to be high risk. Spread occurs through dispersal of existing resistant populations, as well as independent evolution of new resistant populations.

Predicting resistance in pests: Which grains pests are at risk of evolving resistance in the future?

There is a need to be more proactive about which pests may acquire a novel resistance. In a recent project, the resistance risk of 90 commonly encountered grains pests was assessed so the industry could prioritise monitoring and management.

A model was built that combined international data on the evolutionary resistance potential of each pest and the local selection pressure (insecticide use intensity) to which the pest is typically exposed (targeted and off-target pesticide applications). From this, a weighted score was assigned to each pest. Pests were then ranked from highest to lowest by their capacity to develop resistance in an Australian grains system. The analysis made some necessary simplifying assumptions. For example, selection pressure outside of grains was unable to be considered (such as chemical usage in horticulture), pesticide exposure was assumed to correlate with proxies such as the relative incidence of PestFacts reports for each pest, and native pests that have broad native host ranges were assumed most unlikely to have the same intensity of pesticide exposure as cosmopolitan pests with restricted agronomic host ranges. Despite these assumptions, the tool successfully ranked highly all the pests with known resistance (Table 1), even though information on actual resistance was not used to assign risk scores. These pests include green peach aphid (GPA), RLEM, cotton bollworm and diamondback moth. This validates the approach taken while also highlighting the future risk of further resistance evolution (e.g. to new chemical groups) in these notorious pests. The predictions, and the basic model tenets underpinning them, also serve as an important reminder that resistance is an incredibly dynamic evolutionary process in invertebrates.

From within the top nine ranked pests (Table 1), those not known to be resistant that are at greatest risk of **acquiring** resistance are oat aphid, Lucerne flea, cabbage aphid, cowpea aphid and the European earwig. Oat aphid ranks highly because of the large areas of wheat (and other crops) that can receive broad-spectrum insecticide applications. Cowpea aphid (pulses) and cabbage aphid (canola) are also strong resistance candidates because they can be unintentionally sprayed when crops are sprayed for other pests such as native budworm, Etiella and diamondback moth. Lucerne flea and earwigs, which are relatively poor dispersers, are invariably present in or under most crops, sometimes in low numbers, but would regularly be exposed to insecticides when a crop is sprayed for other pests.

Chemical controls of these pests should be carefully considered, and if applied, special attention should be paid to their responses to pesticides.

Predicting the need for and timing of monitoring and spray interventions

Understanding pest lifecycles is often a crucial component of management. For example, if native budworm moths are detected, how long would it take for eggs to hatch into larvae and be detected in sweep nets before economic damage commences? Pest development depends strongly on temperature in very predictable ways. If the location and insect stage are known, the developmental trajectory of

Table 1. The top nine grains pests selected for their evolutionary potential to acquire resistance from 90 grains pests considered. These pests are assessed against four criteria.

Common name	Scientific name	Dominant crop stage	Evolutionary potential rank§	Targeted pesticide rank§	Target and off-target pesticide rank§	Mean rank
Green peach aphid*	*Myzus persicae*	Establishment	1	5	3	3.0
Oat aphid	*Rhopalosiphum padi*	Vegetative	7	7	1	5.0
Redlegged earth mite*	*Halotydeus destructor*	Establishment	17	1	2	6.7
Diamondback moth*	*Plutella xylostella*	Flower/seed	4	4	13	7.0
Lucerne flea	*Sminthurus viridis*	Establishment	14	2	7	7.7
Cabbage aphid	*Brevicoryne brassicae*	Vegetative	8	9	8	8.3
Cowpea aphid	*Aphis craccivora*	Vegetative	2	8	16	8.7
Cotton bollworm*	*Helicoverpa armigera*	Repro	3	18	9	10.0
European earwig	*Forficulina auricularia*	Establishment	19	12	4	11.7

§ Numbers provide the pest ranking for each of the three criteria.

**These pests have already acquired resistance to some modes of action (MoAs).*

the pest can be forecast with high precision, which reduces uncertainty in management decisions.
We have developed the DARABUG2 program, as an integrated and interactive platform for different pest phenology models, to provide a convenient means of predicting development times for a range of different insect pests. It illustrates how complex biological knowledge on species development can be presented in a simple and dynamic way that is context specific. While still only available as a research and extension tool for grains entomologists in the National Pest Information Service, similar tools could readily be made available to other practitioners given demand. Currently, this tool can be accessed via proxy through contacting your local state agriculture department or cesar.

Ongoing research

Predicting Russian wheat aphid impact in Australian grains - yield loss and management response

First detected in Australia in 2016, RWA (Diuraphis noxia) is a new pest for grain growers and so there is a need to understand expected yield impacts and best management practices in an Australian context. Part of an ongoing GRDC research investment addresses these gaps through national field trials, surveillance, and forecasting approaches for colonisation risk and subsequent yield impact potential. Forecasting tools are being used to draw together and synthesise data collected over 2018 and 2019, in different locations and infestation scenarios. This tool will allow an estimation of

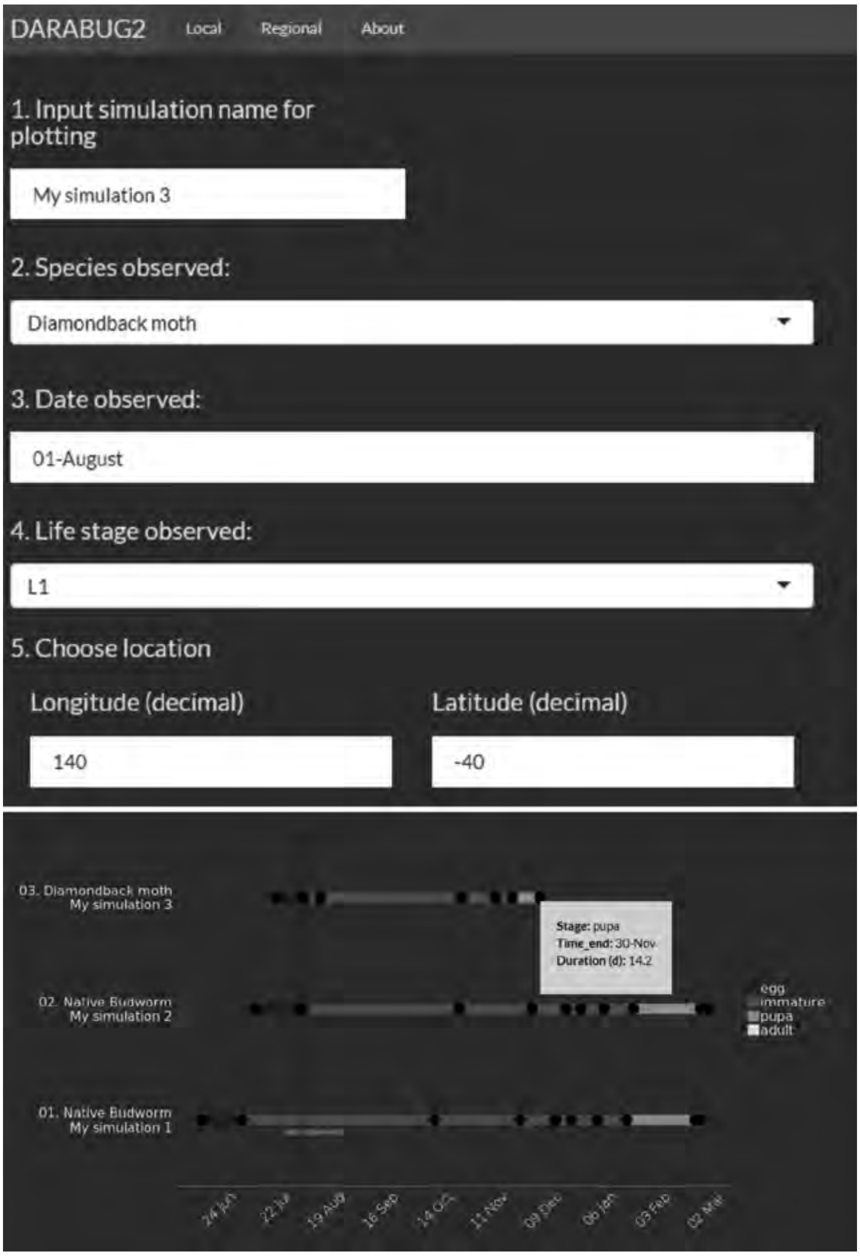

Figure 2. A screenshot of DARABUG2 – an interactive pest development forecasting tool used by entomologists in the National Pest information Service that illustrates how complex biological knowledge on species development can be presented in a simple and dynamic way that is context specific.

colonisation risk and impacts across other cropping systems not studied, such as different years, crop varieties, regions and infestation scenarios. This work is ongoing, but the below example aims to illustrate the use of predictive modelling to extend data collected from field trials into novel conditions not studied in field trials.

As RWA is a cosmopolitan pest, existing international research on RWA is leveraged wherever possible to extend the reach of the model. For example, a study conducted by Ma and Bechinski (2009) on RWA feeding on barley revealed that population growth and thus damage potential of RWA is strongly dependent on both environmental temperature and on crop growth stage. Earlier crop growth stages almost always favoured higher RWA population growth potential, while higher temperatures up to an optimum also favoured higher growth rates (Figure 3).

This knowledge was incorporated into a model of RWA growth. To forecast crop growth, the existing Australian Agricultural Production Systems sIMulator (APSIM) model on cereal growth (Keating et al. 2003) was used by linking it to the RWA population growth model through the assumption that feeding damage was related to the number of RWA on the plant with RWA population growth as shown in Figure 3.

At the time of writing, field trials and green bridge surveillance activities for the first year are still underway and will not be reported. Instead, conditions from one field site (Birchip), for one wheat variety (Scepter⁽ᵖ⁾) for which data has already been collected will be considered. It is important to not over generalise these findings. Only five treatment scenarios were considered for model validation, but the numbers of scenarios can be vastly expanded using a simulation approach. In the forecasting exercise here, 378 treatment scenarios are considered to better quantify the yield impact of RWA colonisation time (when they arrive on the crop) and management time (how long after RWA establishment management occurs). The model assumes that RWA populations do not cause damage after the time of first control (e.g. through follow up management). The yield impacts estimated across these scenarios are summarised in Figure 4.

Results highlight the importance of minimising the risk of early colonisation of RWA at early growth stages to avoid large yield losses. However, even with early colonisation, losses could be avoided through prompt control, with the requirement for prompt control diminishing throughout the season until control eventually offers minimum yield benefits. Thus, monitoring should be more frequent during crop establishment. RWA populations

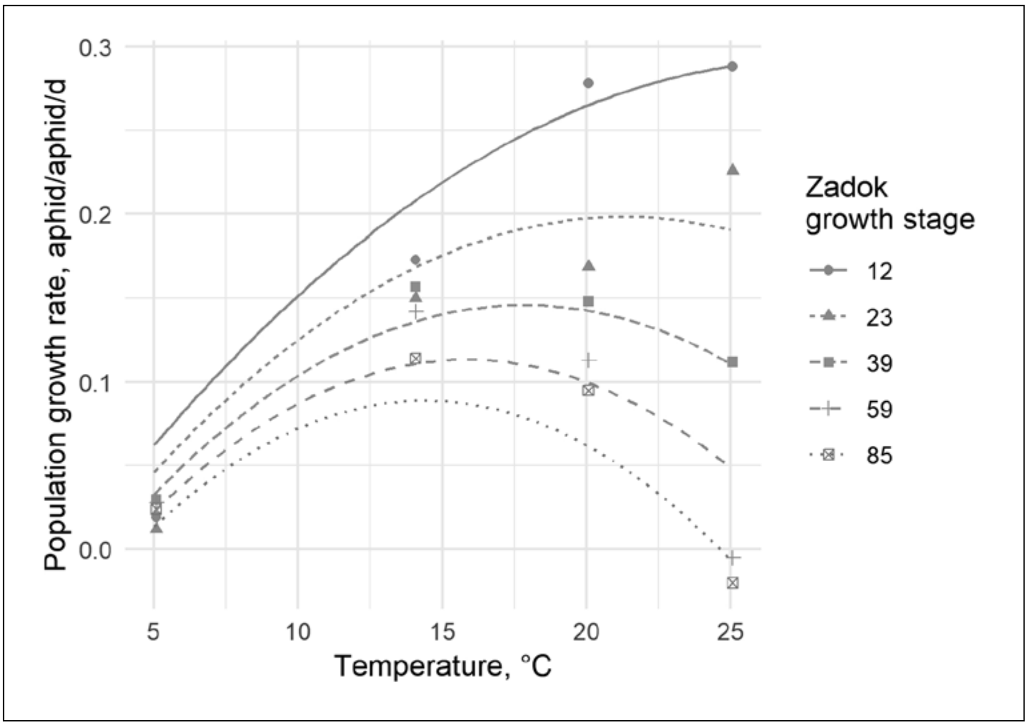

Figure 3. Earlier crop growth stages favour higher RWA growth potential. A model was developed to explain yield loss observed in current field trials using experimental data collected by Ma et al. (2009) on RWA population growth rate and its relationship with plant growth stage at establishment and rearing temperature.

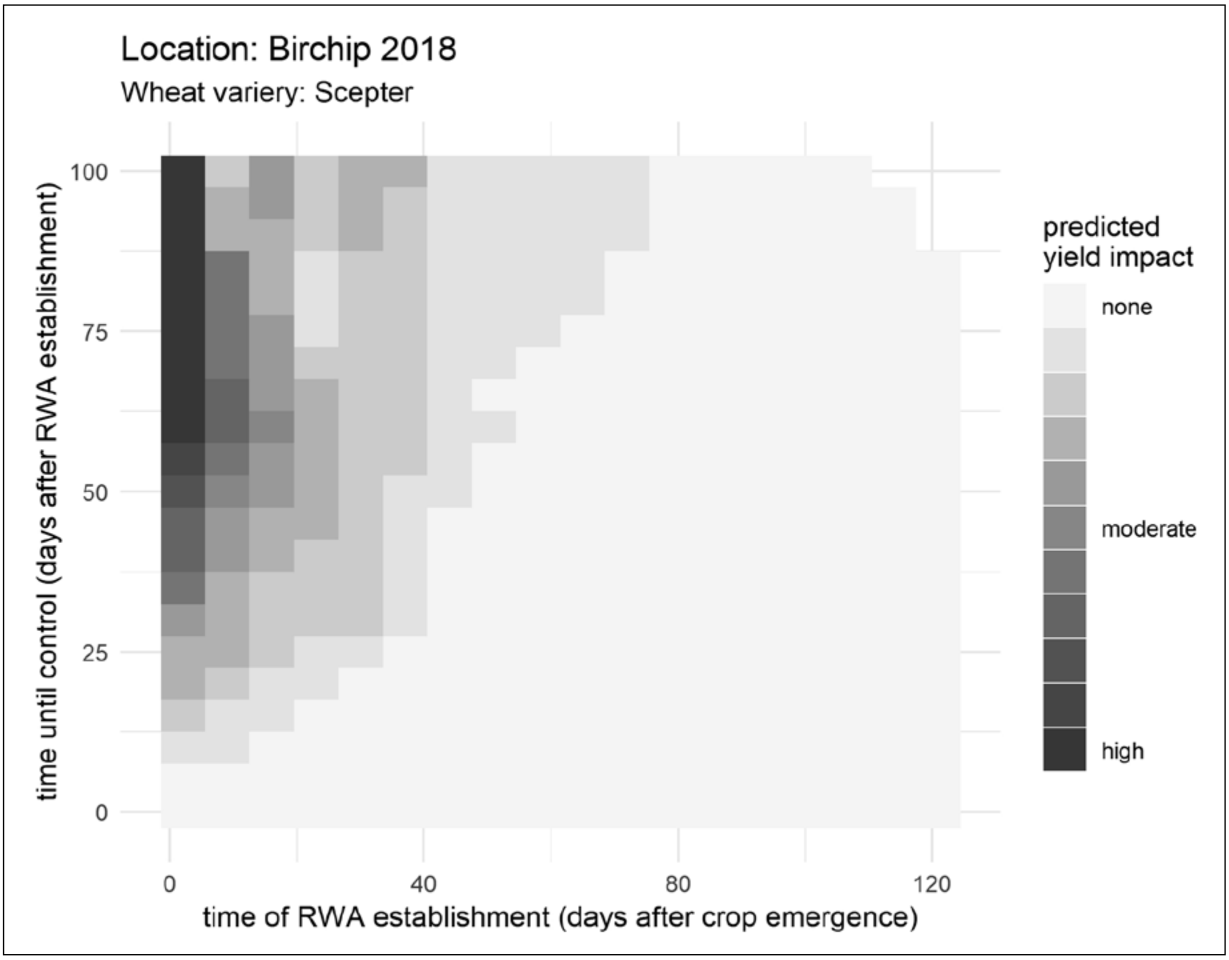

Figure 4. The estimated relationship between yield impact and colonisation time of RWA feeding on wheat (Scepter[b]) and intervention time for 2018 Birchip field trial conditions based on a preliminary model for forecasting RWA damage potential under different climates, management, crop and pest conditions.

colonising the crop at later growth stages are unlikely to economically impact yield.

Future research

The completed and ongoing research presented highlights how pest forecasting is currently helping to reduce uncertainty about pest risks to prioritise monitoring and management. These examples have also highlighted that management recommendations will need to vary depending on the specific growing context (e.g. climatic conditions, region, stage of crop, stage of pest).

While 'rules of thumb' management principles are frequently useful, they are typically fixed across varied contexts or seasons (such as static economic thresholds). Management advice needs to remain simple and comprehensible, but dynamic so that it can respond to different situations (e.g. dynamic economic thresholds that depend on crop stage). Utilising the increasing functionality, affordability and availability of digital systems will also help.

Future opportunity - incorporating beneficial insects into economic thresholds

More sustainable pest management practices require reduced reliance on chemical control and greater utilisation of biological control. However, a large knowledge gap impeding this transition is the uncertainty surrounding required levels of beneficial predators or parasites to mitigate pest damage. One solution to this problem is to link known population growth dynamics of beneficial insects with pest population dynamics (just as pest dynamics were linked to crop dynamics in the RWA example provided above). From here, an estimate of pest population growth potential could be made that considers the impact of beneficial populations. In an interface similar to DARABUG2, local conditions such as climate region, crop stage, beneficial abundance and pest abundance could be used to drive the model. This would generate an estimate of pest population growth and expected yield loss which would be used to assess the cost-effectiveness of control. Currently available economic thresholds for grains crops do not consider the presence of beneficial insects as mitigating factors. Though often not practical, frequent monitoring can overcome these issues through repeated manual assessments of pest and beneficial populations through time to estimate rates of pest increase.

Useful resources

Etiella degree day model

http://www.pir.sa.gov.au/research/services/reports_and_newsletters/pestfacts_newsletter/archive/pestfacts_newsletter_archive_2016/pestfacts_issue_13_2016/the_etiella_degree-day_model_update

Redlegged earth mite resistance management strategies

https://grdc.com.au/FS-RLEM-Resistance-strategy-West

https://grdc.com.au/FS-RLEM-Resistance-strategy-South

Russian wheat aphid tips and tactics

https://grdc.com.au/TT-RWA

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Relative importance of various factors on the water use efficiency of wheat

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GRDC project code: CSA00055

Keywords

- water use efficiency, yield gap, management, wheat, nitrogen, rotation, variety.

Take home messages

- The water use efficiency (WUE) of wheat in most paddocks in western Victoria was well below physiological potential from 2013-2016, however some leading growers were close to this potential.
- Crop management is critical to reducing the gap between actual and potential yields.
- Nitrogen (N) management is the most important predictor of WUE, followed by crop rotation, variety and sowing date, while weeds and diseases appear to be reasonably well managed.
- Significant variation in other factors affecting WUE remains unexplained.

Background

The large gap between actual and physiological (water-limited) yield potential in the Victorian grains industry has long been recognised, for example, Hamblin & Kyneur (1992). A recent assessment (van Rees et al. 2014) suggests that some growers have effectively bridged this yield gap. Many growers, however, have not bridged the yield gap with wheat achieving an average of only 53% of the 'exploitable yield gap' (Hochman et al. 2012). Anecdotal observations of differences in grain yields and quality in adjacent paddocks, where rainfall is presumed to be comparable, have been attributed to a range of factors including different soils (environment), disease, poor nutrition, late sowing, weed competition (management), better varieties (genetics) or simply 'good luck'. On-going increases in the productivity of the Victorian grains industry will be difficult to achieve until the specific underlying causes and their relative effect on this unrealised potential are determined so that appropriate financially viable management solutions can be implemented by growers.

Information collected through technologies, such as yield mapping and remote sensing, has highlighted that variability of grain yield (and the yield gap) extends to within paddocks as well as between farms, regions and across seasons. Studies involving pre-determined multi-factorial designed 'white peg' experiments have been used to assess the size and cause of yield gaps (Anderson et al. 2010). An alternative approach involves observational studies where the conditions of interest are not controlled. While this latter approach has limitations, especially in the form of requiring a large number of observations to make reliable predictions, they also provide some distinct advantages over multi-factorial designs. These include being more logistically efficient in that they use commercial scale rather than small-scale experimental machinery, better reflecting commercial practices, using inherent spatial variability as an asset and allowing a wide range of soil types, environments and grower management practices to be assessed.

This paper reports on a study which monitored 138 paddocks sown to wheat from 2013 to 2016. Most paddocks (> 80%) were in the Wimmera, but paddocks from the Victorian High Rainfall Zone (HRZ) (Western Districts) and Victorian Mallee were also included. The effects of a range of factors including different crop varieties (**G**enetics), soil physicochemical properties, disease risk, weed infestation and rainfall and temperature (**E**nvironment), and grower management including sowing date, fertiliser applications (**M**anagement) on key crop parameters including dry matter production, grain yield and protein were measured. This large data set was then analysed using a range of 'traditional' statistical procedures, as well as recently developed multivariate and machine learning procedures to identify the relative importance of G x E x M factors on the WUE of wheat in growers' paddocks.

Method

A data set comprising 408 datum points from 138 paddocks was compiled from 2013 to 2016, inclusive. Paddocks were selected based on grower interest in the study, which may have introduced a bias in the data. Previous studies, for example, Nuttall et al. (2003), have showed that soils are extremely spatially variable within paddocks in western Victoria. To maximise the assessment of soil properties in the analysis, data was collected from three different datum points in each paddock. The same paddock management was assumed for all data points in each paddock. Sampling points were selected based on either obvious differences in soil type or where the soil seemed uniform. There was a minimum of 50m distance between sampling points. Rainfall and temperature in each paddock were logged using automated tipping bucket rain gauges and air temperature probes. However, due to regular problems such as missing data points, rainfall data used to assess WUE was based on that used from the SILO Patch Point System.

WUE, rather than grain yield, was used as the key response variate to account for the known, overriding effect of growing season rainfall on grain yield. In contrast to other approaches based purely on rainfall, account was made of water stored in the profile prior to sowing (e.g. following a long fallow) or unused at maturity (due to soil constraints on root growth). This was calculated as:

WUE (kg grain/mm water) =
Grain Yield (kg/ha)/WU (mm water) ...Eq. 1.

Where:

WU (mm water) =
(Wv (mm) at sowing –
Wv (mm) at Maturity) + GSR (mm) ...Eq. 2 and

Wv is volumetric water calculated on a soil profile basis (0-120cm) and adjusted for estimated bulk density and GSR is growing season rainfall (April-November).

Data collection protocols were effectively the same as used for the GRDC National Paddock Survey project (which were based on those originally used in an Agriculture Victoria Research (AVR) project), except that no account was made of grower yield maps.

Statistical analysis

A variety of statistical methods was used to account inclusion of both categorical and continuous variables in this multivariate dataset when explaining variation in WUE. Procedures used included univariate statistical comparisons (analysis of variance (ANOVA)), multiple linear regression, Regression Trees (Breiman et al. 1984) and Random Forests (Breiman 2001) between a variable and WUE.

Results

Data summary

Rainfall during the four year study period ranged from Decile 1 to Decile 10 for annual and growing season rainfall.

Grain yields of wheat averaged 3.37t/ha (range: 0.01 to 8.83t/ha), WUE averaged 10.6kg/mm/ha (0.06-29.6kg/mm/ha), grain protein averaged 12.1% (7.3%-20.6%) and GSR 285mm (121-672). The frequency distribution of grain yields was skewed towards < 3t/ha, while for WUE this average was more normally distributed, but with a small number of points at the high (>24kg/mm/ha) end.

Canola was the most common crop preceding wheat in the rotation (43%), followed by the pulses faba beans, lentils, chickpeas and field peas. Few wheat crops followed either fallow or pastures (reflecting the dominance of Wimmera paddocks in the dataset). Twelve percent of the wheat crops surveyed were preceded by a wheat crop. More than 60% of the wheat paddocks survey had been planted to either wheat or barley within the previous two seasons.

Table 1. Relationship between soil type, rate of P fertiliser applied (kg P/ha) and soil Colwell P (mg/kg).								
Soil classification	No.	frequency	Rate of P (kg/ha)			Colwell P (mg/kg)		
			mean	Min.	Max.	mean	Min.	max
Calcarosol	56	0.14	10.6	3	18	32	2	98
Chromosol	66	0.16	16.3	7	24	41	9	143
Dermosol	38	0.09	15.4	7	33	56	31	105
Kandosol	1	0.00	21.0	21	21	56	56	56
Sodosol	36	0.09	13.1	7	20	46	22	115
Tenosol	5	0.01	6.5	6	8	35	22	63
Vertosol	197	0.49	12.1	0	33	34	7	218

The most common wheat varieties grown were Scout (19.2%) followed by Wallup (12.5%), Yitpi (10.3%), Correll (8.8%) and Derrimut (7.4%). The most common soil types were Vertosols (49%), followed by Chromosols (16%), Calcarosols (14%), Sodosols (9%) and Dermosols (9%) (data not presented).

There were wide ranges in both the rate of phosphorus (P) fertiliser applied and plant available P concentrations (Colwell P) on all the major soil types (Table 1). For example, Colwell P ranged from 2 to 98 with a mean of 32mg/kg on the Vertosols (cracking clays). Across all soil types, mean Colwell P concentrations were greater than those likely to produce a yield response to P application. Although weakly correlated, the rate of P fertiliser applied was positively related to soil Colwell P concentration (Figure 1). Much more strongly correlated was the rate of N fertiliser applied which increased exponentially with the amount of nitrate-N measured in the profile (0-120cm) prior to sowing (Figure 2). These data suggest that little account was made of these soil tests when deciding fertiliser rates.

Water use efficiency

The average WUE of wheat in the study was 11.5kg grain/mm/ha (Figure 3), well below the theoretical potential of 25kg/mm/ha recently suggested by Sadras & Lawson (2013). As expected, there was marked variation between paddocks in WUE but notably, a sizable proportion of paddocks recorded WUE above the French & Schultz (1984) frontier of 21kg grain/mm/ha.

WUE was significantly affected by soil type, with the average for Calcarosols (8.5 kg/mm/ha, n=56) significantly lower than that for Vertosols (10.5 kg/mm/ha, n=196), Chromosols (10.7 kg/mm/ha, n=66), Dermosols (11.4 kg/mm/ha, n=38) and Sodosols (12.0 kg/mm/ha, n = 36), which were not significantly different from each other (data not presented).

The WUE of wheat was significantly lower where PREDICTA®B indicated the risk of Rhizoctonia solani was medium (6.8 kg/mm/ha, n=30) or high (5.3 kg/mm/ha, n=9) than below the detectable limit (11.1kg/mm/ha, n=341).

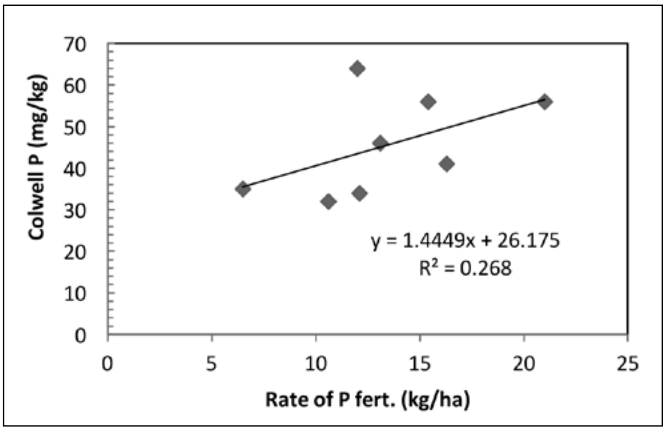

Figure 1. Relationship between the rate of P fertiliser applied and Colwell soil test value.

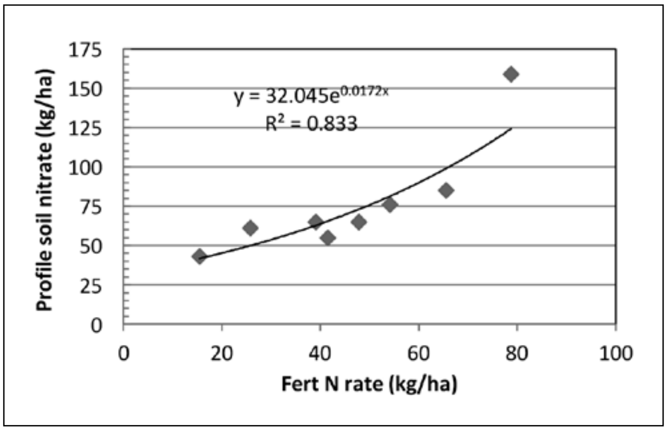

Figure 2. Relationship between the rate of N fertiliser and pre-sowing soil-nitrate (kg/ha) in the profile.

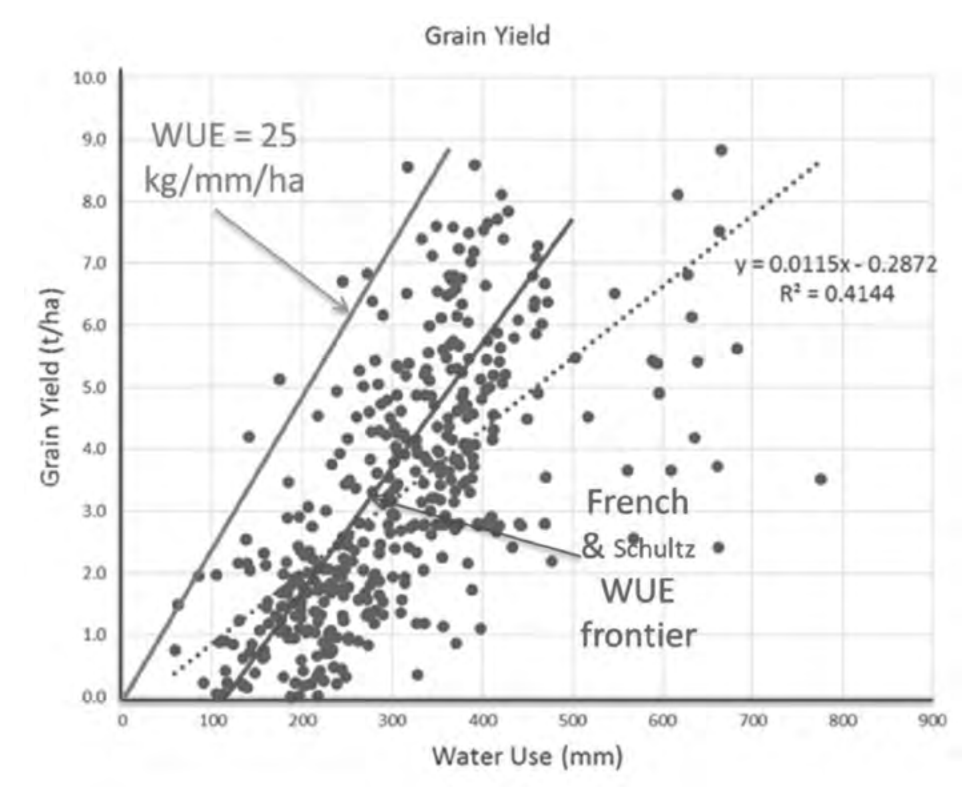

Figure 3. Relationship between water use (mm) and grain yield (t/ha) of wheat across all survey points. The WUE = 25kg/mm/ha line represents the theoretical frontier (Sadras & Lawson 2013) of 25kg grain /mm/ha, whereas the French & Schultz WUE frontier line represents French & Schultz (1984) benchmark (21kg/mm/ha).

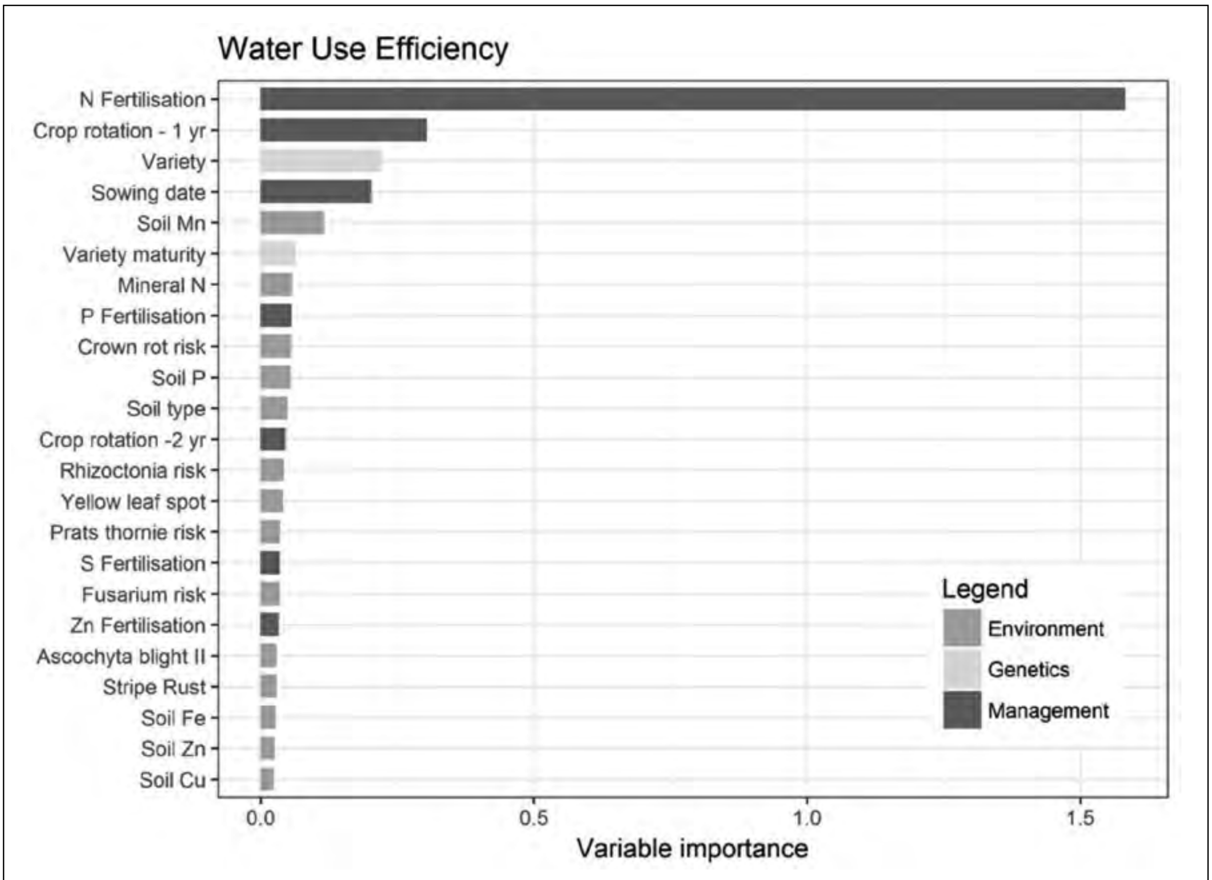

Figure 4. Relative importance of different environmental, genetic and management factors on the WUE of wheat in growers' paddocks (2013-2016) based on Conditional Forest Analysis.

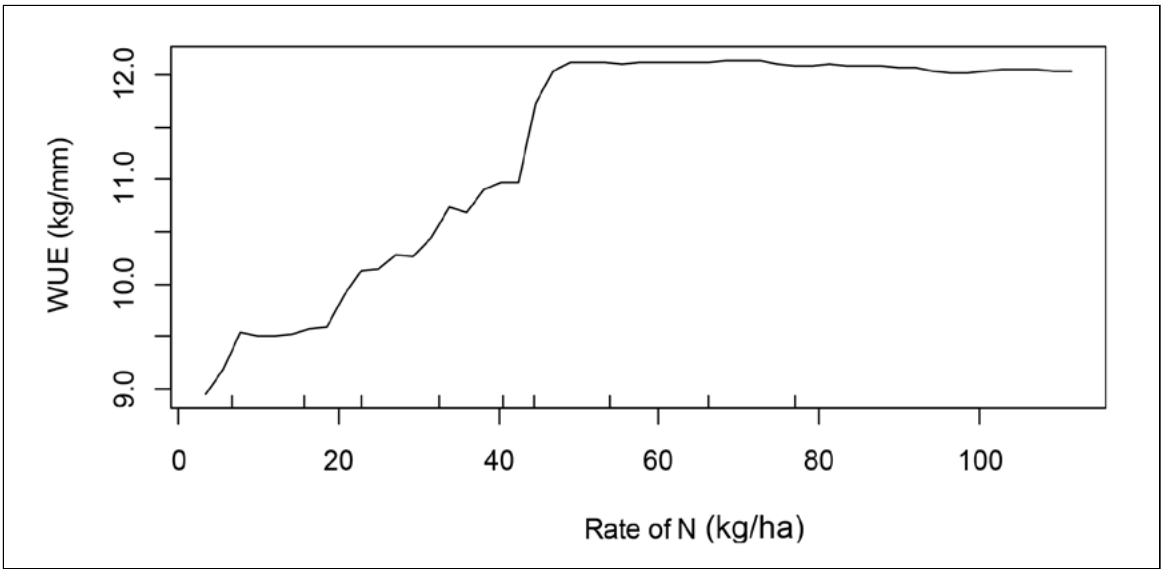

Figure 5. Partial dependence of WUE on rate of N applied (kg/ha) in growers' paddocks (2013-2016).

Conditional Inference Forest Analysis (Figure 4) indicated that the rate of N fertiliser applied was the most important factor influencing WUE, followed by crop rotation (Year 1), variety, sowing date, and soil Diethylene Triamene Penta Acetic Acid manganese (DTPA Mn). The importance of N rate on WUE can be judged by the partial dependence plots. For example, WUE increased rapidly from less than 9kg / mm/ha at low rates of N before asymptoting to 12kg / mm/ha at rates of 50kg N/ha or greater (Figure 5).

The proceeding rotation had the greatest influence on WUE after N rate. Results based on ANOVA analysis (Table 2) indicated WUE (which took account of profile soil water prior to sowing and post-harvest) varied by nearly 70% depending on the previous rotation. The highest WUE values (kg/ mm/ha) were recorded when wheat followed either vetch (13.9), fallow (12.3) or a pulse (12.1), which were significantly greater (P<0.05) compared to wheat following a cereal (10.4). The lowest WUE values occurred when wheat was preceded by either canola (8.9) or pasture (8.2).

Table 2. Effect of previous crop in rotation on WUE (kg grain/ mm/ha) of wheat. Means followed by the same letter are not significantly different (P= 0.05).

Previous crop	Mean WUE (kg/mm/ha)	n
Vetch	13.9a	24
Fallow	12.3abc	7
Pulse	12.1ab	134
Cereal (incl. oats)	10.4bc	33
Canola	8.9c	162
pasture	8.2c	9

Discussion

This study aimed to generate an evidence-based 'hierarchy' of factors (biophysical, genetic and management) that influence WUE of wheat in growers' paddocks. In contrast to other studies with similar aims, in which factorial designed 'white peg' experimentation was used, for example, Anderson et al. (2010), the results in this study were based on current grower management practice where both logistical and cost pressures strongly influence decisions.

There has been considerable debate in the scientific literature about the relative importance of 'G' versus 'E' versus 'M' on long term gains in grains productivity. This study clearly showed that factors under grower control ('Management') were pivotal in determining WUE of wheat. The rate of N fertiliser applied was the most influential factor affecting WUE of wheat, followed by 'rotation' with 'sowing date' the fourth most influential factor. The rate of N applied to a wheat crop ranged from as little as 4kg N/ha (as monoammonium phosphate (MAP) applied at sowing) to 140kg/ha (split as multiple in-season applications). Increasing the N rate from 20 to 50kg/ ha resulted in WUE increasing from 9.5 to 12.0kg/ mm/ha (Figure 5), an increase of more than 25%. A range of factors influence grower N management decisions including assessments of yield potentials, which are strongly related to seasonal conditions, and individual attitudes to financial risk. It was hypothesised that soil mineral N supply prior to sowing would be negatively related to the amount of N subsequently applied. Surprisingly, a strong positive relationship was found between the two.

Profile soil nitrate ranged from 14 to 361kg/ha, a value that would be more than adequate to produce the highest yields recorded (9t/ha) with a grain protein concentration of 12% and assuming an uptake efficiency of approx. 50% and little or no in-crop N mineralisation. The fact that N rates were not negatively correlated with soil N at sowing could reflect low rates of soil testing by growers in western Victoria, especially for 'deep N', and/or a lack of confidence by growers and advisers in soil test results.

Previous crop rotation was the second most influential predictor of WUE. Nearly half of the wheat crops were preceded by canola (44%) with 'cereal' (wheat, barley or oats) comprising most of the crops used in the two years prior to the wheat crop studied. Very few wheat crops were preceded by either a fallow or pasture, confirming the long-term trend since the 1990s towards continuous cropping, not just in the Wimmera but also the Victorian Mallee and to a lesser extent the HRZ.

Fallowing and pastures traditionally provided an important role in controlling both disease, weeds and, indirectly, increasingly short-term supply of mineral N to wheat. Despite the high frequency of cereals in the two years preceding the wheat, both weed infestation and disease risk were generally low or non-detectable (using PREDICTA® B testing), respectively. There were, however, some paddocks where there was significant in-crop weed infestation, and which was found by regression analysis to significantly ($P<0.05$) affect WUE (data not presented). It is difficult to determine to what extent weed populations in these paddocks were influenced by the effectiveness of in-crop weed control or may have reflected significant build-up of weed seed banks in previous rotations — this may in part explain the strong effect of the previous rotation, and to a lesser extent the rotation prior to that, on WUE. Similarly, whereas our measurements focused on potential disease risk as indicated by PREDICTA® B assays, the final impact of disease on WUE would have been also strongly influenced by variety selection (selection of 'tolerant' varieties), as well as seed and in-crop fungicide treatment for foliar diseases.

Despite the dominance of canola in rotations immediately preceding wheat, these crops also had the equally lowest WUE (with grass pasture) of 8.9kg/mm/ha. In contrast including vetch, fallow or a pulse in the prior rotation produced a WUE of more than 12kg/mm/ha, or more than a third greater. It would be expected that the three most efficient rotation options in terms of WUE (i.e. pulses) would produce benefits in both N supply e.g. Armstrong et al. (2019), as well as disease and weed breaks. This finding may also indicate a strong strategic and tactical reliance on the use of N fertilisers by growers to supply N requirements for wheat rather than through N_2 fixation associated with growth of a pulse or vetch. However, given that continuous cropping systems are strongly linked to both declining soil N and organic carbon (C) levels in similar environments (Armstrong et al. 2019), the dependence of WUE on rate of N fertiliser application may become even greater in coming years.

Interestingly, fallow produced the equal highest WUE, although this finding was based only on data from seven points. This finding would not reflect the greater quantity of soil water storage as this was accounted for in the soil water measurement used to calculate WUE. As well as soil water, fallowing also produces benefits to following crops in the form of both increased soil mineral N supply and weed/disease control (O'Leary and Connor 1997). There has been a reassessment of the value of fallowing in recent years from both a productivity and financial perspective (Hunt 2016), especially in light of the high potential of water stored deep in the profile to contribute to grain yield (Kirkegaard et al. 2007). Results from this study would support this reappraisal.

The current study focuses on WUE where account was made of soil water contained in the profile prior to sowing and that remaining at harvest i.e. it is an indicator of the physiological ability of the crop itself to utilise soil water. This WUE approach, popularised by French & Schultz (1984), is widely used by growers and advisers as a benchmark for grain production as water is undoubtedly the key determinant of grain yield. In semi-arid cropping systems, however, a key factor determining productivity is the efficiency in which all rainfall, including that occurring during the preceding fallow, is stored in the soil. As such, it is expected that management factors such as tillage/stubble retention (O'Leary and Connor 1997), which can strongly interact with soil type, as well as fallow weed control (Hunt et al. 2013) which were not measured in this study, would also strongly influence eventual grain yields rather than just WUE.

This study combined a range of 'traditional' statistical approaches such as ANOVA, single/multiple regression, as well as non-parametric approaches such as Random Forests. It is important to recognise that all these approaches have both strengths and weaknesses and that a strength of this study was that a multi-faceted approach was used. It is also important to recognise that statistical analysis is there to assist interpretation of the data rather than being ‘unquestionable’. For example, we are still at a loss to explain the relatively high ranking of soil Mn in the Conditional Forest Analysis. It is important, therefore, that appropriate technical expertise is used to interpret the results and that follow up experimentation may be justified in some cases to help elucidate some findings.

While most of the paddocks monitored were in the Wimmera region of north western Victoria (390 to 430mm annual rainfall), paddocks from the Mallee (325 to 360mm) and the Western Districts of the High Rainfall Zone (> 650mm) were also assessed. The study period (2013 to 2016) covered a large range of annual rainfall and growing season conditions ranging from Decile 1 to greater than Decile 9, allowing for a robust assessment of potential interactions between different environmental and management factors and seasonal conditions. Subsequent re-analysis, where data from both the low and HRZs were removed, produced little change in the key factors influencing WUE, suggesting that these results are potentially applicable across wide sections of western Victoria. Surprisingly, the most challenging part of this project was obtaining reliable grower records. Whereas this in part reflects how busy growers are, in others it was obvious that accurate records were not kept, which limited not only our ability to utilise the full (biophysical) data set available, but raises questions about how some growers can benchmark their performance and use records to improve future decisions.

Conclusions

The WUE of wheat in most paddocks in western Victoria appears to be well below physiological potential.This and other studies suggest that some growers are achieving the physiological potential. Hence, there is significant scope for many growers to reduce the gap between actual and potential yields through their crop management decisions. The key determinant of water use efficiency appears to be N management. Several other factors including crop rotation, variety and sowing date are also critical. Although most wheat crops were preceded by canola, despite highest water use efficiencies occurring after legumes phase. Significant variation in explaining WUE remains unaccounted for, and it is important that these ‘unknowns’, such as possibly frost and heat stress, are identified. This study has provided evidence-based research to underpin future extension and research priorities to improve the productivity of the grains industry in western Victoria. Knowing what factors are important, however, does not mean that ‘solutions’ are readily available.

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Understanding alphabet resistant annual ryegrass

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GRDC project codes: UCS00020, UA00158

Keywords

- alphabet resistance, multiple resistance, cross-resistance, survey, mode of action (MoA), resistance testing.

Take home messages

- Alphabet herbicide resistance is more common in high rainfall zones.
- Resistance to Group J and Group K herbicides in ryegrass has been confirmed in SA, Vic and NSW.
- The use of new mode of action (MoA) herbicides should be included to delay resistance to any one herbicide.
- Use herbicide resistance testing to identify opportunities to use groups still effective.

Alphabet resistance

Weed populations resistant to many different modes of action (MoA) herbicides are sometimes referred to as possessing 'alphabet resistance'. Resistance in these cases is usually conferred by **multiple-resistance types**, that is, the accumulation of two or more resistance mechanisms. This usually occurs by sequential selection, i.e. repeated use of one herbicide (or herbicides from the same MoA e.g. Group Bs) selects for resistance and is followed by overuse of a second MoA which develops resistance to the second herbicide. The population is now resistant to two MoA herbicides. Alternatively, resistance to more than one MoA herbicide can be conferred by **cross-resistance**. In this circumstance, **one** mechanism of resistance confers resistance to more than one MoA. The most common mechanism conferring cross-resistance is metabolic resistance, whereby herbicides are more rapidly detoxified by metabolising enzymes. Some forms of metabolic resistance can confer cross-resistance to Hoegrass®/Decision® (Group A) and Glean®/Logran® (Group B), such as ryegrass biotype SLR31 which has been extensively investigated by Preston and Powles.

Resistance can also be conferred by multiple-resistance comprising of Group A target site resistance (mechanism 1) plus Group B target site resistance (mechanism 2). One ryegrass biotype identified in the 2016 north-eastern Victorian survey (Sample 76) collected south-west of Rochester was confirmed resistant to triallate (J), sulfonylureas (B), Axial® (A) and glyphosate (M). It is most likely that there are four individual mechanisms of resistance (multiple resistance) in this population. Each mechanism can confer exclusive resistance to one MoA (multiple resistance) or more than one MoA (cross-resistance). While resistance to four MoAs is not common, resistance to three MoAs, e.g. A, B and to one other MoA herbicide (e.g. trifluralin (D), triallate (J), glyphosate (M)) is becoming increasingly common in ryegrass.

Weed resistance surveys supported by GRDC indicate that in the more intensively cropped areas of southern Australia where herbicide selection pressures have been high, alphabet resistant ryegrass is becoming more prevalent (Figure 1). The highest proportion of alphabet resistant ryegrass has been detected in the SA South East (SE) with the majority of ryegrass samples resistant to three

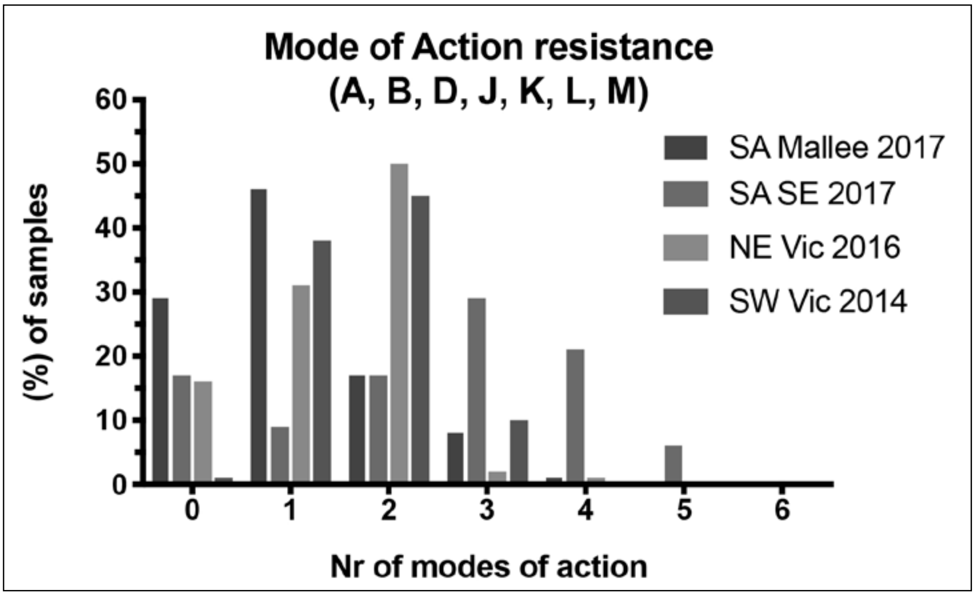

Figure 1. Percentage of samples from random weed surveys resistant to different MoA herbicides.

MoA, and a significant number resistant to four and five MoA. In lower rainfall areas such as the SA Mallee, almost 30% of ryegrass samples were not resistant, with the majority (45%) resistant to one MoA, and 15% to two MoAs. In the higher rainfall zones of south western and north-eastern Victoria, the majority of ryegrass samples were resistant to two MoA. Needless to say, in every region there are a proportion of paddocks with no resistance or resistance to only one MoA. Through the use of resistance testing, these benefits can be exploited by determining those MoAs that are still effective.

Herbicide resistance in Victoria

Resistance to post-emergent herbicides

The GRDC has supported the University of Adelaide's weeds group since 2005 to conduct annual weed surveys across three regions of Victoria. The methodology involves randomly selecting 150–200 paddocks and collecting weed seeds prior to harvest. Reasons for the presence of plants at the end of the season could include: (1) Resistant plants that have survived herbicides, (2) Germination occurred post-herbicide application, (3) Sub-lethal effects due to shading or poor herbicide/ adjuvant choice/poor application equipment, and (4) Reduced herbicide uptake due to plant stress or (5) a combination of points 1 to 4. Testing using pot trials under optimum spraying conditions (accurate herbicide application on non-stressed weeds at correct timings) is conducted the following season under outdoor winter conditions. These studies are aimed at identifying the incidence and changes in resistance mechanisms at 5-year intervals in addition to monitoring for resistance to recently registered herbicides. The results are expressed as the percentage of paddocks containing resistant ryegrass as determined by a pot test and where survival in that pot test was ≥20% (Tables 1 and 2).

The surveys have identified that resistance to the cereal selective Group A and Group B herbicides ranges between 33% and 96% across Victoria. The effectiveness of Group A and Group B herbicides varies between regions. For example, ryegrass from 33% of paddocks surveyed in Western Victoria

Table 1. Percentage of paddocks containing herbicide resistant ryegrass in Victoria to post-emergent herbicides. Paddocks were scored as resistant if the seeds collected exhibited ≥20% survival in a pot test conducted the following winter. Samples that exhibited <20% survival were not classed as resistant. Letters below the herbicide name represent the MoA labelling.

Region of Victoria	Year	Hoegrass®	Axial®	Select®	Glean®	Intervix®	Glyphosate
		A	A	A	B	B	M
Southern	2014	86	54	3	96	33	4
Western	2015	70	33	3	60	31	7
Northern	2016	72	60	4	74	51	3

For each herbicide, recommended field rates plus recommended adjuvants (if required) were used.

in 2015 exhibited resistance to Axial®, whereas resistance is higher in the other two regions.

Clethodim (Select®) is arguably the most important herbicide in break crops. The incidence of resistance to 500ml/ha clethodim in the pot trials under winter conditions on non-stressed ryegrass was below 5% in the Victorian samples. To put this into perspective, the incidence of glyphosate resistance was similar to clethodim. However, frequently during the growing season, there are reports of poor control with clethodim. This discrepancy of reduced performance with clethodim is, therefore, likely to be due to other factors such as environmental stress reducing herbicide performance.

Across 450 paddocks randomly surveyed in Victoria between 2014 and 2016, glyphosate resistance in ryegrass was detected in 4% of paddocks. This is a real concern because glyphosate is the most commonly used herbicide pre-sowing and for pre-harvest crop-topping. Studies to investigate the viability of glyphosate resistant ryegrass seed after crop-topping with glyphosate have revealed the strategy was ineffective in sterilising seed. This suggests that in a mixed population, including glyphosate resistant and susceptible individuals, crop-topping at the correct timing with glyphosate would only sterilise susceptible individuals, but not resistant individuals. Resistance testing for glyphosate resistance would aid in product choice in pulse crops where paraquat is an alternative.

Resistance to pre-emergent herbicides

With the exception of resistance to trifluralin in western Victoria (31% of paddocks resistant) and triallate resistance in southern and north-eastern Victoria (11-12% of paddocks resistant), resistance to pre-emergent herbicides remains low. In north-eastern Victoria, the high incidence of mixed farming has likely contributed to the reduced selection pressure on pre-emergent herbicides. In situations, where high stubble loads and large ryegrass seedbanks are common such as in southern Victoria, the use of trifluralin alone is not likely to be effective due to poor herbicide-seed contact. Here, full rates of diverse pre-emergent herbicide mixtures are common. Heavier reliance on trifluralin in western Victoria with fewer herbicide/weed control strategies compared to mixed farming in northern and southern Victoria has most likely contributed to the higher incidence of trifluralin resistance. Since no resistance to propyzamide has been detected from the random weed surveys or from commercial resistance testing indicates that it is rare.

Resistance to Group J and Group K herbicides is generally low in Victoria except triallate, which has been available for more than 30 years. It is likely that the long-term exposure of ryegrass to triallate has eliminated susceptible individuals, increasing triallate resistance. Such resistant individuals are more likely to develop cross-resistance to other herbicides in Group J. Group J and Group K herbicides have become widely adopted as the main herbicide defence against alphabet resistant ryegrass in both cereal and broadleaf crops, and resistance is likely to increase if they continue to be heavily relied upon. Recent University of Adelaide studies have shown that cross-resistance between the Group J and Group K herbicides is highly unpredictable, making it difficult to determine if resistance to one herbicide will elicit cross-resistance to another Group J/K herbicide. Resistance testing can aid growers identify which pre-emergent herbicides are still effective.

New MoA herbicides

Several herbicides, most which have MoAs that differ to currently registered herbicides (Groups E, Q, R), are in development (Table 3). The Group K herbicide Devrinol-C® (napropamide) belongs to a unique chemical class (acetamides) different to other Group K herbicides. Devrinol-C® has been registered for the 2019 growing season, whereas

Table 2. Percentage of paddocks containing herbicide resistant ryegrass in Victoria to pre-emergent herbicides. Paddocks were scored as resistant if the seeds collected exhibited ≥20% survival in a pot test conducted the following autumn-winter. Samples that exhibited <20% survival were not classed as resistant. Letters below the herbicide name represent the MoA labelling.

Region of Victoria	Year	Trifluralin	Propyzamide	Triallate	Arcade®	Boxer Gold®	Sakura®
		D	D	J	J	J/K	K
Southern	2014	2	0	11		0	0
Western	2015	31	0	3		0	0
Northern	2016	0	0	12	2	2	0

For each herbicide, recommended field rates were used.

Table 3. Summary of new herbicides expected for registration by 2020.

Code/Product name	Chemical Name	Mode of Action	Selectivity	Weed control
F9600SC	Bixlozone	Q	Cereals, canola	Grasses and broadleaf weeds
Luximo®	Cinmethylin	?	Wheat	Grasses
Ultro®	Carbetamide	E	Pulses	Ryegrass, brome, barley grass
*Devrinol-C®	Napropamide	K	Canola	Ryegrass

*registration in November 2018

? Under investigation

the registration for the other three herbicides (bixlozone, cinmethylin and carbetamide) is pending. The herbicides in Table 3 are all pre-emergent herbicides and selective in a variety of crops. Trials have shown that in addition to other weed species, these herbicides control some alphabet resistant ryegrass. If used as part of an integrated weed control strategy, these alternative MoA herbicides are likely to reduce selection pressure on any one MoA.

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Summary of key weed research activities in the northern grains region

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GRDC project codes: US00084, UWA00171

Keywords

- alternative weed control, chaff lining, chaff tramlining, site-specific weed control, targeted tillage.

Take home messages

- High amounts of chaff are required for suppression of weed emergence in chaff lines.
- 'Weed chipper' is a targeted tillage system for fallow weed control.
- Site-specific weed control creates the opportunity to use alternative physical weed control technologies.

Background

Chaff lining and chaff tramlining

With many annual weeds in Australian cropping systems retaining their seed at maturity, harvest weed seed control (HWSC) is an alternative approach to weed control that is now widely adopted by Australian grain growers (Walsh et al. 2017). Several similarly effective HWSC systems have been developed to suit a range of crop production practices (Walsh et al. 2013). Chaff lining and chaff tramlining have recently become very popular with growers due to the low cost and simplistic approach of these systems to targeting weed seeds at harvest. These techniques concentrate the chaff fraction into very narrow windrows (<30cm) directly behind the harvester or onto dedicated wheel tracks. The chaff environment is sub-optimal for seedling establishment and these practices can be as effective as other forms of HWSC (Broster et al. 2018).

Targeted tillage

Tillage can provide highly effective weed control, but when used conventionally (i.e. 100% soil disturbance), it cannot be routinely used in conservation cropping systems due to the impact on soil health. The development of weed detection technologies creates the opportunity to incorporate strategic tillage operations for targeting individual weeds or weed patches in fallow situations. The 'weed chipper' is a targeted tillage system that incorporates weed detection with rapid response tynes for site-specific fallow weed control.

Alternative weed control technologies

Physical and thermal weed control techniques were in use well before herbicides were introduced and the development of new options has continued throughout the herbicide era. Most of these technologies have not been developed, primarily due to cost, speed of operation and fit within farming systems. The introduction of weed detection and actuation technologies creates the opportunity to target individual weeds. This greatly increases the cost-effectiveness of many directional alternative weed control techniques. The challenge now is to identify which of these research and development activities should focus on.

Materials and methods

Chaff lining and chaff tramlining

A series of pot experiments investigated the influence of increasing amounts of wheat, barley, canola and lupin chaff on the emergence of annual ryegrass. In trials at three locations — Toowoomba, Wagga Wagga and Narrabri, eight rates of chaff were spread over a known number of annual ryegrass seed (100 or 200) on the surface of potting mix filled trays or pots. Chaff amounts used (0, 3, 6, 12, 18, 24, 30, and 42t/ha) were calculated as amounts equivalent to those concentrated in a 30cm wide row during the harvest of 0, 0.25, 0.5, 1, 1.5, 2, 2.5 and 3.5t/ha yielding wheat crops using a 12m front. Once the chaff was evenly spread across the soil surface, the pots were watered thoroughly and maintained at or near field capacity for 28 days.

Chaff amount = 0.3 x grain yield (t/ha) x (harvester width (m)/tramline width (m)).

Note: Assuming chaff yield is 30% of grain yield.

Differences between chaff types and rates on annual ryegrass emergence over a 28 day period.

Targeted tillage

A rapid response tyne system has been developed with the operational specifications of being able to specifically cultivate targeted weeds when present in a field at densities of up to 1.0 plant/10m^2 at an operational speed of 10km/h. The rapid response tyne was based on the retrofit of a Shearer Trashworker tyne with a hydraulic breakout system. The hydraulic breakout system is typical of many other manufacturers thus permitting a design approach which could be adapted to accommodate other arrangements. The design focused the engineering on minimising the number of additional components and keeping the design simple whilst achieving the chipping action similar to a conventional hoe in well under half a second. A modular approach to the design was taken so as to permit the system to be readily scaled.

Field testing using two prototype rigs at Narrabri and Toowoomba was conducted on a range of problematic fallow weed species. The targeted tillage system was evaluated in a series of field trials for efficacy on weeds of winter fallows (annual ryegrass, wild oats, sowthistle and wild turnip) and summer fallows (barnyard grass, feathertop Rhodes grass, fleabane and sowthistle). The efficacy of the response tyne on the targeted weeds species across a range of growth stages was also investigated.

Comparison of weed control technologies

There is a diverse array of alternative physical and thermal weed control technologies with a proven ability to control weeds. The majority of these have not been commercialised and evidence of their efficacy is from a range of strictly controlled laboratory trials or studies, making cost-effectiveness comparisons difficult. While inputs and control methods differ significantly between physical control options, all systems share an energy requirement value for activation and use. Therefore, the energy required for effective weed control can be a reasonably accurate approach to comparing the efficiency and efficacy of physical control systems on an energy consumed per weed or hectare basis.

The direct energy requirements for the control of two-leaf weed seedlings were estimated from published reports on the weed control efficacy of a comprehensive range of physical weed control techniques (Table 1). To determine the energy requirement per unit area, a weed density of 5.0 plants/m^2 was chosen to represent a typical weed density in Australian grain fields (Llewellyn et al. 2016).

Results and discussion

Chaff lining and chaff tramlining

Preventing the emergence of annual ryegrass in chaff lining or chaff tramlining systems requires the concentration of very high rates (>42t/ha) of chaff material. The enhanced suppression of annual ryegrass emergence with increasing amounts of wheat chaff was clearly evident in pot trials conducted at three locations in 2018 (Figure 1). Regardless of location, there were no differences ($P>0.05$) in annual ryegrass emergence for chaff treatments between 3t/ha and 18t/ha (Figure 1). The 30t/ha and 42t/ha chaff treatments produced the lowest ($P<0.05$) emergence of just 49.5% and 20.7%, respectively. However, annual ryegrass emergence was not prevented in these studies, even at the highest wheat chaff rate of 42t/ha. At the lower chaff rates (3t/ha to 12t/ha), annual ryegrass emergence was consistently lower ($P<0.05$) at Wagga Wagga than the two other locations. Emergence in the Wagga Wagga trial was lower ($P<0.05$) than both sites at 3t/ha, 6t/ha and 12t/ha chaff rates and lower than one site at the 24t/ha chaff rate. However, at the 42t/ha chaff rate, emergence at Wagga Wagga was higher ($P<0.05$) than at the other two sites.

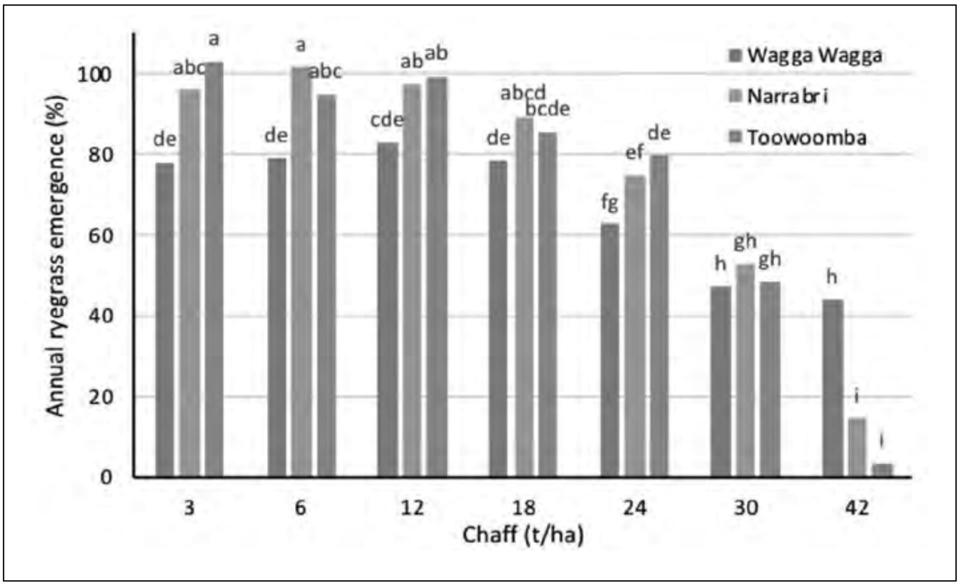

Figure 1. Influence of increasing amounts of wheat chaff on the emergence of annual ryegrass in pot trials conducted at three locations. Means with same letter are not significantly different (P=0.05.)

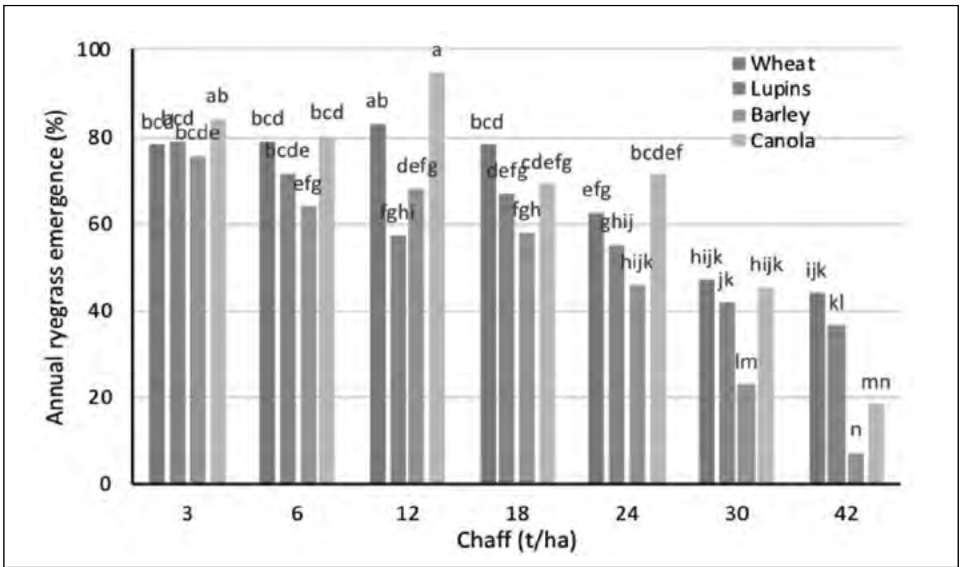

Figure 2. Influence of increasing amounts of wheat, barley, lupin and canola chaff on the emergence of annual ryegrass in pot trials conducted at Wagga Wagga, NSW. Means with same letter are not significantly different (P=0.05).

Barley chaff was generally more suppressive of annual ryegrass emergence at equivalent rates of wheat, canola and lupin chaff. When these four chaff types were compared in a single study at Wagga Wagga, there was generally lower annual ryegrass emergence through barley chaff, however these values were only significantly lower (P<0.05) at the highest chaff rates (30t/ha and 42t/ha) (Figure2)

Targeted tillage

Engineering research, development and testing were conducted on the University of Western Australia (UWA) test rig at (Figure 3A). As with any engineering design, the process involved iterative improvements to the design layout. Once the system was able to achieve a chipping cycle time of less than 400m from actuation to return to standby position and the design had been simplified and deemed reliable, the pre-commercial rig (Figure 3D) was designed and built.

Figure 3. Initial proof-of-concept rig, UWA (A), University of Sydney (USyd) trailer mounted self-powered rig (B), Qld Department of Agriculture and Food (QDAF) 3-point-linkage rig (C) and pre-commercial rig – the 'Weed Chipper' (D) used in the testing and validation of targeted tillage fallow weed control.

Weed kill field testing achieved very high efficacy on all targeted summer and winter annual weeds regardless of growth stage (Tables 1, 2 and 3). The survival of any weeds during testing was due to the design of current cultivator sweeps not being suitable for targeted tillage. Weed control was 100% effective when the weed was targeted by the point of the sweep, however there was high weed survival when the weed was hit by sweep side. There was also reduced efficacy when weeds were excessively large. When feathertop Rhodes grass was >70cm diameter, there was only poor control (Table 2). The system is highly effective on both broadleaf and grass weeds with potentially little resulting soil disturbance (Figure 4).

Table 1. Response tyne efficacy following direct or partial sweep impact on four winter and three summer weed species at eight growth stages, Narrabri, NSW, 2017 and 2018.

Planting date	Wild oats (% control)		Turnip weed (% control)		Sowthistle (% control)		Annual ryegrass (% control)		Feathertop Rhodes grass		Barnyard grass		Fleabane	
	Direct contact	Partial contact	Direct contact	Partial contact	Direct contact	Partial contact	Direct contact	Partial contact	Direct contact	Partial contact	Direct contact	Partial contact	Direct contact	Partial contact
2 leaf	100	0	100	100	100		100	0	100	-	100	-	100	-
4 leaf	100	-	100	0	100	-	100	0	100	-	100	-	100	-
6 leaf	100	-	100	100	100	-	100	0	100	-	100	-	100	-
8 leaf	100	0	100	-	100		100	0	100	-	100	-	100	-
10 leaf	100	0	100	-	100	-	100	0	100	-	100	-	100	-
Bolting/tillering	100	0	100	-	100	-	100	0	100	-	100	-	100	-
Early flowering/heading	100	0	100	-	100		100	0	100	-	100	-	100	-
Flowering	100	-	100	-	100	-	100	0	100	-	100	-	100	0

- Indicates no treatments where there was partial contact of the tyne with the weed.

Table 2. Response tyne efficacy on two winter weed species at three growth stages, Gatton, Qld, 2017.

Weed Size	Wild Oats	Sowthistle
	Control (%)	
Small	*	100
Medium	100	85
Large	98	75

** Indicates that established weeds were either missed by the tyne (alignment issue) or the tyne did not activate.*

Table 3. Response tyne efficacy on three summer weed species at three growth stages, Gatton and Hermitage, Qld, 2017.

Summer 2016/2017	Weed size	Barnyard Grass	Feathertop Rhodes Grass	Windmill Grass
		Control (%)		
Gatton	Medium	100	94	100
	Large	96	91	100
	X-Large	99	87	96
Hermitage	Medium	98	78	100
	Large	92	33	100
	X-Large	83	8	*

** Indicates that established weeds were either missed by the tyne (alignment issue) or the tyne did not activate.*

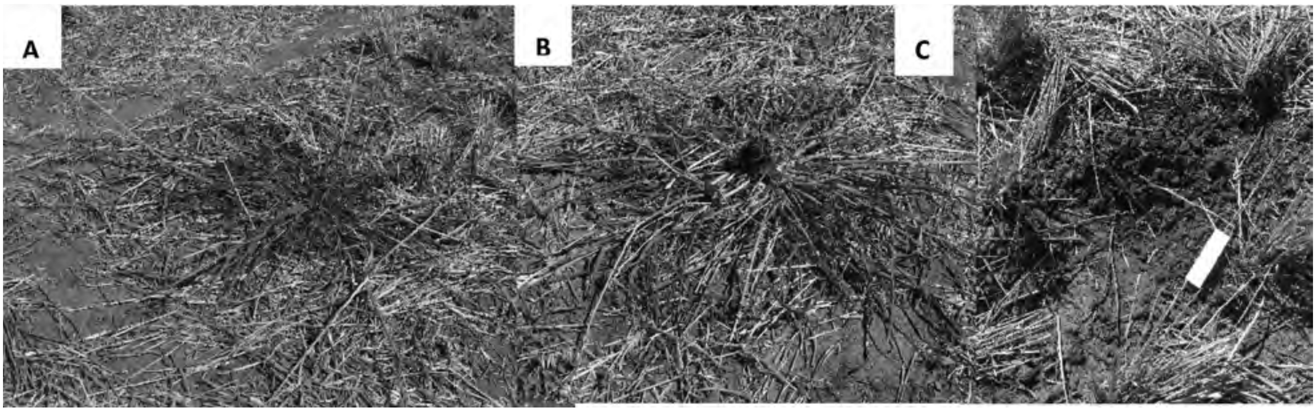

Figure 4. Wild oats pre- targeted tillage (A), post-targeted tillage (B) and the resulting 'divot'(C).

The efficacy of targeted tillage for weed control is entirely reliant on accurate weed detection. Given that the initial use of targeted tillage will be in fallow, then it is appropriate that current available real-time detection technologies be incorporated in preparation for commercial use. Current boom spray mounted detection systems (Weed Seeker® and WeedIt) are coupled to spray nozzles that can be rapidly triggered. Preliminary tests using the WeedIt sensing system on the Shenton Park rig demonstrated its high suitability for fallow weed control. The WeedIt system was chosen as being a more suitable system for targeted tillage and has now been incorporated into the pre-commercial Weed Chipper rig. Trials using the system coupled to a 6m pre-commercial Weed Chipper (Figure 3D) are currently underway.

Comparison of weed control technologies

As a group, soil disturbance-based options are the most energy efficient form of physical weed control when applied as a broadcast (whole field) treatment (Table 4) with no additional energy inputs beside the draft force requirements. Although tillage can be a highly effective weed control option, the soil disturbance involved is not compatible with conservation cropping systems and therefore, this approach needs to be used sparingly. There are a group of thermal weed control technologies (flaming, hot water foaming and steaming) using chemical or electrical energy that may be used for broadcast weed control (Table 4). In comparison to tillage and herbicide-based options, these approaches are considerably more energy expensive. With 100-fold to 1000-fold higher energy requirements, it is not surprising that these technologies have not been widely adopted for use in large scale cropping systems.

Site-specific weed control

The opportunity for substantial cost savings and the introduction of novel tactics are driving the future of weed control towards site-specific weed management. This approach is made possible by the accurate identification of weeds in cropping systems using machine vision typically incorporating artificial intelligence. Once identified, these weeds can be controlled through the strategic application of weed control treatments. This precision approach to weed control creates the potential for substantial cost savings (up to 90%) and the reduction in environmental and off-target impacts (Keller et al. 2014). More importantly for weed control sustainability, site-specific weed management creates the opportunity to use alternative physical weed control options that currently are not suited for whole paddock use.

Accurate weed detection allows physical weed control treatments to be applied specifically to the targeted weed. As weed identification processes develop to include weed species, size and growth stage, there exists the potential for some approaches (such as electrical weeding, microwaving and lasers) to be applied at a prescribed lethal dose. This dramatically reduces the amount of energy required for effective weed control (Table 5). For example, microwaving, as one of the most energy expensive weed control treatment as a broadcast treatment (42,001 MJ/ha), requires substantially less energy when applied directly to the weed targets (17.8MJ/ha). Thus, even though the same numbers of weeds are being controlled (5 plants/m^2) the specific targeting of these weeds results in a 99% reduction in energy requirements.

Table 4. Total energy requirement estimates for alternative weed control options applied as broadcast treatments. Estimates are based on the control of two-leaf weeds present at five plants/m^2.

Weed control method	Energy consumption (MJ/ha)
Flex tine harrow	4
Sweep cultivator	11
Rotary hoe	13
Organic mulching	16
Rod weeding	18
Spring tooth harrow	22
Basket weeder	29
Roller harrow	29
Disc mower	31
Tandem disk harrow	36
Flail mower	57
Offset disk harrow	64
UV	1701
Flaming	3002
Infrared	3002
Hot water	5519
Hot foam	8339
Steam	8734
Freezing	9020
Hot air	16902
Microwaves	42001
Plastic mulching	211003

Table 5. Total energy requirement estimates for alternative weed control options when applied as site-specific treatment. Estimates are based on the control of two-leaf weeds present at five plants/m^2.

Weed control method	Energy consumption (MJ/ha)
Concentrated solar radiation	14.4
Precise cutting	14.4
Pulling	14.4
Electrocution: spark discharge	14.5
Nd:YAG IR laser pyrolysis	15.1
Herbicides	14.8
Hoeing	15.7
Water jet cutting	15.8
Stamping	16.5
Nd:YAG IR laser pyrolysis	16.9
Microwaves	17.8
Abrasive grit	24.5
Thulium laser pyrolysis	25.9
CO_2 laser cutting	54.8
Targeted flaming	59.9
Electrocution: continuous contact	60.9
Nd:YAG laser pyrolysis	84.4
CO_2 laser pyrolysis	92.3
Nd:YAG UV laser cutting	129.4
Hot foam	131.3
Dioide laser pyrolysis	133.1
Nd:YAG IR laser cutting	204.4
Targeted hot water	517.6

Conclusions

The emergence of annual ryegrass can be significantly suppressed by increasing amounts of chaff concentrated in chaff lines and chaff tramlines. It was only at very high rates of wheat (42t/ha) that the annual ryegrass emergence was effectively reduced, therefore much higher amounts will be needed to prevent suppression.

The Weed Chipper is currently being demonstrated throughout the northern grains region. It is hoped that this system will become widely used as an alternative to herbicides for fallow weed control.

The specific targeting of individual weeds results in significant energy savings and makes previously impractical options available for use in commercial production systems. The opportunities here are immense for the future management of problem weeds.

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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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Nitrogen fertiliser placement in wheat and canola – effects on yield, quality and nitrogen use efficiency

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GRDC project code: DAV00143

Keywords

- mid-row banding, wheat, canola, urea.

Take home messages

- Field trials conducted during 2016 and 2017 showed that mid-row banding nitrogen (N) fertiliser in-season significantly increased uptake of fertiliser N by wheat compared to surface application.
- The effects of N placement on grain yield have been more variable — mid-row banding significantly increased grain yield compared to banding below the seed at sowing or top-dressed urea in-season at one out of six field trials from 2016 to 2018.
- Under drier conditions in the Mallee, mid-row banding in-season was shown to increase grain protein in wheat by 0.5%-1.6% compared with all other methods of application.
- Adoption of mid-row banding requires consideration of capital and operational costs and machinery function against potential improvements in grain yield and quality in a given farming system.

Background

Nitrogen management is a continual challenge for growers and advisers, given it is a significant expense that can be unpredictable due to variable seasons. As a result, researchers and the grains industry are constantly searching for new ways to apply N that can improve N use efficiency and productivity. The 'Four Rs' framework is commonly used to guide improvements in management of fertilisers based on the principles of 'right rate, right time, right place and right product'. This paper outlines findings from field trials undertaken during 2018 focusing on N placement.

Placement of N fertilisers can have a variety of impacts on availability of N and the crop response. Banding N below the soil surface has been shown to influence various N loss mechanisms including ammonia volatilisation (Rochette et al. 2013) and denitrification (Drury et al. 2006). Foliar application can result in leaf uptake, but can cause leaf burn depending on rate and conditions following application, while applying high rates of fertiliser close to seed can result in toxicity and reduced crop establishment. A series of field trials commencing in 2016 investigated the effect of in-season N fertiliser placement on wheat yield, quality and N use efficiency. These trials have highlighted that mid-row banding N (where N is banded below the soil surface to every second inter-row) has the potential to increase N use efficiency and in some cases increase grain yield or protein compared to surface applications. This paper outlines findings from 2018 when mid-row banding was tested against a range of other placement methods in both wheat and canola, at sowing and in-season.

Method

Two field trials were established in 2018 testing various combinations of application method, timing and rate of N fertiliser. Sites were established at Ouyen (wheat, Kord CL Plus) and Longerenong (canola, 44Y90 CL) with N applied either at sowing or during the season (Ouyen; GS30, Longerenong; GS2.0) at rates of 25kg N/ha and 50kg N/ha in addition to the 7kg/ha applied as Granulock® Z at sowing. Urea was the N source in granular and liquid forms. Treatments included:

- Mid-row banded at 35-50mm using a twin disc opener (granular and liquid).
- Banded at 25mm below the seed (granular and liquid, sowing only).
- Mid-row placement using ultra-high-pressure injection (liquid).
- Streaming nozzle (liquid).
- Top-dressed (granular).

Additional plots receiving further rates of 15kg and 100kg N/ha as granular urea at sowing were also added to establish the yield potential of the site. To avoid crop failure due to dry seasonal conditions (growing season rainfall (GSR): 102mm at Ouyen and 187mm at Longerenong), both sites were irrigated twice between 7 September and 5 October (coinciding with pre-flowering to early grain filling). Irrigation of 20mm was applied on each occasion and irrigation at this time was likely to be about half the efficiency of rainfall.

Results and discussion

Crop response to N placement

Both trial sites responded strongly to additional N fertiliser in 2018 despite the dry seasonal conditions experienced. At Ouyen, soil N at sowing was 56kg N/ha (1.2m depth) and wheat grain yield and protein increased by 49% and 40% at N rates of 50kg and 100kg N/ha, respectively, compared to where no additional N was applied (Figure 1). At Longerenong, soil N at sowing was 101kg/ha (1.2m depth) and applying 100kg N/ha increased canola grain yield by 25%, however, the effect on oil content was limited. Significant reductions in crop establishment and grain yield were also observed at Ouyen where 100kg N/ha was banded below the seed at sowing, demonstrating the effects of inadequate seed-fertiliser separation combined with dry soil conditions. Due to the sensitivity of canola to fertiliser toxicity, at Longerenong the 100kg N/ha rate was top-dressed.

At Ouyen, placement of N at sowing had a significant ($P<0.05$) impact on wheat yield — banding N below the seed or in a mid-row configuration significantly increased grain yield (by up to 16%) compared to mid-row placement using ultra-high-pressure injection or streaming nozzles. There was also a trend towards a significant increase (9%-10%) in grain yield compared with topdressing (Table 1). However, at Longerenong, placement of N at sowing had no significant effect on grain yield (Table 2). Given that both sites received rainfall of at least 10mm within two weeks of sowing, it is unlikely that

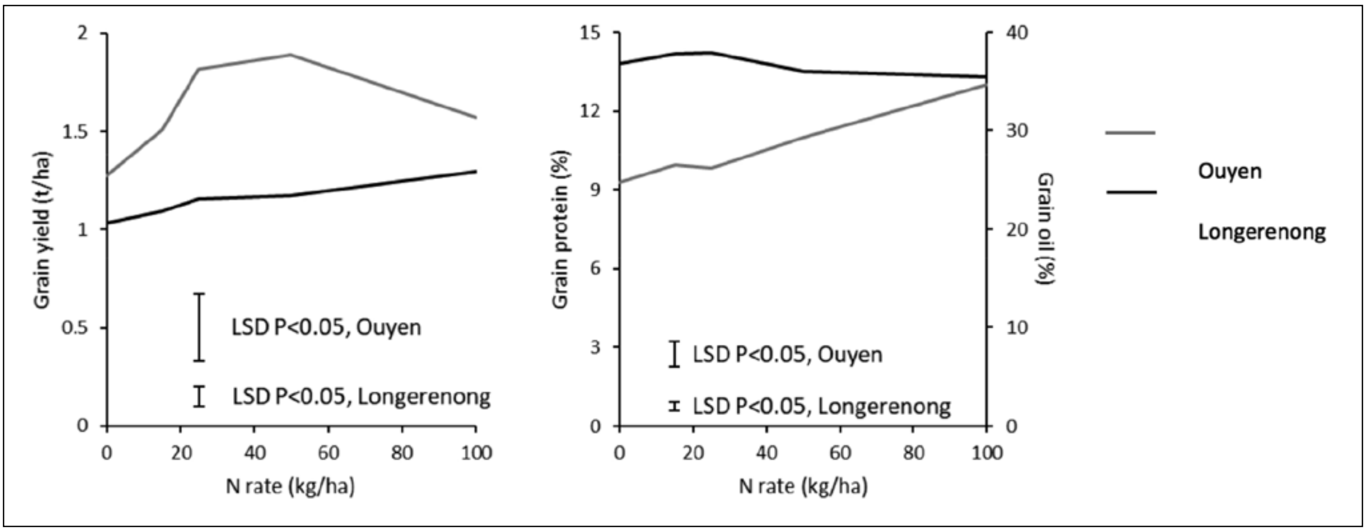

Figure 1. Grain yield and protein/oil content response to N application rate at Ouyen and Longerenong in 2018.

Table 1. Wheat grain yield and protein response to N application method at sowing and in season at Ouyen in 2018. Values presented are the mean of both 25kg N/ha and 50kg N/ha rates. Superscripts indicate significant differences (P<0.05). Treatments followed by the same letter are not statistically different.

Method of application	Sowing		In-season	
	Grain yield (t/ha)	Grain protein (%)	Grain yield (t/ha)	Grain protein (%)
Ultra-high-pressure injection	1.7[b]	10.8	1.6	11.2[b]
Banded below seed	1.9[a]	10.4	-	-
Mid-row banded	1.9[a]	10.9	1.6	12.2[a]
Streaming nozzle	1.6[b]	10.4	1.7	10.6[c]
Top-dressed	1.7[ab]	10.3	1.7	10.7b[c]
Lsd *(P<0.05)*	*0.2*	*ns*	*ns*	*0.6*

ns: not significant

the benefit of banded application at Ouyen was related to N loss due to ammonia volatilisation. An alternative explanation may relate to N tie-up or immobilisation — at Ouyen, stubble from the previous season was slashed prior to sowing, spreading it evenly across the soil surface compared to Longerenong where stubble remained standing. While total stubble load at both sites was similar, it is possible that by spreading stubble across the soil surface that N immobilisation may have increased at Ouyen, potentially favouring treatments where N was banded below the surface. The effect of N placement at sowing on grain protein/oil content was limited at both Ouyen and Longerenong.

Placement of fertiliser N in-season did not significantly affect grain yield at either Ouyen or Longerenong. However, similar to results at Ultima in 2017, mid-row banding N at GS30 significantly increased grain protein at Ouyen by 9%-15%, while maintaining equivalent yield to other application methods. A similar observation was made where N was applied by ultra-high-pressure injection, although the increase in grain protein was lower. This result may indicate that by applying N in between the crop rows during the growing season that crop access to the fertiliser is slowed, thereby having a greater influence on grain protein. Conversely at Longerenong, grain oil content was not affected by placement of N in-season.

Granular versus liquid urea

Field trials conducted in 2016 and 2017 were undertaken using liquid urea solution except where granular urea was top-dressed, raising questions about the efficacy of liquid versus granular sources. In 2018, machinery modifications were made to allow a direct comparison of N source for the mid-row banded treatment. While it is expected that an aqueous urea solution will behave differently to a granular product in the short term following application, across both sites, times and rates of application and placement, no significant effect of urea source was found on either grain yield or protein in 2018.

Ultra-high pressure injection as an alternative method to mid-row band fertiliser

Across both sites, ultra-high-pressure injection resulted in similar grain yield or grain protein/oil content compared with other application methods including mid-row banding using a twin disc opener. However, where significant effects of application

Table 2. Wheat grain yield and protein response to N application method at sowing and in season at Longerenong in 2018. Values presented are the mean of both 25kg N/ha and 50kg N/ha rates.

Method of application	Sowing		In-season	
	Grain yield (t/ha)	Grain oil (%)	Grain yield (t/ha)	Grain oil (%)
Ultra-high-pressure injection	1.2	36.7	1.2	36.4
Banded below seed	1.2	36.9	-	-
Mid-row banded	1.2	36.6	1.2	36.3
Streaming nozzle	1.2	36.4	1.2	36.9
Top-dressed	1.2	37.0	1.2	37.2
Lsd *(P<0.05)*	*ns*	*ns*	*ns*	*ns*

ns: not significant

method were measured (grain yield where N was applied at sowing and grain protein where N was applied in-season at Ouyen), mid-row application by this method did not result in equivalent grain yield/ protein. While applying N using ultra-high injection is practical for handling higher stubble loads and narrower row spacings, it does not necessarily result in the same placement of N as a disc opener where the fertiliser is placed in the bottom of a furrow. Instead, the liquid is used to cut through the stubble and soil, resulting in a different pattern of distribution and concentration within the soil. This effect also depends on stubble load, soil type and conditions at the time of application, potentially affecting fertiliser availability to the crop and resulting in the observed differences in grain yield and protein between the two methods of mid-row banding.

Effect of placement on N use efficiency

Studies over numerous years have shown that on average, just 44% of the N fertiliser that is applied to Australian grain crops is taken up by the crop in the year of application (Angus and Grace 2017). While fertiliser recovery results for the 2018 field trials are not available at the time of writing, results from 2016 and 2017 indicated consistent increases in crop uptake where N fertiliser was applied by mid-row banding rather than by streaming nozzles or in a mid-row surface arrangement — average crop uptake of 60% for mid-row banding compared with 41%-42% for surface applications. While these improvements in N use efficiency also resulted in reduced loss of fertiliser N, the effects on grain yield and protein have been less consistent and it will be important to find ways to more consistently link improvements in crop N-recovery to productivity and profit.

Industry application

After undertaking a total of six field trials between 2016 and 2018, it has been found that crop response to placement of N fertiliser varies with season, soil type and timing of application. At three of the six sites, mid-row banding showed potential to increase yield compared with other methods of application, however at only one of these sites was it higher yielding than the current industry practice (i.e. banded below the seed at sowing or top-dressed granular in-season). For the Mallee, under dry seasonal conditions, mid-row banding of N in-season showed potential to significantly increase grain protein (increases of 0.5%-1.6%) compared with other methods of application. These results need to be considered against the costs of shifting to mid-row banding, particularly in the case of in-season applications where the increase in capital and operational costs would be greater.

Conversely, applying mid-row banding at sowing may be less expensive in terms of capital and operational costs while offering similar yields to banding below the seed and allowing application of higher rates of N without risking fertiliser toxicity (as observed at Ouyen when 100kg N/ha was banded below the seed). While the use of ultra-high-pressure injection in a mid-row configuration was only tested in 2018, it appears able to address some of the issues with applying mid-row N using conventional ground engagement tools. However, its performance in 2018 was variable and like other methods, its commercial application would need to be considered in relation to cost and availability of equipment to apply this on a large scale.

Conclusion

Nitrogen fertiliser placement had a variable effect on grain yield and protein/oil content in 2018. At Ouyen, where conditions were drier, surface application of 25-50kg N/ha at sowing tended to reduce grain yield compared to where N was banded either below the seed or in a mid-row configuration. However, banding a high rate of N (100kg N/ha) below the seed resulted in significant reductions in emergence. In situations where the risk of fertiliser toxicity is high and high rates of N are required at sowing, mid-row banding offers the potential to improve separation between seed and fertiliser. Application of N by mid-row banding in-season at Ouyen also significantly increased grain protein compared with all other methods of application, consistent with results at Ultima in 2017. At Longerenong, however, the effect of N placement on grain yield and oil content in canola was limited in 2018. In 2016 and 2017, mid-row banding of N fertiliser in-season significantly improved N use efficiency in wheat, however, given the variable response in grain yield and quality, it is important to consider the likely changes in capital and operational costs associated with changes in method of N application.

Useful resources

Sandral, G., Tavakkoli, E., Harris, F., Koetz, E., Diffey, S., Angus, J. (2018). Improving nitrogen fertiliser use efficiency in wheat using mid-row banding.

https://grdc.com.au/resources-and-publications/grdc-update-papers/tab-content/grdc-update-papers/2018/02/improving-nitrogen-fertiliser-use-efficiency-in-wheat-using-mid-row-banding

Wallace, A., Nuttall, J., Marsh, J. (2018). Refining nitrogen placement in cereals – mid-row banding.

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Notes

Southern Region pulse performance and agronomy update 2018 — Victoria

Jason Brand and Josh Fanning.

Agriculture Victoria.

GRDC project codes: DAV00150, DAV00154, DAN00212, UA00163, DAS00131, DAS00139, DAV00129, DAV00128, DAV00144

Keywords

- pulse varieties, herbicide tolerance, sowing dates, lentil, chickpea, faba bean, field pea, disease management, ascochyta blight, bacterial blight, Turnip yellows virus, aphids, frost.

Take home messages

- After several seasons of growth, the area sown to pulses in Victoria stabilised in 2018 in response to challenging climatic conditions and lower yields in 2017. Unfortunately, 2018 again proved to be challenging in many regions, particularly the Mallee and Wimmera, with extremely dry conditions and very low yields. High prices with faba beans have benefited many growers in the higher rainfall zone (HRZ) and west and south Wimmera. Many areas of the industry have now matured to a point where growers and advisers see pulses as part of the overall system for enduring on-farm profitability.
- Varieties: Three new pulse varieties were released in 2018 for production in 2019 — the first faba bean (PBA Bendoc⁽ᵇ⁾) and a new lentil (PBA Hallmark XT⁽ᵇ⁾) with high levels of tolerance to some imidazolinone (Group B) herbicides when applied post-emergence, and a faba bean (PBA Marne⁽ᵇ⁾) with adaptation to the lower rainfall and short season areas.
- Pathology
  - If seed was retained from paddocks infected with field pea bacterial blight or chickpea ascochyta during 2018, seed testing is recommended to reduce carryover of disease inoculum into 2019.
  - A disease management plan will be required to control pulse diseases during 2019.
  - In inoculated plots, Turnip yellows virus reduced grain yield by approx. 40% in field peas and 25% in lentils. More research is being conducted to validate these results.
- Sowing time: In contrast to previous sowing date trials which showed reduced grain yield from delayed sowing, in 2018 significant increases in grain yield in lentils and chickpeas at Ouyen from delayed sowing were observed. This was primarily due to the extremely frosty conditions during the reproductive phase. Economically, lentils would have made a loss at the yields achieved in the trials in 2018. Growing chickpeas would have been highly profitable (estimated returns of \$200-\$500/ha) at most sowing dates. primarily due to the extremely frosty conditions during the reproductive phase. Economically, lentils would have made a loss at the yields achieved in the trials in 2018. Growing chickpeas would have been highly profitable (estimated returns of \$200-\$500/ha) at most sowing dates.
- Novel herbicide tolerance: A breeding line with improved Group C herbicide tolerance demonstrated tolerance to a range of Group C products and has the potential to further enhance the yield stability in lentils across a range of soil types and improve weed control options.

Introduction

This paper highlights some of the key findings from pulse research in Victoria in 2018, discussing implications for the industry into the future:

- Frost and dry conditions in 2018 severely impacted trials and all results need to be treated with caution. Grain yields at all Southern Pulse Agronomy (SPA) sites (Horsham, Curyo and Ouyen) were generally less than 1t/ha except for some chickpea varieties and breeding lines at Ouyen.
- Pathology: Dry conditions in most parts of Victoria during 2018 meant that pulse diseases were less evident. However, ascochyta blight in chickpeas and bacterial blight in field peas were observed in some paddocks. In field trials, significant yield losses due to these diseases were observed, indicating the potential impact of diseases in dry seasons where there was no control.
- Novel herbicide options: Improvements in tolerance to Group C herbicides will have significant benefits for pulses, enhancing weed control in the farming system. Current Group C herbicide options can cause significant crop damage, particularly on lighter sandy soils. Improved Group C tolerance in lentils has been identified through the germplasm enhancement program and is being incorporated into adapted lines through the breeding program. In 2018, a trial at Ouyen investigated the relative tolerance of a new lentil breeding line with improved tolerance to Group C herbicides to metribuzin applied on a light sandy soil and a sandy loam in comparison to PBA Jumbo2Φ. Trials at Curyo and Horsham investigated the response of this line to a range of Group C products.
- Sowing dates: A range of higher yielding pulse varieties have been released and are being developed with improvements in agronomic traits including biomass production, lodging resistance, disease resistance, herbicide tolerance, maturity and pod retention. In addition, growers are sowing crops earlier to maximise yield potential and reduce risks of heat and terminal drought stress. However, this can also increase the risk of disease and frost or poor pod set under cold conditions. Research in 2018 at Ouyen and Horsham focused on understanding the opportunity for earlier sowing in lentil and chickpea varieties and breeding lines with a broad range of flowering and maturity times.

New variety releases

(Jeff Paull, University of Adelaide and Laura James, Arun Shunmugam and Jason Brand, Agriculture Victoria).

Faba beans

PBA BendocΦ

PBA BendocΦ (tested as AF15369) is the first faba bean variety with a high level of tolerance to some imidazolinone (Group B) herbicides when applied post-emergence. This not only increases the in-crop options for broadleaf weed control, but also enables the variety to be grown where some Group B (including the sulfonylureas) herbicide residues persist from applications to the previous crop. PBA BendocΦ has similar yield to the major faba bean varieties grown in southern Australia and is resistant to ascochyta blight. Seed is small to medium in size and suited to the Middle East markets. Seed is available through Seednet.

PBA MarneΦ

PBA MarneΦ (tested as AF09169) is an early flowering, high yielding faba bean that has shown adaptation to the lower rainfall and short season areas throughout southern Australia where yield is generally greater than current varieties. PBA MarneΦ offers the potential to expand faba bean production into areas that are currently considered marginal and to improve reliability in established areas during below average rainfall seasons. Seed is light brown and medium in size and suitable for co-mingling with the current faba bean varieties for export to the major food markets in the Middle East. Seed is available through Seednet.

Lentils

PBA Hallmark XTΦ

PBA Hallmark XTΦ (tested as CIPAL1422) is a superior yielding herbicide tolerant lentil. It builds on the success of the other herbicide tolerant red lentils, PBA Herald XTΦ and PBA Hurricane XTΦ. It incorporates the same improved tolerance to some Group B herbicides, but with higher grain yields and improved agronomic characteristics. PBA Hallmark XTΦ has greater early vigour, similar ratings to ascochyta blight and improved ratings to botrytis grey mould when compared to PBA Hurricane XTΦ. These features, combined with its herbicide tolerance, will make PBA Hallmark XTΦ a preferred variety in many cropping regions. PBA Hallmark XTΦ is in the process of an Australian Pesticides and Veterinary Medicines Authority (APVMA) permit and registration for imazethapyr use.

PBA Hallmark XT(|) is a medium red lentil, so this variety can provide an alternative market class option to the popular small red lentil PBA Hurricane XT(|). Seed is available through PBSeeds.

Pulse pathology 2019

(Joshua Fanning, Piotr Trebicki, Mohammad Aftab, Narelle Nancarrow, Tim Nigussie, Grant Hollaway and Jason Brand, Agriculture Victoria).

2018 survey results

Agriculture Victoria (AgVic) conducted a survey of 42 chickpea and lentil crops in the Wimmera and Mallee. Within chickpea crops 30% and 70% were affected with low levels of ascochyta blight respectively. No lentil foliar disease symptoms were observed in the 22 crops assessed.

Each crop was assessed for symptoms of root disease. Root lesion nematode damage was observed in every crop, but usually at low to medium levels. Currently, the yield losses in pulses due to root lesion nematodes are not known in Victoria.

Pulse disease management in 2019

Pulse diseases are best managed through implementation of a proactive plan prior to sowing. Avoid sowing 2019 crops next to paddocks which had the same crop type during 2018. Using disease free seed will reduce the risk of seed borne transmission of diseases into the 2019 season. Seed testing may be warranted along with application of seed treatments for the control of fungal diseases.

Disease ratings

The latest pulse disease ratings can be found in the Victorian Pulse Disease Guide 2019 http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/grains-pulses-and-cereals/pulse-disease-guide

Disease ratings in pulses are based on the reaction of the variety to the pathogen in ideal conditions for disease development. The ratings published are generated through both controlled environment and field conditions, to allow accurate ratings for growers to manage diseases when the disease has ideal conditions for development. Therefore, the environment within the local area and season should always be considered when developing management plans for the crops and varieties that are grown.

There are two important changes to disease ratings for 2019.

Pathotype 2 of ascochyta blight in faba beans has become dominant in Victoria, compared to previously where it was only identified around the Kaniva region. This significant finding by the South Australian Research & Development Institute (SARDI) means that the varieties Farah(|), PBA Zahra(|) and PBA Rana(|) are now all more susceptible to ascochyta blight. The new bean variety PBA Marne(|) is also more susceptible, while PBA Bendoc(|) will remain resistant.

In South Australia (SA), the ascochyta blight ratings for the lentil varieties PBA Hurricane XT(|) and PBA Hallmark XT(|) have been changed to moderately resistant to moderately susceptible (MRMS) from moderately resistant (MR). Currently there is not a change to the Victorian rating.

Soil-borne diseases

With a drier than average 2018 season, soil-borne diseases were detected more frequently in Victoria. This was a result of weakened root systems and the need for plants to extract water and nutrients from the soil more effectively, resulting in above ground symptoms. Rhizoctonia root rot and root lesion nematodes were commonly identified during 2018. They can be identified and monitored within paddocks using a PREDICTA® B test.

Bacterial blight

Significant bacterial blight infection was observed in field trials near Horsham, with the grain yield not measured due to the severity of infection (Table 1). Despite the severe infection, there is clear variation in the varieties, with some newer breeding lines showing a trend towards greater resistance or equal resistance as the released varieties such as PBA Percy(|), PBA Pearl(|) and PBA Oura(|).

Table 1. Bacterial blight infection in field pea varieties and breeding lines at Horsham during 2018, assessed at two different times as a percentage (%) of plot affected and the pairwise significance.

Variety	Percentage of plot affected (%) and pairwise significance			
	25/09/2018		15/10/2018	
Breeding Line 1	6	a	49	a
Breeding Line 2	9	ab	73	bcd
PBA Percy(b)	15	abc	69	b
Breeding Line 3	15	abc	83	bcdef
Breeding Line 4	16	abc	71	bc
Breeding Line 5	20	abc	86	bcdef
PBA Pearl(b)	23	abcd	79	bcde
PBA Oura(b)	26	abcd	88	bcdef
Breeding Line 6	30	abcde	93	ef
Breeding Line 7	36	bcdef	86	bcdef
PBA Coogee(b)	38	bcdef	91	def
Breeding Line 8	39	cdef	91	def
Breeding Line 9	41	cdef	89	cdef
PBA Butler(b)	50	defg	96	ef
Kaspa(b)	56	efg	99	f
PBA Gunyah(b)	64	fg	100	f
PBA Wharton(b)	77	g	90	cdef
Lsd (P<0.05)	29.8		19.8	
P value	<0.001		<0.001	

Chickpea ascochyta blight management

Anecdotal suggests evidence that newer fungicides have a curative effect on chickpea ascochyta blight. There are also several fungicides on permit or previously on permit that are used to manage ascochyta blight where there is minimal evidence of their ascochyta blight control in Victoria. Therefore, two trials were developed to asses 10 different fungicide timings or actives to manage ascochyta blight in chickpeas with these treatments presented in table 2. Within these treatments there were untreated (nil) plots and plots with no disease (fortnightly Chlorothalonil spray) as control plots to assess the effectiveness of treatments. Strategic sprays were applied before rainfall events, at key growth stages, to maximise foliage protection, which were 4th node and late vegetative / early flowering stage. Post infection sprays were applied when the first ascochyta blight lesions were observed with trials inspected at least weekly. Due to late rainfall, all treatments had a podding Chlorothalonil fungicide applied to protect the pods and seed quality.

Despite drier than average conditions and low grain yields in Horsham during 2018, there were still plots severely affected by ascochyta blight (Table 3). All fungicide treatments resulted in reduced disease

Table 2. Fungicide treatments and the number of sprays applied for each fungicide spray to assess control of Ascochyta Blight in chickpea at Horsham during 2018.

Seed Treatment	Rate (g/kg)	In Season Fungicide	Rate (gai/ha)	Timing	Number of Sprays
Thiram	0.72	Captan	1000	Strategically	2+1[A]
Thiabendazole	0.4				
Thiram	0.72	Propiconozole[B]	125	Strategically	2+1[A]
Thiabendazole	0.4				
Thiram	0.72	Chlorothalonil	1080	Strategically	3
Thiabendazole	0.4				
Thiram	0.72	Tebuconazole	200	Strategically	2+1[A]
Thiabendazole	0.4	Azoxystrobin	120		
Thiram	0.72	Bixafen	45	Strategically	2+1[A]
Thiabendazole	0.4	Prothioconazole	90		
Thiram	0.72	Tebuconazole +	200	Post Infection	1+1[A]
Thiabendazole	0.4	Azoxystrobin	120		
Thiram	0.72	Bixafen	45	Post Infection	1+1[A]
Thiabendazole	0.4	Prothioconazole	90		
Fluxapyroxad	0.5	Bixafen	45	Post Infection	1+1[A]
		Prothioconazole	90		
Thiram	0.72	Chlorothalonil	1080	Fortnightly	7
Thiabendazole	0.4				

[A] *This was a final podding spray of chlorothalonil (1080 gai/ha) due to a late rainfall event*

[B] *Please note propiconozole was not under permit during 2018*

Table 3. Grain yield, percentage plot affected with ascochyta blight and percentage of pods affected with ascochyta blight in plots treated with 10 fungicide treatments at Horsham during 2018. Different letters indicate pairwise significance where the variety, treatment or interaction were significant (P<0.05).

Treatment[A]	Timing	Yield (t/ha)			Plot affected (%)		Pod Infection (%)		
		Genesis™090	PBA Striker⁽ᴰ⁾	Mean	Genesis™090	PBA Striker⁽ᴰ⁾	Genesis™090	PBA Striker⁽ᴰ⁾	Mean
Nil	Nil	0.42	0.18	0.30 a	15 bc	54 d	58	63	60 d
Thiram (0.72g/kg) + Thiabendazole (0.4g/kg)on seed Captan (1000gai/ha)	Strategically	0.53	0.41	0.47 b	6 abc	18 c	26	23	24 c
Thiram (0.72g/kg) + Thiabendazole (0.4g/kg)on seed Propiconozole (125 gai/ha)	Strategically	0.54	0.43	0.48 bc	0 a	14 abc	23	26	24 c
Thiram (0.72g/kg) + Thiabendazole (0.4g/kg)on seed Chlorothalonil (1080 gai/ha)	Strategically	0.50	0.49	0.49 bc	9 abc	11 abc	9	13	11 b
Thiram (0.72g/kg) + Thiabendazole (0.4g/kg)on seed Tebuconazole (200 gai/L) + Azoxystrobin (120gai/ha)	Strategically	0.61	0.39	0.5 bc	11 abc	10 abc	15	20	18 bc
Thiram (0.72g/kg) + Thiabendazole (0.4g/kg)on seed Bixafen (45 gai/L) + Prothioconazole (90gai/L)	Strategically	0.58	0.52	0.55 bcd	6 abc	4 abc	13	18	15 b
Thiram (0.72g/kg) + Thiabendazole (0.4g/kg)on seed Tebuconazole (200 gai/L) + Azoxystrobin (120gai/ha)	Post Infection	0.60	0.50	0.55 bcd	6 abc	7 abc	15	13	14 b
Thiram (0.72g/kg) + Thiabendazole (0.4g/kg)on seed Bixafen (45gai/L) + Prothioconazole (90gai/L)	Post Infection	0.60	0.51	0.56 bcd	3 ab	15 bc	5	16	11 b
Fluxapyroxad (0.5g/kg) Bixafen (45gai/L) + Prothioconazole (90gai/L)	Post Infection	0.63	0.51	0.57 cd	3 ab	6 abc	6	16	11 b
Thiram (0.72g/kg) + Thiabendazole (0.4g/kg)on seed Chlorothalonil (1080gai/ha)	Fortnightly	0.65	0.60	0.62 d	0 a	9 abc	1	0	1 a
Mean		0.57	0.45		6	15	17	21	
		P value	**Lsd**		**P value**	**Lsd**	**P value**	**Lsd**	
Variety		<.001	0.042		<.001	4.37	0.069	ns	
Treatment		<.001	0.093		<.001	9.78	<.001	8.752	
Variety x Treatment		0.303	ns		0.005	13.83	0.758	ns	

[A] *All treatments had a chlorothalonil (1080gai/ha) spray applied prior to the November rainfall event at podding.*

severity and significantly (P<0.05) higher grain yield than the untreated plots. However, distinguishing between treatments was difficult due to the low grain yields. In a dry season the results highlight that all control methods reduced ascochyta blight infection and particularly pod infection. Grain quality data is currently being analysed and will enable us to assess the economic impacts.

Two further trials on chickpea ascochyta blight management, compared different breeding lines with two fungicide treatments which included a lower cost Chlorothalonil and a Bixafen + Prothioconazole treatments which were both applied at the 4th node and late vegetative/early flowering stages. Both treatments had an early podding stage Chlorothalonil spray applied. These two treatments were compared against untreated (nil) plots and plots with no disease (fortnightly Chlorothalonil spray). Table 4 shows the upcoming breeding lines against named varieties and their ascochyta blight infection during 2018 at Horsham. These results highlight the improvements in the breeding program with resistance to ascochyta blight, and that growers may be able to reduce the number of fungicide applications with the release of new chickpea varieties in the future.

Pulse viruses

There are several viruses affecting pulse crops across south-eastern (SE) Australia. Most of the viruses are spread by insect vectors, mainly green peach aphid, blue-green lucerne aphid and cowpea aphid, but some are also seed or contact transmitted. Based on recent surveys, Turnip yellows virus (formerly known as Beet western yellows virus), Cucumber mosaic virus and Pea seed borne mosaic virus are the most commonly detected and are widespread. Yield losses associated with pulse viruses are often crop and virus specific and season dependent. Although uncommon, during conducive conditions, virus incidence can reach high levels and can cause total crop losses. During an average year, virus incidence across pulse crops remains low to medium, although high levels are quite often detected in particular crops or locations.

As Turnip yellows virus is one of the most damaging viruses in SE Australia with a very wide host range, and also affecting canola crops, field trials were established in Horsham in 2018 to examine yield losses in lentils and field peas when infected with the virus. Field plots were infected with Turnip yellows virus early in the growing season

Table 4. Percentage plot affected of 15 chickpea varieties with ascochyta blight, when three different fungicide treatments were applied compared to no treatment.

Variety	Chlorothalonil (1080gai/ha) Fortnightly	Bixafen (45gai/ha) Prothioconazole (90gai/ha) Strategically	Chlorothalonil (1080gai/ha) Strategically	Nil	Mean
CICA1454	4	10	13	19	11
CICA1352	4	13	14	29	15
CICA1652	4	A	A	38	17
Genesis™090	5	21	10	33	17
CICA1156	5	14	18	35	18
CICA1552	5	11	16	50	21
D11094	6	18	19	40	21
Almaz⍉	5	24	13	50	23
Kalkee	8	14	19	53	23
CICA1551	8	14	20	53	23
PBA Slasher⍉	5	16	25	58	26
CICA1521	4	26	16	70	29
CICA1841	9	40	23	55	32
PBA Monarch⍉	8	39	23	68	34
Howzat⍉	8	31	24	76	35
Mean	6	20	17	48	
	P value	**Lsd**			
Variety	<.001	5.7			
Treatment	<.001	3.0			
Variety x Treatment	<.001	11.4			

[A] No data for these plots due to lack of seed.

by placing green peach aphids, which had been previously feeding on virus infected plants, into plots selected for virus treatment. Aphids and selected virus-treated plots were covered to contain the aphids and prevent virus contamination of control (healthy) plots (Figure 1). After the virus inoculation period, cages were removed, and then the trial was sprayed with insecticide. Plants were monitored for disease symptom development, harvested, and yield losses were determined. To better understand virus epidemiology, aphid activity was also monitored throughout the growing season, as well as monitoring of background virus presence. Sticky traps, water traps, and a solar powered suction trap (Figure 2) were deployed to collect aphid population data and to determine the height of aphid activity and therefore the potential of virus spread. Sampling of randomly selected plants was also conducted during the growing season. The plants were then tested to determine the overall virus infection with Turnip yellows virus, as well as other pulse viruses.

Overall, virus incidence across the region was very low in 2018 compared to previous years. Aphid activity was below detection levels during the early plant growth stages when plants are the most vulnerable to virus infection. A peak of aphid activity was recorded in October/November which was later than usual and explains the lower virus incidences compared to previous years. However, despite the late population peak, aphid numbers were extremely high when compared to previous years, with green peach aphid (Figure 3) and blue-green aphid the most abundant species across pulse crops. The inoculation method used for the field trials was successful, resulting in approx. 90% infection in both field peas and lentils. No obvious symptoms of virus infection were observed in inoculated field pea or lentil plots at any time throughout the season, however despite dry conditions and overall low yield potential, yield was significantly reduced by approximately 40% in field peas and 25% in lentils. Plant biomass at harvest was significantly reduced by virus infection in lentils, but not field peas.

This study shows significant yield losses as a result of virus infection, despite the absence of typical virus symptoms. The lack of any visible virus symptoms in lentils and field peas infected with Turnip yellows virus was surprising and concerning as it has implications for assessments of crop health and virus estimation. Further epidemiological studies need to be conducted to determine the interactions between pulse crops, virus infection and yield losses with different growing conditions and varied levels of virus presence.

Figure 1. Field inoculation using infected green peach aphid.

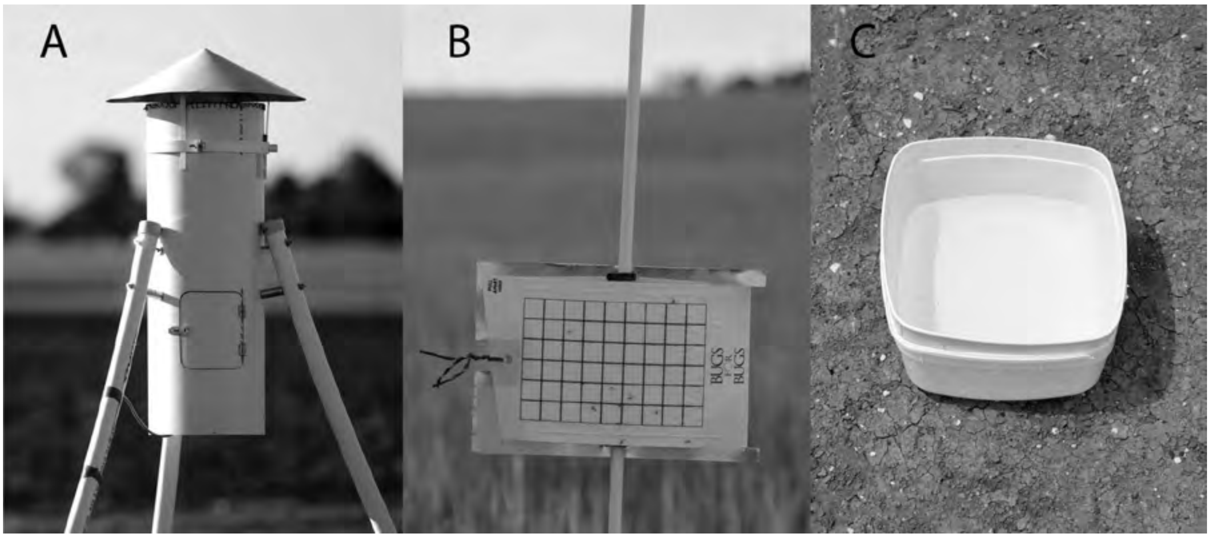

Figure 2. Aphid monitoring — (A) solar powered suction trap, (B) sticky trap and (C) water trap.

Figure 3. Green peach aphid, an important vector of pulse viruses in Australia.

Conclusion – pulse pathology

Although there were dry conditions in Victoria during 2018, the results from surveys and field trials highlight the importance of disease control in all years to prevent grain yield losses. In viruses, despite no visible symptoms, Turnip yellows virus reduced grain yields by approx. 40% in field peas and 25% in lentils. More research will be conducted to validate these results. Consult the latest disease ratings in the Victorian Pulse Disease guide 2019 and be aware that Pathotype 2 of faba bean ascochyta is widespread in Victoria.

Agronomic research highlights

(Jason Brand, Tim Nigussie, Mitchell Fromm, Abby Griffin, Agriculture Victoria and Michael Moodie, Moodie Agronomy and Christine Walela, Sarah Day and Penny Roberts, SARDI).

Southern Pulse Agronomy (SPA) is a collaborative agronomic research program supported by GRDC, DJPR and SARDI, with agronomic trials across SA and Victoria. Some key findings from 2018 in Victoria are highlighted below, particularly related to herbicide tolerance and sowing dates. Further research and details relating to agronomy and new varieties will be discussed during the updates. A complete summary of trials will be available later in 2019.

Herbicide tolerance – improved Group C tolerance in lentils

In the trial at Ouyen, the relative tolerance of a lentil breeding line to metribuzin applied on a light sandy soil and a sandy loam was compared to PBA Jumbo2$^{\phi}$. 2018 was a relatively dry year and as such the uptake of Group C chemicals, which is predominantly driven by root uptake, was lessened, resulting in lower crop damage levels than were expected. In general, higher herbicide damage scores and lower biomass were observed on the sandhill compared with the swale, probably due to the higher leaching and lower water holding capacity of the sandhill soil (Table 5). Across both soils, the post sowing pre-emergent (PSPE) treatments generally resulted in slightly higher crop damage scores than the 4-node application. On the sandy soil, the higher application rate killed PBA Jumbo2$^{\phi}$ and almost killed SP1333. Overall, SP1333 had significantly lower damage symptoms, particularly at the lower application rates.

Biomass production on the sandhill was significantly lower than the swale, with PBA Jumbo2$^{\phi}$ producing no or very little biomass in all herbicide treatments, while SP1333, had no biomass at the higher application rates and a 55% and 70% reduction in biomass at the lower application rates

Table 5. Herbicide damage score (0 – no damage, 100 – complete plant death; Aug 28) and maturity biomass (t/ha) of a lentil breeding line with improved tolerance to Group C herbicides in comparison with PBA Jumbo2A in response to two application rates of metribuzin post sowing pre-emergent (PSPE) and at the 4-node growth stage on a sandhill (sand) compared with a swale (sandy loam) at Ouyen in 2018.

Breeding Line/Variety	Application Rate (gai/ha)	Application Timing	Herbicide Damage (0-100)		Maturity Biomass (t/ha)	
			Sandhill	Swale	Sandhill	Swale
PBA Jumbo2⏀	0	nil	0	0	0.91	2.28
SP1333	0	nil	0	0	1.42	2.59
PBA Jumbo2⏀	105	PSPE	91	55	0.05	1.50
SP1333	105	PSPE	38	20	0.62	2.00
PBA Jumbo2⏀	105	4-node	85	30	0.08	1.77
SP1333	105	4-node	21	19	0.45	2.27
PBA Jumbo2⏀	210	PSPE	100	71	0.00	0.61
SP1333	210	PSPE	98	76	0.00	0.94
PBA Jumbo2⏀	210	4-node	100	85	0.00	0.61
SP1333	210	4-node	91	60	0.10	1.31
LSD (P<0.05)						
Herbicide x Variety			10	16	0.22	ns
Herbicide			9	14	0.17	0.53
Variety			3	5	0.10	0.29
CV			9	24	30	21

of the PSPE and 4-node timings, respectively. On the swale, both PBA Jumbo2⏀ and SP1333 showed significant biomass reduction from all the herbicide treatments, however the reduction was 10% less in SP1333 than PBA Jumbo2⏀. Grain yields are not presented, due to the poor season and the high shattering rate of SP1333.

In trials at Curyo and Horsham investigating the response to Group C herbicides, the new lentil breeding line with improved tolerance, showed significantly less herbicide damage than PBA Jumbo 2⏀ to eight different Group C herbicides applied at the 4-node crop growth stage (data not shown). Maturity biomass and grain yield assessments indicated both the breeding line and PBA Jumbo2⏀ potentially had some reduction due to herbicide application, although specific differences were difficult to assess due to the dry seasonal conditions.

Conclusion

These results indicate that the level of Group C tolerance in SP1333 can reduce herbicide damage from Group C chemicals and this could be particularly beneficial on sandy soils. This tolerance trait, along with other adaptive traits, is being incorporated into advanced breeding lines for further assessment and has the potential to further enhance the yield stability in lentils across a range of soil types and improve weed control options.

Sowing dates

Grain yields of lentil varieties and breeding lines ranged between 0.15t and 0.55t/ha at Ouyen and 0.05t and 0.57t/ha at Horsham in 2018 (Tables 6 and 7), which was well below the estimated potential of 0.70t to 1.50t/ha based on biomass at maturity and visual pod counts. At both sites, several frosts, in addition to very dry conditions during the flowering and podding phase, significantly impacted on grain yields, particularly the earlier sown treatments which were further advanced in the reproductive phase and unable to recover. Based on assessments at Ouyen, it was estimated that 80%-90% of pods were affected in the April 12 'I' treatment, 60%-70% of pods in the April 12 'D', April 26 and May 10 treatment and 20%-40% of pods in the May 25 treatment (data not shown). Varietal differences were not obvious. No specific assessments were recorded at Horsham, although visually, pod damage was similar.

At Ouyen across all varieties, yields increased linearly by 7.2kg/day from 0.19t/ha sown April 12 to 0.50t/ha sown May 25. The dry sown treatment, which emerged at a similar time to May 10, had grain yields similar to the April 26 sown treatment. The trend was similar at Horsham, where across all varieties yields increased linearly by 11.8kg/day from 0.10t/ha sown April 20 to 0.43t/ha sown May 18, but then decreased to 0.32t/ha sown June 1. The April

20 dry sown treatment which emerged between the May 4 and May 18 treatments, had grain yields similar to the June 1 treatment.

The trends observed in 2018 are completely opposite to long term trial results, particularly in the Mallee for lentils, which generally indicate significant benefits from earlier sowing. Comparing the varieties, the mid to late maturing variety CIPAL1504 was highest yielding at both sites. CIPAL1504 has now consistently performed well, particularly in all Mallee trials across multiple seasons and sites, except where Botrytis grey mould was a yield limiting issue.

In addition to the reproductive frosts in the Ouyen trial, there was a significant vegetative frost, which enabled assessment of potential varietal differences. The breeding line 10H202L showed the worst damage, followed by PBA Hurricane XT⦹ and CIPAL1522 (data not shown). All other varieties/lines showed little damage. Potential linkages to breeding families are being explored and will be addressed in the update presentation, however currently there appears to be no specific link to the imidazolinone tolerance trait, which had been suggested in industry.

Economically, lentil varieties and breeding lines would have made a loss at the yields achieved in the trials in 2018.

Table 6. Grain yield (t/ha) of lentil (A) and chickpea (B) varieties and breeding lines sown at four sowing dates in 2018 at Ouyen. All sowing dates were irrigated 'I' with 10mm of water at sowing, except Apr 12 'D', which was sown dry and established on rainfall in early May.

A. Lentil						
Variety	**Apr 12 'D'**	**Apr 12 'I'**	**Apr 26 'I'**	**May 10 'I'**	**May 25 'I'**	**Ave**
CIPAL1504	0.25	0.27	0.42	0.43	0.48	0.37
PBA Greenfield⦹	0.33	0.23	0.31	0.41	0.55	0.37
PBA Jumbo2⦹	0.29	0.19	0.26	0.38	0.54	0.33
PBA Hurricane XT⦹	0.29	0.19	0.28	0.36	0.52	0.33
CIPAL1522	0.17	0.16	0.29	0.38	0.53	0.31
CIPAL1721	0.27	0.16	0.23	0.37	0.43	0.29
10H202L	0.26	0.15	0.25	0.38	0.40	0.29
PBA Ace⦹	0.19	0.18	0.24	0.28	0.55	0.29
Ave	*0.26*	*0.19*	*0.29*	*0.37*	*0.50*	*0.32*
LSD *(P<0.05)*						
TOS x Variety	*ns*					
TOS	*0.11*					
Variety	*0.05*					
CV	*26*					
B. Chickpea						
Variety	**Apr 12 'D'**	**Apr 12 'I'**	**Apr 26 'I'**	**May 10 'I'**	**May 25 'I'**	**Ave**
CICA1454	0.97	0.42	0.85	1.11	1.11	0.89
Genesis™ 090	0.93	0.48	0.70	0.98	1.16	0.85
Kalkee	0.92	0.46	0.74	1.02	1.05	0.84
CICA1551	0.89	0.29	0.77	1.02	1.15	0.82
PBA Striker⦹	0.92	0.40	0.78	0.95	1.02	0.81
CICA1352	0.95	0.31	0.54	1.02	1.11	0.79
D12084	0.74	0.41	0.72	0.89	0.91	0.73
D11022	0.79	0.36	0.64	0.80	0.97	0.71
Ave	*0.89*	*0.39*	*0.72*	*0.97*	*1.06*	*0.81*
LSD *(P<0.05)*						
TOS x Variety	*0.15*					
TOS	*0.10*					
Variety	*0.05*					
CV	*10.5*					

Grain yields of chickpea varieties and breeding lines ranged between 0.29t and 1.16t/ha at Ouyen and 0.12t and 0.70t/ha at Horsham in 2018 (Tables 6 and 7), which was below potential, particularly for early sown treatments. At Ouyen, yields were impressive for the later treatments, which were able to respond to later rain events, however at Horsham, the response was much less. Similar to lentils, several frosts and dry cold conditions during the flowering and podding phase significantly impacted on grain yields. At Ouyen, unlike lentils though, it was only the Apr 12 'I' treatment which was unable to recover and set adequate yield.

Across all varieties at Ouyen, yields increased from 0.39t/ha sown April 12 to 1.06t/ha sown May 25. The dry sown treatment, which emerged at a similar time to May 10, had grain yields similar to the April 10 sown treatment. At Horsham, the early sown irrigated treatment had lowest yields (0.34t/ha), while other treatments were similar (between 0.50t and 0.62t/ha). The trends observed in 2018 are completely opposite to long term trial results in the Mallee and Wimmera for chickpeas which generally indicate significant benefits from earlier sowing.

Comparing the varieties at Ouyen, CICA1454 was the highest yielding, slightly greater than Genesis™090, while at Horsham, Kalkee had highest yields, slightly higher than CICA1454. The earlier flowering breeding lines, which were severely impacted by frost, were lowest yielding at both

Table 7. GGrain yield (t/ha) of lentil (A) and chickpea (B) varieties and breeding lines sown at four sowing dates in 2018 at Horsham. All sowing dates were sown dry 'D', except a treatment at April 20 which was irrigated 'I' with 10mm of water at sowing.

A. Lentil						
Variety	**Apr 20 'D'**	**Apr 20 'I'**	**May 04 'D'**	**May 18 'D'**	**Jun 01 'D'**	**Ave**
CIPAL1504	0.43	0.23	0.35	0.47	0.39	0.37
CIPAL1522	0.38	0.07	0.28	0.57	0.42	0.34
CIPAL1721	0.36	0.08	0.29	0.39	0.37	0.30
PBA Hurricane XT⦸	0.35	0.11	0.20	0.37	0.29	0.26
10H202L	0.29	0.08	0.20	0.40	0.31	0.26
PBA Ace⦸	0.21	0.06	0.18	0.46	0.26	0.23
PBA Greenfield⦸	0.19	0.06	0.23	0.37	0.27	0.22
PBA Jumbo2⦸	0.26	0.07	0.16	0.37	0.26	0.22
Ave	*0.31*	*0.10*	*0.24*	*0.43*	*0.32*	*0.28*
LSD *(P<0.05)*						
TOS x Variety	*0.11*					
TOS	*0.09*					
Variety	*0.04*					
CV	*22.3*					
B. Chickpea						
Variety	**Apr 20 'D'**	**Apr 20 'I'**	**May 04 'D'**	**May 18 'D'**	**Jun 01 'D'**	**Ave**
Kalkee	0.61	0.58	0.64	0.72	0.55	0.62
CICA1454	0.54	0.45	0.51	0.70	0.75	0.59
CICA1551	0.54	0.35	0.57	0.61	0.69	0.55
CICA1352	0.58	0.38	0.56	0.68	0.55	0.55
Genesis™ 090	0.49	0.24	0.50	0.74	0.70	0.53
PBA Striker⦸	0.48	0.12	0.53	0.55	0.63	0.46
D11022	0.42	0.29	0.46	0.46	0.49	0.42
D12084	0.34	0.27	0.39	0.48	0.49	0.39
Ave	*0.50*	*0.34*	*0.52*	*0.62*	*0.61*	*0.52*
LSD *(P<0.05)*						
TOS x Variety	*0.16*					
TOS	*0.13*					
Variety	*0.06*					
CV	*18.2*					

sites. CICA1454 has now consistently performed well, particularly in all Mallee trials across multiple seasons and appears to have slightly improved resistance to ascochyta blight. From an economic perspective, growing chickpeas would have been highly profitable at Ouyen (estimated returns of $200-$500/ha) at all sowing dates except Apr 12 'I' which would have broken even. At Horsham, due to higher production costs associated with disease management, growing chickpeas could have 'broken even'.

Conclusion

In 2019, growers are encouraged to continue sowing pulses in the optimal sowing window and avoid delayed sowing unless there is a strategic management advantage, related to disease or weed control or they are being sown in a frost prone region. In the long term, from a Victorian perspective, early sowing has generally proved profitable as heat events and rapidly drying soil, during late spring in the flowering and podding phase occur almost every year and cause significant yield loss with delayed sowing.

Lentil can be a highly profitable crop, but the last 2 seasons have reminded us that there are still many challenges to ensure long term reliability. Growers are encouraged to continue to take a long term view being aware that the long term price average for lentils is between $500 and $600/t.

In chickpea, CICA1454 has now consistently performed well in all Mallee trials across multiple seasons and appears to have slightly improved resistance to Ascochyta blight. From an economic perspective, growing chickpea would have been profitable (estimated returns of $200 - $500/ha) at most sowing dates.

Acknowledgements

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Notes

Frost response in lentils

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Keywords

- pulse, radiant frost, remote sensing, reproductive period.

Take home messages

- The Mallee experienced an above average number of frost days during 2018, where the trial site (12km north west of Ouyen) recorded 37 mornings below 0°C between August and October.
- Lentils were most susceptible to frost during the flowering and pod filling stage, where temperatures below 0°C at canopy height decrease grain yield and quality.
- Frost applied at flowering reduced grain yield when a threshold of 31°C.hr (<0°C) was reached, with a yield decline of 3.8% per °C.hr.
- Frost applied during pod filling reduced grain yield by 2% per °C (<0°C).
- Under severe frost conditions experienced in 2018, conventional and imidazolinone (imi) tolerant lentils were equally affected by natural frosts, indicating that imi tolerance was not linked to increased frost sensitivity.

Background

Radiant frost can significantly reduce the yield and quality of lentils, with economic losses due to frost damage in broadacre cropping estimated to be $360 million per year in Australia (March et al.2015, Watt. 2013, Rebbeck et al. 2007). For lentils, frost damage can occur at any development stage following emergence, but the greatest potential for damage coincides with the reproductive period.

Over recent years, frost damage has occurred across widespread parts of the Mallee and Wimmera and caused significant reductions in grain yield and quality. Recent increases in the severity and duration of frost across southern Australia (Crimp et al. 2016), combined with the widespread adoption of earlier sowing of pulses, have increased crop exposure to frost damage. Furthermore, industry perception exists that Group B herbicide tolerant lentil varieties suffer greater yield reductions compared to conventional lentil varieties because of frost.

Management strategies to mitigate frost damage are through avoidance, manipulating variables such as sowing date, crop and variety selections. However, these strategies can create alternative problems, including shifting the reproductive phase further into the heatwave window. Reducing stubble loads also can reduce the severity of frost, however, this does not offer a practical solution where yield gains associated with standing stubble are greater.

This paper reports on field trials conducted at Horsham in 2017 and Ouyen in 2018 which aimed to identify the fundamental response of lentils to frost damage, opportunities to detect damage using electronic sensors and the relative response of Group B tolerant varieties compared with conventional varieties.

Method

Mobile frost chambers were used to examine the effect of simulated frost on lentil growth and yield near Horsham (2017) and Ouyen, Victoria (2018). Experimental work in 2017 assessed the response of lentils (cv. PBA Jumbo 2⁽ᵗʰ⁾) to 12 frost scenarios, where temperatures below 0°C were applied at flowering, early pod, flat pod, and pre-filled pod. In 2018, experimental work at Ouyen was designed to determine if Group B herbicide (imi) tolerance in lentils is linked to increased sensitivity to frost. In this trial, frost was applied at either the late vegetative or late podding stage. The trial was replicated six times and included six lentil varieties differing in imi rating.

Imi tolerant varieties — PBA Hurricane XT⁽ᵗʰ⁾, PBA Herald XT⁽ᵗʰ⁾, PBA Hallmark XT⁽ᵗʰ⁾, CIPAL 1721.

Conventional varieties — PBA Jumbo 2⁽ᵗʰ⁾, PBA Flash⁽ᵗʰ⁾.

Frost application

In both years, temperatures below 0°C were applied to lentils, using mobile field frost chambers (Nuttall et al. 2018), where these simulated frost events were applied over a single night between 9pm and midnight. These were compared with two sets of control plots — open control (OC) constituting lentils grown under ambient air throughout the growing period, and a chamber control (CC) where plants were protected from frost using chambers which were installed when frost conditions were forecast. During the 2018 season, the OC plots included natural frosts.

Cold load

To account for the varying severity in frost (temperature × duration) imposed on lentils, the cold load was calculated as the sum of degrees Celsius (^{0}C) below 0^0C for the logged temperature data to give a ^{0}C.hr.

Remote sensing

Proximal sensing was used to monitor the crop to determine whether non-destructive methods could be used to detect early (pre-visual) frost damage within lentils. A portable spectrometer was used to determine reflectance indices including normalised difference vegetation index (NDVI) (Rouse Jr, 1974 #682) and photochemical response index (PRI) (Gamon, 1992 #636).

Results and discussion

2018 season

In 2018, the Mallee sustained a significant number of frost days during late winter and spring, coinciding with late vegetative and early reproductive phase of many crops. The trial site 12km north west of Ouyen recorded 37 mornings below 0^0C at canopy height between August and October with temperatures dropping below -2^0C on 26 of these mornings. The crop canopy temperature was approximately 2^0C lower than that recorded at 1.2m above the ground surface in a Stevenson screen (1.2m) (data not shown). This demonstrates that crops experience colder temperatures than those generally recorded by weather stations. Growing season rainfall (April-October inclusive) was 93mm, well below the long-term average of 178mm.

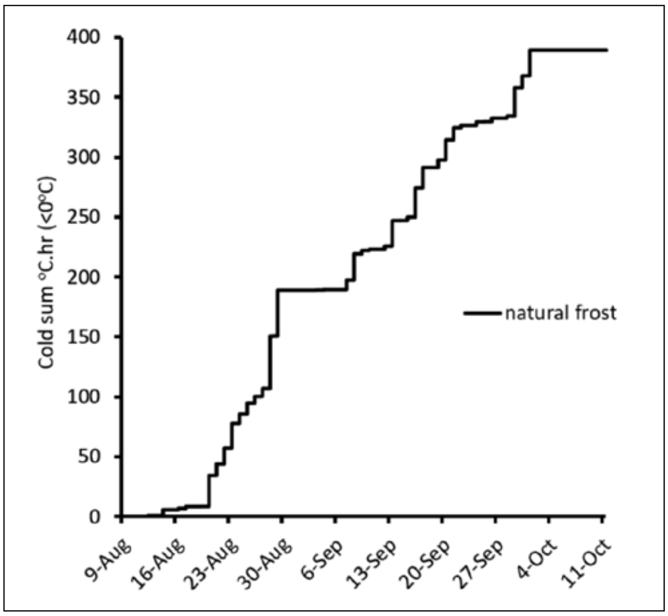

Figure 1. Cumulative cold load ^{0}C.hr (<0^0C) of natural frost recorded received by lentils during the reproductive period at the Ouyen trial site during 2018. Cold load ^{0}C.hr (<0^0C) is the total time and temperature crops were exposed to below zero degrees at canopy.

Timing of frost

A relationship between lentil yield response and cold load was defined using field data during 2017 at Horsham, Victoria, where no natural frost was recorded during the reproductive window. At flowering, damage occurs when a threshold of 31^0C.hr (<0^0C) is reached, hereafter yield decline was 3.8% per ^{0}C.h. At pod filling for every degree hour below zero, there was a 2% reduction in grain yield. The difference in response to frost at flowering and pod filling indicates that timing, intensity and duration affect the extent to which lentils recover from frost. The capacity for lentils to recover is greater at flowering, but limited by intensity and duration.

The response of lentils to frost in 2018 differed to that observed in 2017 (Figure 2). In 2018, absolute yields were lower and there was no clear relationship between cold load (applied and natural) and grain yield. This is due to a combination of dry seasonal conditions (decile 1) and multiple, severe natural frosts during the reproductive period. For the 2018 trial, the OCs (crops that were exposed to natural frosts only) received 78^{0}C.hr (<0^{0}C), during the treatment window (five days pre and post vegetative and pod filling frost application) compared to the maximum cold load applied to the treated plots in 2017 (67^{0}C.hr <0^{0}C). Yields measured in 2018 suggest that in years where yield potential is lower, the effect of frost is less compared to years with average rainfall.

Lentil marketability is strongly influenced by visual characteristics such as discolouration, deformation and shrivelling. Frost, as well as other abiotic stresses, can affect these qualities. For lentils exposed to a range of frost scenarios (2017 trials), there was a corresponding degradation in visual quality with increasing cold load (Figure 3). In contrast, there was minimal damage to lentil grain when frost was applied at flowering, regardless of intensity and duration (data not shown).

Variety response to frost

For the natural frost conditions which occurred in 2018, all varieties were equally susceptible to frost (p = 0.441), indicating that imi tolerance was not linked to increased frost sensitivity under these conditions (Figure 4a). Furthermore, the cumulative yield impact induced by the artificial frost applied at the late vegetative and podding stage, over the natural frost effects, was also equivalent for the conventional and imi varieties (Figure 4b). Future work would include verifying this pattern of response to frost under wetter growing conditions

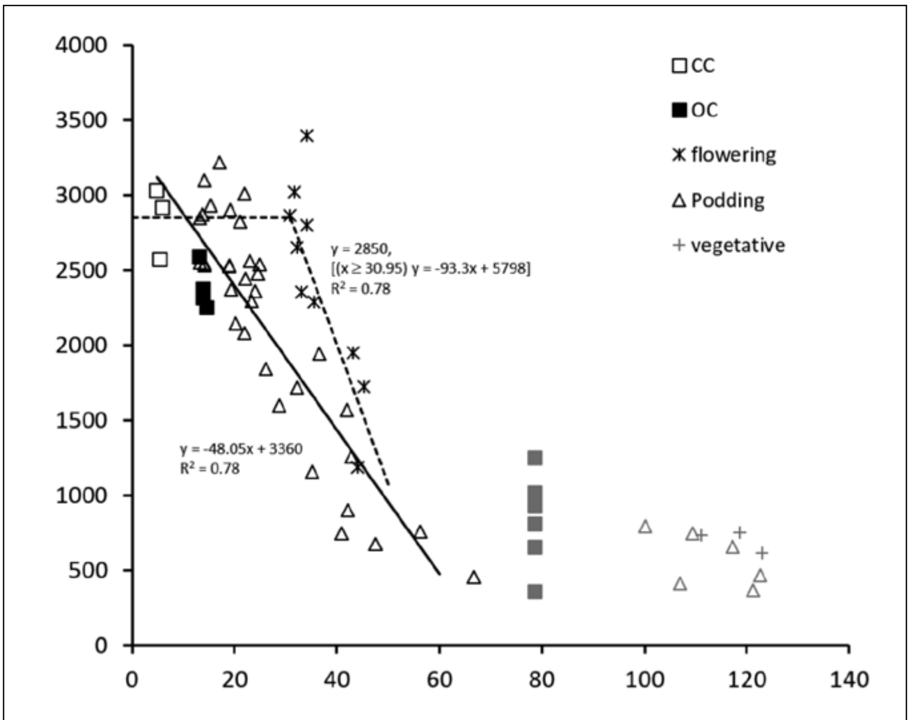

Figure 2. Relationship between lentil cv. PBA Jumbo 2$^{\phi}$ grain yield and cold load (°C.hr <0°C) associated with frost treatments applied at five different growth stages — late vegetative, flowering, early pod, flat pod and filling pod. The 2017 data (black) is fitted by two regression models. The 2017 CC and flowering data were fitted with a segmented regression (dash line). The 2017 CC, OC and pod filling stages were fitted with a linear regression (solid line). The 2018 data (grey) have cold loads >70 ^{0}C.hr <0^{0}C, and cold loads did not relate to yield reduction. For this analysis, the cold loads were defined by the cumulative temperature below 0^{0}C during the treatment window (five days either side of applied treatments), when the canopy was exposed to natural and applied frost.

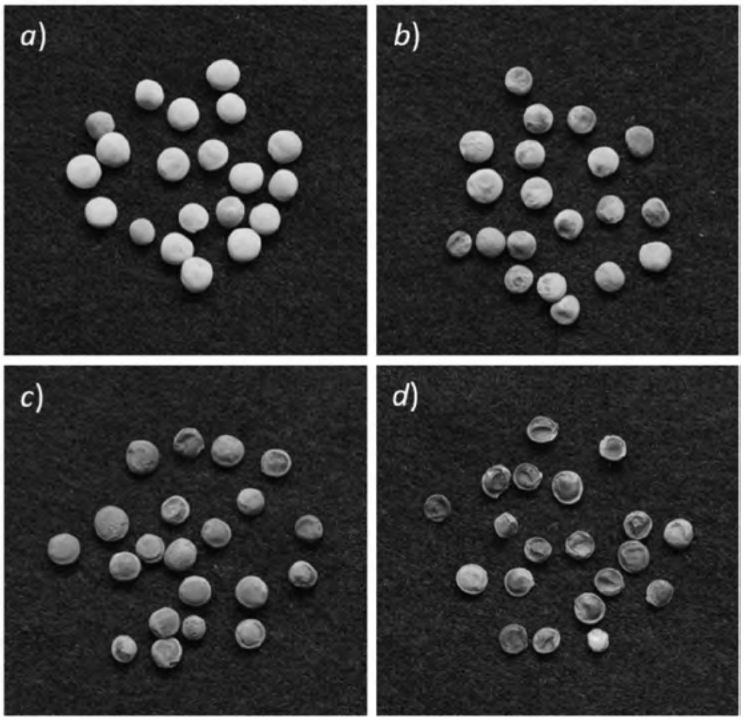

Figure 3. Frost affected lentil grain. Visual characteristics of lentil cv. Jumbo 2$^{\Phi}$ where frost treatments of varying intensities have been imposed on plants during the pod filling phase. A control (5°C.hr <0°C) a) is compared with b) 16, c) 22 and d) 43°C.h.

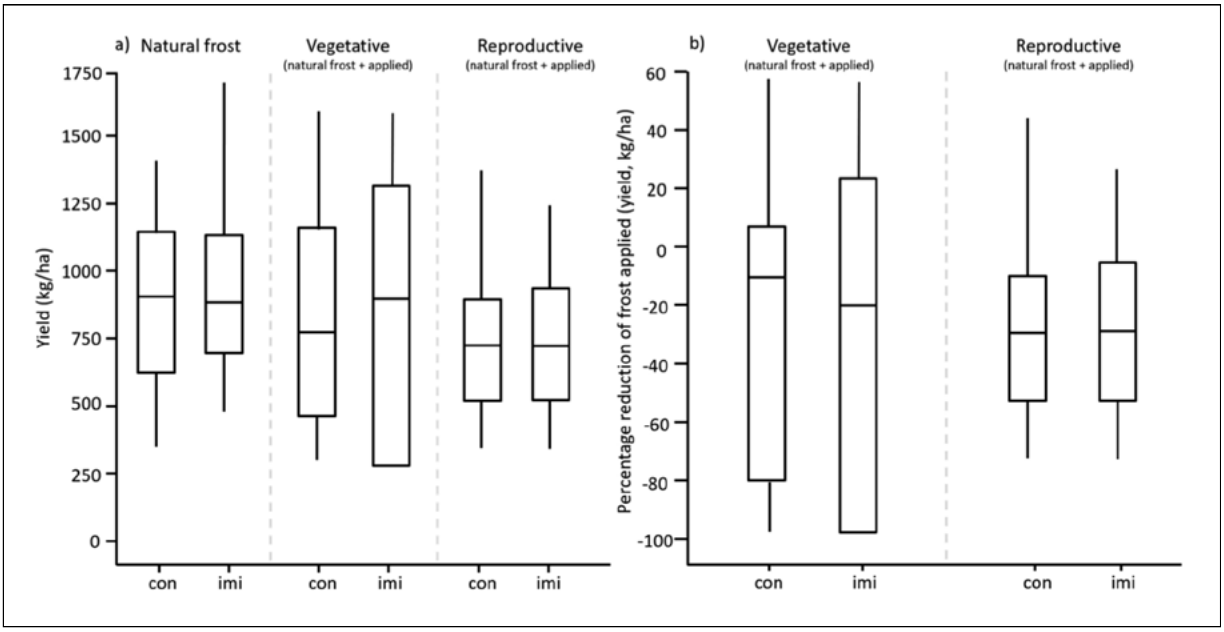

Figure 4. Comparison of conventional to imi varieties tested in 2018 field trial at Ouyen. The differences in grain yield across conventional and imi varieties a), and the reduction in grain yield (%) of frost applied at vegetative and pod filling, compared to natural frost only b). Frost treatments are natural frost, applied at vegetative and natural frost, applied at reproductive and natural frost.

where yield potential is greater than in 2018, and alternative frost stress patterns.

For pooled response across conventional and imi varieties, there was an overall reduction in grain yield of 40% and 13% for artificial frost pyramided on natural frosts (average minimum -2.4°C), applied during the vegetative (average minimum -5.07°C) and reproductive (average minimum -4.58°C) phase, respectively (Figure 4a). The effect of the applied frost was equivalent for the late vegetative and pod filling treatments.

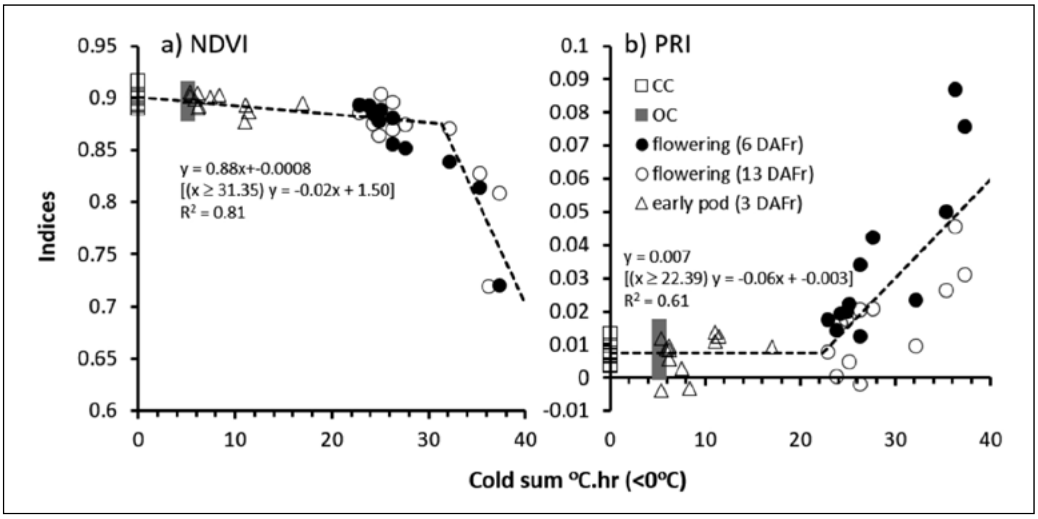

Figure 5. Reflectance indices for lentil cv. Jumbo 2⁽ᵇ⁾ exposed to frost at varying intensities expressed as cold loads. Reflectance indices a) NDVI and b) PRI were measured using a portable spectrometer 10cm above the canopy at 6 days after frost (DAFr)and 13 DAFr (following flowering application) and 3 DAFr (following podding treatment). Segmented regression models are for CC, OC, flowering and early podding data. 0 DAFr is the day following the night of frost application.

Early detection using remote sensing

The impact of frost to lentils was measured using proximal sensing following the application of artificial frosts in 2017. Several reflectance indices were strongly correlated with cold load, including NDVI and PRI. There was a strong negative correlation between cold load and NDVI where cold loads exceeded 31.3^{0}C.hr (<0^{0}C). PRI was more sensitive to frost damage compared to NDVI, where beyond a threshold of 22.39 °C.hr (<0^{0}C), PRI increased, indicating a step-change response induced by frost above this threshold.

The good agreement of NDVI and PRI to crop reflectance of frost affected crops supports the potential to utilise non-destructive measurements using proximal and remote sensing tools (e.g. vehicle mounted, airborne or satellite imagery). This work requires ongoing validation to confirm the utility of these and other potential indices and extend the assessment of frost damage to a larger scale spatial context (e.g. paddock scale).

Conclusion

Radiant frost continues to limit production of lentils in southern Australia, reducing grain yield and causing deformation of grain. Lentils are susceptible to frost damage at any time from emergence to maturity, but are most susceptible to frost during the pod filling stage, where we defined for every degree hour below zero, there is a 2% reduction in grain yield. There was no difference between imi tolerant and conventional varieties, under severe frost conditions, from the late vegetative to late pod filling stage. Preliminary work shows that there is a strong relationship between NDVI and PRI with cold load, indicating that there is potential to apply these technologies on a paddock scale to assess frost damage. Ongoing work is required to build on the fundamental response of lentils to frost effects, where the influence of the indeterminate growth habit, imi tolerance and diagnostics using remote sensing need further defining.

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GRDC

GRAINS RESEARCH
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CORPORATION

Final session
Day 2

Australian agvet chemical review program in perspective

Gordon Cumming.

Grains Research and Development Corporation (GRDC).

Keywords

- crop protection, agvet, chemicals, APVMA, regulations, review, reconsideration.

Take home messages

- The Australian agvet regulatory system is a scientific, evidence-based risk assessment process which is highly recognised internationally.
- Agvet chemicals are nominated for review based on key criteria of concern including human health (toxicology and occupational health and safety), environment, residues and trade, target crop safety and efficacy.
- The greatest direct influence that grain growers can have on retaining their access to agvet chemicals is to only use chemicals for their registered or permitted use and closely adhering to all label directions for use.
- Maintenance of access to agricultural chemicals for broadacre use is reliant on growers showing strong stewardship in following label directions for use.

Background

The Australian Pesticides and Veterinary Medicines Authority (APVMA) is the Australian Government regulator of agricultural and veterinary (agvet) chemical products. It is responsible for the regulation of agvet chemicals into the Australian market place and needs to be satisfied that the intended use does not harm the health and safety of people, animals and crops, the environment, and trade. It does this through:

- Evidence-based evaluation and approval of active constituents and the registration of agvet chemical products.
- The review of certain agvet chemicals of concern to ensure that they continue to meet contemporary scientific standards.

For an agvet chemical product to legally be manufactured, imported, supplied or sold in Australia, it must be registered by the APVMA. The registration process involves scientifically evaluating the safety and efficacy (effectiveness) of a product in order to protect the health and safety of people, animals, plants and the environment.

The APVMA looks to new data, information and science when considering the ongoing safety of a registered product, the full range of risks and how human exposure can be minimised through instructions for use and safety directions.

The assessment determines whether the agvet product, when used in accordance with the label or permit directions for use, would have a harmful effect on human health, occupational health and safety, the environment or trade.

The APVMA's approach to chemical risk assessment

All products registered for use in Australia have been through a robust chemical risk assessment process and are safe when used as per the label instructions.

As Australia's agvet chemical regulator, it is the role of the APVMA to consider all relevant scientific material when determining the likely impacts on human health and worker safety including long term and short-term exposure to users and residues in food before registering a product.

It is the role of the regulator to determine whether products used according to label instructions could result in a level of exposure that poses an unacceptable risk.

Consistent with regulators in other countries, the APVMA uses a risk-based, weight-of-evidence assessment, which considers the full range of risks, including studies of cancer risks, and how human exposure can be minimised through instructions for use and safety directions.

Chemical risk assessment = hazard assessment + exposure assessment

Hazard assessment: Is an assessment of the data related to the intrinsic toxicity potential of an active constituent and/or formulated product.

Exposure assessment: Is an assessment of the likely exposure of humans and environmental organisms that takes into account how the chemical product is to be used, the type and formulation of the product, and the crops or animals to be treated.

Australian Chemical Review Program

The APVMA considers a wide range of scientific data submitted by registrants in support of an application to approve an active constituent or to register a product containing that active constituent. The Chemical Review Program reconsiders the registration of agvet chemicals in cases where credible new scientific information has been generated after a product has been registered that suggests the existence of previously unknown risks to human health, worker safety, the environment, trade and/or product performance has been identified.

If this happens, the APVMA can initiate a reconsideration process (commonly called a chemical review) to assess the identified risk(s) and determine whether changes are needed to ensure that the product can continue to be used safely and effectively.

Chemical reconsiderations are managed under the auspices of the APVMA's Chemical Review Program, which was established in 1995.

The APVMA may undertake a reconsideration to scientifically reassess the risks and determine whether regulatory changes are necessary. Depending on the review's findings, active constituents and the products containing them might:

- be confirmed as safe and appropriate for the registered use(s).
- be restricted in use, by making label amendments to limit the situations in which product(s) may be used, or;
- have its registration suspended pending specific action or cancelled or be withdrawn voluntarily from the market by the registrant(s).

The reconsideration process incorporates legislative, administrative and scientific elements that contribute to the final decision to affirm, vary, suspend or cancel a registration. As a result, reconsiderations can be complex, have high resource requirements and long timeframes.

Prior to 2014, chemical reconsiderations were not time limited—the timeframe of individual reviews was determined by the scope and specific details of the review. For this reason, the time that it has taken to complete individual reviews has been highly variable, ranging from less than six months for the most straightforward label review to more than 10 years for some of the more technically complex and large reviews. The average time taken to complete a review has been just over three years.

From 1 July 2014, chemical reviews will be completed within a prescribed timeframe — under current legislation, a reconsideration must be completed within a maximum of 57 months.

Listing of agricultural chemical reviews

Over the more than 20 years that the Chemical Review Program has been in place, a total of 63 reviews have been completed, with 13 chemicals currently under active review. An additional 19 chemicals have been identified for review prioritisation (Table 1).

Of the 13 chemicals currently under review, eight have broadacre grains registrations as highlighted in Table 1.

Of the 63 completed chemical reviews, 10 had broadacre grains registrations and are listed in Table 2 with a brief description of the regulatory decisions which resulted in:

- Registrations cancelled of two products (endosulfan and fenthion).

- Label amendments/variations of four products (atrazine, dimethoate, diuron, omethoate).
- No changes to broadacre cropping use patterns of four products (bifenthrin, bromoxynil, carbendazim, glyphosate).

A full description of the review status details and regulatory decision(s) for all current and completed chemical reviews is available on the APVMA website.

Listing of chemical reviews: https://apvma.gov.au/chemicals-and-products/chemical-review/listing

Prioritisation of chemicals nominated for review

Agvet chemicals nominated for review by the APVMA are given an order of priority according to the level of concern that led to the nomination.

The APVMA and its external advisory agencies use a scoring process to prioritise nominated chemicals for review, based on key criteria of concern including human health (toxicology and occupational health and safety), environment, residues and trade, target crop safety and efficacy. The priority for each chemical nomination is determined by assessing it against each of the criteria and evaluating the outcomes.

Human health (toxicology and occupational health and safety)

Chemicals that are nominated for review are assessed for their effect on human health against the following criteria:

- Special concerns
  - o demonstrated or potential adverse effects in humans.
- Acute and chronic risk.
- Scheduling of the chemical.
- Exposure to the chemical from food.
- Regulatory action taken overseas (for example, Canada, the European Union, the United Kingdom, the United States of America).
- Hazardous substances.
- Other toxicity (health hazard).
- Industrial exposure in Australia.
- Form of concentrated chemical (includes formulated products).
- Exposure to working strength chemical (mixing, loading or application).
- Frequency of application.
- Post-application exposure (handling of treated crops and animals).
- Toxicity.
- User exposure.

Environment

Chemicals that are nominated for review are assessed for their effect on the environment against the following criteria:

- Environmental exposure
  - o form and method of application.
  - o volume of use (kilograms per annum).
  - o scale of use (hectares per annum).
  - o persistence (soil or aquatic half-life).
  - o bioaccumulation potential.
  - o mobility or leaching potential.
- Environmental toxicity.
- Aquatic toxicity.
- Terrestrial bird or mammalian toxicity.
- Terrestrial plant toxicity.
- Other non-target organisms.
- Sensitivity of receiving environment.
- Demonstrated adverse effects.
- Regulatory action taken overseas on environmental grounds (for example, the US Environmental Protection Agency, the Canadian Pest Management Regulatory Agency or the European Union).

Residues and trade

Chemicals that are nominated for review are assessed for their impact on residues and trade against the following criteria:

- Absence of maximum residue limits (MRLs).
- Reported incidents of residue violations.
- Reported incidents of adverse effects on trade.
- Compatibility with other countries' MRLs.
- International regulatory action.
- Residues resulting from use according to the label and the appropriateness of existing directions (for example, hydroponics versus field use).

Note: Dietary exposure is considered under human health.

Target crop safety

Chemicals that are nominated for review are assessed for their effect on target crop safety against the following criteria:

- Reported incidents of phytotoxicity and adverse interactions with target crops.
- Reported incidents of adverse effects to treated target animals.

Efficacy

Chemicals that are nominated for review are assessed for their efficacy against the following criterion:

- Lack of efficacy (confirmed report(s) of serious incident(s) of chemical failure; substantial incidents of chemical failure).

Chemicals nominated for reconsideration

Identifying and nominating chemicals for review is an ongoing process. The APVMA regularly assesses chemicals nominated for review to ensure the highest risks are being targeted based on up-to-date scientifically based information.

The reconsideration process is initiated when new scientific information raises concerns relating to the safety or effectiveness of the chemical.

The formal legislative process commences when the APVMA decides it is necessary to undertake a reconsideration and issues a legal notice to holders placing their approvals and registrations under review.

The APVMA follows a consultative process with the public, industry and federal and state government agencies to seek input on prioritising chemicals, or types of chemicals, that have been identified for review.

Currently, five chemicals have now been prioritised for detailed scoping prior to commencement of reconsideration. The remainder are to be prioritised for reconsideration after the first five have commenced the reconsideration process.

Currently there 13 chemicals or types of chemicals under review and 19 chemicals the APVMA had identified for future review. Five of these are currently being scoped prior to commencement of the review process.

More information on the chemicals under review, nominated and prioritised for reconsideration is available from: https://apvma.gov.au/node/10876

Table 1. Current chemicals with reviews in progress, those that have be prioritised (1 to 5) for future reviews and those that have been identified for review but not yet prioritised.

Current reviews in progress	Prioritised		Yet to be prioritised
	Priority	Chemical	Chemical
2,4-D [1,2,3] *	1	Dithiocarbamates [1,2] *	Acephate [1,2]
Chlorpyrifos [1,3] *	2	Second generation anti-coagulant rodenticides [1,2,3]	Amitrole [1,2] *
Diazinon [1,2,3]	3	Cyanazine and Simazine [2,3] *	Carbofuran [1,2,3] *
Diquat [1,2,3] *	4	Phorate [1,3]	Chlorothalonil [1,2,3] *
Fenitriothion [1,2,3] *	5	Metal phosphides (only those used for grain treatment) [1,2] *	Dicofol [1,2,3]
Fipronil [1,2,3] *			Fenutatin Oxide [1,2,3]
Maldison [1,2]			Hexazinone [3] *
Methidathion [1,2]			Levamisole [1,2]
Methiocarb [1,2,3] *			Methomyl [1,2,3]
Molinate [1,2,3]			Permethrin [1,2] *
Neomycin [1]			Picloram [2,3] *
Paraquat [2,3] *			Propargite [1,3]
Procymidone [1,2] *			Triazole fungicides [1,2] *
			Trichlorfon [1]

Reason for reconsideration

[1] Public health: Includes a consideration of mammalian toxicology and the risk to people from exposure to residues in food.

[2] Worker safety: Includes a consideration of mammalian toxicology and the risk to people using chemical products, re-entering treated areas and handling treated materials.

[3] Environmental safety: Includes a consideration of ecotoxicology, environmental fate and the risk to organisms from exposure to chemicals in the environment during use and remaining in the environment after use.

** Registered use in broadacre grain cropping.*

Table 2. Agvet chemicals with broadacre grains registrations for which reviews are completed with a brief description of the regulatory decision.

Chemical	Regulatory decision
Atrazine	Label variation.
	Specifically, these changes were to further reduce the risk of atrazine entering waterways, update the information on withholding periods and additional information on weed resistance reporting.
Bifenthrin	Related only to those products containing bifenthrin at 80g/L or 100g/L for which a 500mL pack size had been approved.
	Registration cancellation of 500mL packs with active concentration greater than 80g/L.
Bromoxynil	Changes to withholding period for grazing and cutting for stock food.
Carbendazim	Removal of horticultural and ornamental crops from label.
	Revised safety directions and added birth defects warning statement and male infertility in laboratory animals' statement.
	Re-entry intervals added to label instructions.
Dimethoate	Cancellation of home garden products.
	Restriction of pastures, fodder and oilseed uses to early crop emergence stages only.
Diuron	Label variations to remove or amend those uses where risk from runoff cannot be managed.
	Removal of some horticultural crops and non-agricultural situations.
Endosulfan	All registrations cancelled 11 October 2010.
Fenthion	All registrations cancelled 15 October 2015.
Glyphosate	In May 1997, following the review, the APVMA introduced additional restrictions on the use of glyphosate in or around waterways to limit the potential risks to the aquatic environment.
Omethoate	Removed all use patterns on food producing crops.
	Removed all use patterns for the use of omethoate on crops fed to food producing animals.
	Use restricted to bare earth barrier spray outside of crop.

The cost of registration, reconsideration and its impact on chemical availability

The number of research-based companies involved in the discovery of new chemistries has been declining. In part this is due to the increasing costs of the discovery and development of new pesticides. The average cost to bring a new active ingredient to market from 2010-2014 was an estimated US$286 million – approximately US$134 million more than in 1995.

It is harder and harder to find new active ingredients, despite the fact that chemical companies are screening more molecules than ever before. Only one in 160,000 active ingredients discovered today will pass the rigorous testing requirements to become a registered pest management product.

The additional costs associated with product defence, when a chemical goes through the reconsideration process, can be extremely high if additional data is required to meet current regulatory scientific requirements/standards. A registrant investment decision takes into consideration these additional costs. For older, generic products such expenditure may never be recovered from the market place.

Conclusion

The greatest direct influence that grain growers can have on retaining access to agvet chemicals is to ensure that there are no adverse experiences. This can be achieved by using chemicals for their registered use and closely adhering to all label directions for use including application timing, rates, spray drift mitigation statements and withholding periods.

Failure to do so can result in exceeding of MRLs in commodities, the potential for environmental damage and human health risks. These outcomes then put additional regulatory focus on those agvet chemicals, adding to the body of evidence that may then result in a negative review for the grains industry, leading to further use restriction or cancellation of registrations.

Maintenance of access to agricultural chemicals for broadacre use is reliant on growers showing strong stewardship in following label directions and supporting registrants who invest in new use patterns, both with new actives and old off patent (generic actives).

Useful resources

Australian Pesticides and Veterinary Medicine Authority (APVMA): https://apvma.gov.au/

APVMA: Chemical Review: https://apvma.gov.au/

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We are getting new herbicides — do we need to worry about diverse weed management now?

Peter Newman.

Australian Herbicide Resistance Initiative /WeedSmart.

Keywords

- new herbicides, herbicide resistance, cross resistance.

Take home messages

- We know that ryegrass and other weeds can be beaten by 'driving down' the seed bank using a diverse range of tools. Many growers who have been on this program for a decade or more are having a win. It is not easy, but we can win, however, it takes more than herbicides alone.

Introduction

Growers have been told for years that there are no new herbicides on the horizon to fix herbicide resistance problems, but alas, some new herbicides are on the way. It is possible that there will be several new herbicides on the market in the coming years, possibly even a new mode of action. Do we need to continue on the path of adopting diverse weed management practices, including herbicide and non-herbicide tools, or will the new products fix the problems?

You will probably guess that I will suggest that there is a need to use a diverse range of weed control tools, and below are a few reasons why I believe that diversity is still the answer. Do not get me wrong — I support new herbicides and am excited about the opportunity they bring. I believe we can get the best out of them by continuing to adopt some non-herbicide tools to add to the farming system.

EP162 – metabolic cross resistance

Last year, I saw the most alarming herbicide resistance data during my 25 year long career. Below is an excerpt from the Australian Herbicide Resistance Initiative (AHRI) insight, August 2018, summarising this data.

AHRI insight #105

A population of ryegrass from Eyre Peninsula, South Australia called EP162 may just be the world's most herbicide resistant ryegrass population. It has been confirmed resistant to all of the pre-emergent herbicides – Avadex®, Arcade®, trifluralin, propyzamide and Sakura®, as well as two lesser known herbicides, EPTC and thiobencarb. It was sampled in 2014 during the random survey led by Peter Boutsalis from the University of Adelaide with GRDC investment, just two years after the release of Sakura® in Australia. You guessed it, metabolic cross resistance is at play. Paraquat and the triazines still work on this population, but that is it!

Unpredictable pattern of cross resistance

A random survey in the South East of South Australia, also by Peter Boutsalis and team, found many more populations of ryegrass with multiple cross resistance to a range of pre-emergent herbicides, and the perplexing thing is that there is no predictable cross resistance pattern.

The only herbicide that was spared was Edge® (propyzamide), but the bad news is that EP162 may be the first ryegrass population in the world with confirmed propyzamide resistance. This is the subject of further research.

This is the research by the team of Chris Preston, Peter Boutsalis, David Brunton and Gurjeet Gill from the University of Adelaide with GRDC investment.

This is the worst herbicide resistance news that I have seen in my 25 year long career simply due to the fact that so many herbicides are failing simultaneously.

What does this mean for new herbicides?

Previously, new herbicides were tested on susceptible weeds. Now the new herbicides not only need to kill the susceptible weeds, they need to kill cross resistant monsters like those detailed above. The cross resistance pattern to the herbicides is completely unpredictable. How would a herbicide company feel about bringing out a product with a label claim that 'this product might kill your weeds, depending on its cross resistance status'? This makes for a very challenging environment for the chemical companies. On the upside, there is the ability to test new products against the 'cross resistant monsters' before they come to market.

Test

Herbicide resistance testing has never been very popular, and at times it has been hard to see the value of the test because it often just confirmed what was already suspected. Not anymore. Testing will become a high priority in years to come. Growers will need to know if the pre-emergent herbicides they are applying will work. Given that the cross resistance pattern is completely unpredictable, the only way will be to test — a lot.

My case for the need to continue with diverse weed management

1. Some weed populations will be resistant to the new herbicides before they are even released to market.
2. Pre-emergent herbicide + crop competition = high level control. The best pre-emergent herbicides give approx. 90% control of ryegrass. Adding crop competition can boost this into the high 90s.
3. Late germinating weeds. Weeds have adapted to germinate late to avoid knockdown and pre-emergent herbicides. Crop competition, stopping seed set and harvest weed seed control are needed to tackle these.
4. Keep the cost down. New herbicides are not cheap. If the life of low cost, off patent herbicides can be extended, growers can contain herbicide costs and use new, more expensive herbicides strategically and in mixes with older products.
5. EP162.
6. There is no sign of a new knockdown herbicide that I am aware of. We need to keep glyphosate and paraquat working.
7. Growers need to be confident about the future of cropping. If they feel in control of their weed seed bank, through the use of a diverse range of tools, they can be confident that they will be able to maintain a profitable cropping rotation, regardless of what resistance issues they face.

Want a little more information about diverse weed control? Check out the WeedSmart Big 6 at www.weedsmart.org.au

Summary

We know that ryegrass and other weeds can be beaten by 'driving down' the seed bank using a diverse range of tools. Many growers who have been on this program for a decade or more are having a win. It is not easy, but we can win, however, it takes more than herbicides alone.

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Notes

THE 2017-2019 GRDC SOUTHERN REGIONAL PANEL

JANUARY 2019

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

CHAIR - JOHN BENNETT

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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DEPUTY CHAIR - MIKE MCLAUGHLIN

Mike is a researcher with the University of Adelaide, based at the Waite campus in South Australia. He specialises in soil fertility and crop nutrition, contaminants in fertilisers, wastes, soils and crops. Mike manages the Fertiliser Technology Research Centre at the University of Adelaide and has a wide network of contacts and collaborators nationally and internationally in the fertiliser industry and in soil fertility research.

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PETER KUHLMANN

Peter is a farmer at Mudamuckla near Ceduna on South Australia's Western Eyre Peninsula. He uses liquid fertiliser, no-till and variable rate technology to assist in the challenge of dealing with low rainfall and subsoil constraints. Peter has been a board member of and chaired the Eyre Peninsula Agricultural Research Foundation and the South Australian Grain Industry Trust.

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JON MIDWOOD

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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FIONA MARSHALL

Fiona has been farming with her husband Craig for 21 years at Mulwala in the Southern Riverina. They are broadacre, dryland grain producers and also operate a sheep enterprise. Fiona has a background in applied science and education and is currently serving as a committee member of Riverine Plains Inc, an independent farming systems group. She is passionate about improving the profile and profitability of Australian grain growers.

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ROHAN MOTT

A fourth generation grain grower at Turriff in the Victorian Mallee, Rohan has been farming for more than 25 years and is a director of Mott Ag. With significant on-farm storage investment, Mott Ag produces wheat, barley, lupins, field peas, lentils and vetch, including vetch hay. Rohan continually strives to improve productivity and profitability within Mott Ag through broadening his understanding and knowledge of agriculture. Rohan is passionate about agricultural sustainability, has a keen interest in new technology and is always seeking ways to improve on-farm practice.

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RICHARD MURDOCH

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 CHILVERS

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 six 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 RUSSELL

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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LUCY BROAD

Lucy Broad is the General Manager of the Grains Research and Development Corporation's (GRDC) Grower Communication and Extension business group. Lucy holds a Bachelor of Science in Agriculture, majoring in agronomy, and prior to working at the GRDC spent the last 13 years as Director and then Managing Director of Cox Inall Communications and Cox Inall Change, Australia's largest and leading public relations agency working in the Agribusiness and Natural Resource Management arena. Her entire career has been in communications, first with the Australian Broadcasting Corporation and then overseeing communications and behaviour change strategies for clients across the agriculture, natural resource management, government and not-for-profit sectors.

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GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

2017–2019 SOUTHERN REGIONAL CROPPING SOLUTIONS NETWORK (RCSN)

JANUARY 2019

The RCSN initiative was established to identify priority grains industry issues and desired outcomes and assist the GRDC in the development, delivery and review of targeted RD&E activities, creating enduring profitability for Australian grain growers. The composition and leadership of the RCSNs ensures constraints and opportunities are promptly identified, captured and effectively addressed. The initiative provides a transparent process that will guide the development of targeted investments aimed at delivering the knowledge, tools or technology required by growers now and in the future. Membership of the RCSN network comprises growers, researchers, advisers and agribusiness professionals. The three networks are focused on farming systems within a particular zone – low rainfall, medium rainfall and high rainfall – and comprise 38 RCSN members in total across these zones.

REGIONAL CROPPING SOLUTIONS NETWORK SUPPORT TEAM

SOUTHERN RCSN CO-ORDINATOR: JEN LILLECRAPP

Jen is an experienced extension consultant and partner in a diversified farm business, which includes sheep, cattle, cropping and viticultural enterprises. Based at Struan in South Australia, Jen has a comprehensive knowledge of farming systems and issues affecting the profitability of grains production, especially in the high rainfall zone. In her previous roles as a district agronomist and operations manager, she provided extension services and delivered a range of training programs for local growers. Jen was instrumental in establishing and building the MacKillop Farm Management Group and through validation trials and demonstrations extended the findings to support growers and advisers in adopting best management practices. She has provided facilitation and coordination services for the high and medium rainfall zone RCSNs since the initiative's inception.

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LOW RAINFALL ZONE CO-LEAD: BARRY MUDGE

Barry has been involved in the agricultural sector for more than 30 years. For 12 years he was a rural officer/regional manager in the Commonwealth Development Bank. He then managed a family farming property in the Upper North of SA for 15 years before becoming a consultant with Rural Solutions SA in 2007. He is now a private consultant and continues to run his family property at Port Germein. Barry has expert and applied knowledge and experience in agricultural economics. He believes variability in agriculture provides opportunities as well as challenges and should be harnessed as a driver of profitability within farming systems. Barry was a previous member of the Low Rainfall RCSN and is current chair of the Upper North Farming Systems group.

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LOW RAINFALL ZONE AND MEDIUM RAINFALL ZONE LEAD: JOHN STUCHBERY

John is a highly experienced, business-minded consultant with a track record of converting evidence based research into practical, profitable solutions for grain growers. Based at Donald in Victoria, John is well regarded as an applied researcher, project reviewer, strategic thinker and experienced facilitator. He is the founder and former owner of JSA Independent (formerly John Stuchbery and Associates) and is a member of the SA and Victorian Independent Consultants group, a former FM500 facilitator, a GRDC Weeds Investment Review Committee member, and technical consultant to BCG-GRDC funded 'Flexible Farming Systems and Water Use Efficiency' projects. He is currently a senior consultant with AGRIvision Consultants.

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HIGH RAINFALL ZONE LEAD: CAM NICHOLSON

Cam is an agricultural consultant and livestock producer on Victoria's Bellarine Peninsula. A consultant for more than 30 years, he has managed several research, development and extension programs for organisations including the GRDC (leading the Grain and Graze Programs), Meat and Livestock Australia and Dairy Australia. Cam specialises in whole-farm analysis and risk management. He is passionate about up-skilling growers and advisers to develop strategies and make better-informed decisions to manage risk – critical to the success of a farm business. Cam is the program manager of the Woady Yaloak Catchment Group and was highly commended in the 2015 Bob Hawke Landcare Awards.

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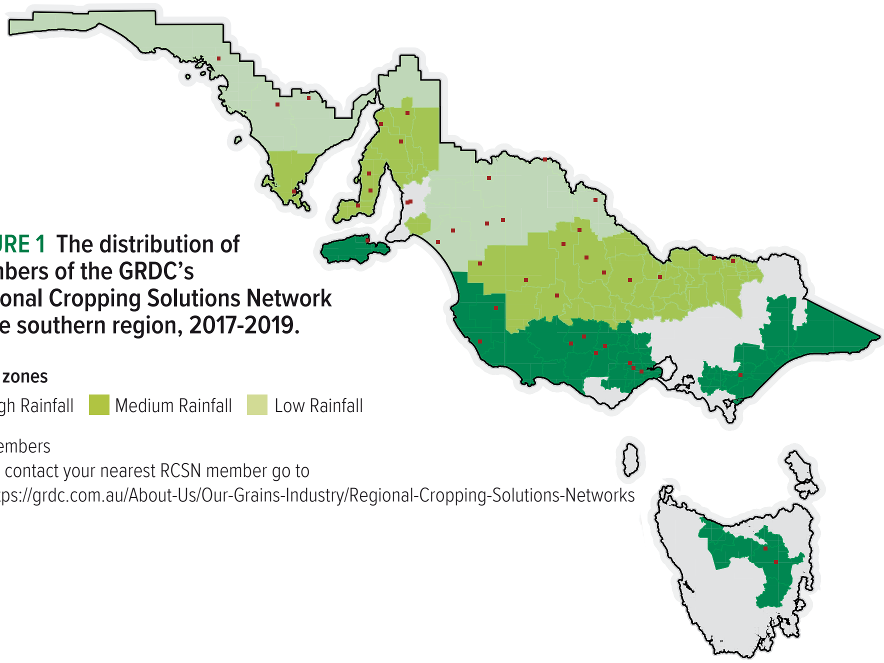

FIGURE 1 The distribution of members of the GRDC's Regional Cropping Solutions Network in the southern region, 2017-2019.

RCSN zones

High Rainfall | Medium Rainfall | Low Rainfall

Members

To contact your nearest RCSN member go to https://grdc.com.au/About-Us/Our-Grains-Industry/Regional-Cropping-Solutions-Networks

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GRDC™
GRAINS RESEARCH & DEVELOPMENT CORPORATION

OBITUARY

GRAIN STORAGE EXPERT WAS ON TOP OF HIS FIELD

Peter Botta will be sadly missed by his many friends in the grains industry

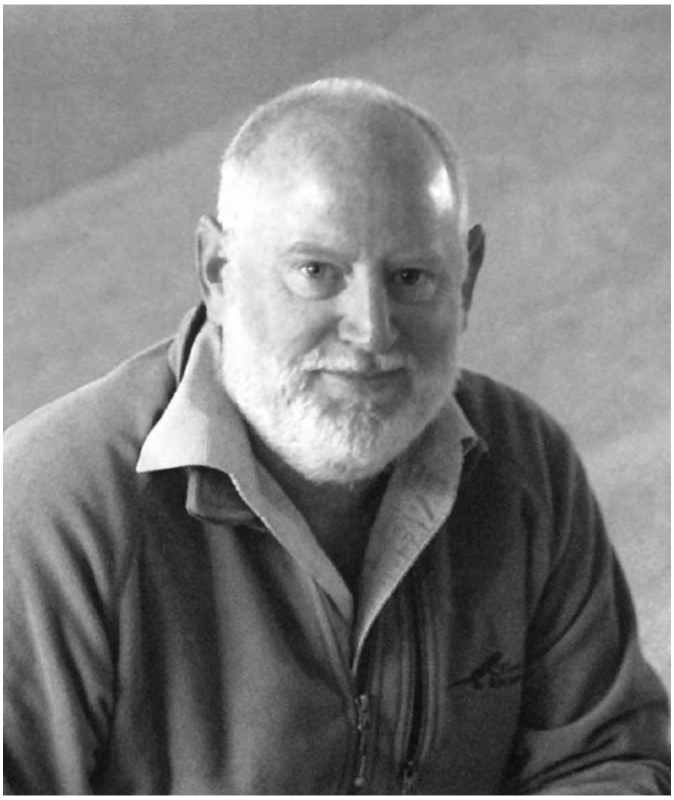
PHOTO: JEANETTE SEVERS

The Australian grains industry is mourning the sudden passing of grain storage expert and friend Peter Botta. As a Victorian-based consultant, Peter helped growers in the southern region with information and practical on-farm workshops over the past decade.

After a career as an entomologist working for the Victorian Department of Agriculture, Peter helped establish the Australian Standard AS 2628-2010, which relates to how well a grain silo is sealed. The industry uses this standard to determine the ability of a sealed structure to hold gas and its resulting suitability for fumigation.

As a consultant, Peter held hundreds of GRDC-supported on-farm grain storage workshops for growers across southern NSW, Victoria, South Australia and Tasmania.

These workshops were attended by thousands of farmers, who also sought specific advice from Peter relating to their individual circumstances and on-farm grains storage infrastructure. He worked hard to ensure growers understood what was needed when buying gas-tight sealable silos.

He contributed to numerous research papers, posters, fact sheets, booklets, videos, *GroundCover*™ articles and the 2002 grain storage book entitled *Stalk To Store*. He presented research nationally and internationally on the topic.

Peter was consulted for every *GroundCover*™ stored grain special feature and Kondinin Group research report related to grain storage. His knowledge on the topic was second-to-none.

Working with Peter inevitably resulted in a friendship. There was always a meal, or a coffee shared at a local restaurant or with his family at home in Benalla, Victoria.

Growers, manufacturers and others in the industry admired Peter for his straight-talking, no-nonsense approach to grain storage and for the honourable and honest person that he was.

Peter was a key member of the nation GRDC Grain Storage Extension team, who will miss him immensely but will continue to carry on the legacy he leaves behind, as he would have wished.

The GRDC extends its deep condolences to Peter's family.

(Source: GRDC GroundCover™ Issue 136: September – October 2018)

Acknowledgements

The ORM team would like to thank those who have contributed to the successful staging of the Victorian GRDC Grains Research Update:

- The local GRDC Grains Research Update planning committee that includes both government and private consultants and GRDC staff, RCSN and panel members (see page 2 for list of contributors).
- Industry supporters that include:

Adama Australia Pty Ltd
Australian Grain Technologies (AGT)
Agriculture Victoria
Alosca Technologies
Back Paddock Company
BASF Australia Ltd
Bayer Crop Science
CeRDI - Federation Uni
Decipher AgTech
Nuseed Pty Ltd
Pioneer Seeds (GenTech Seeds)
Seed Force Pty Ltd
Seednet
Syngenta Crop Protection Pty Ltd
UPL Australia Limited
Wengfu Australia

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/Bendigo-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.

2019 Bendigo GRDC Grains Research Update
Evaluation

1. Name

ORM has permisssion 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**).

DAY 1

3. National yield gap analysis - what is it telling us? ***Harm van Rees***

Content relevance /10 Presentation quality /10

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

4. In-crop weed search and destroy technology: ***Guillaume Jourdain***

Content relevance /10 Presentation quality /10

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

Concurrent sessions: please circle the session you saw, and review its content relevance and quality

5. 11.05 am	**Nitrogen and soil organic matter decline - what is needed to fix it?** *Jeff Baldock*	**Statistics made sexy:** *Dale Grey*	**Herbicide residue in soil - what is the scale and significance:** *Mick Rose*	**Fixing more N - improving the performance of inoculants in suboptimal conditions:** *Liz Farquharson*	**None**

Content relevance /10 Presentation quality /10

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

6. 11.45 am	**Pest patrol – RQA under the spotlight:** *Elia Pirtle*	**Emerging management tips for early sown winter wheats:** *James Hunt*	**Cost effective outcomes for ameliorating sandy soils:** *Lynne Macdonald*	**Canola - optimum management strategies:** *Cam Taylor*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

7. 12.25 pm	**Cereal and soil borne disease wrap up:** *Grant Hollaway*	**Herbicide residue in soil - what is the scale and significance:** *Mick Rose*	**Nitrogen and soil organic matter decline - what is needed to fix it?** *Jeff Baldock*	**Statistics made sexy:** *Dale Grey*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

LUNCH

8. 2.00 pm	**Sustaining our herbicides options into the future:** *Chris Preston*	**Providing advice to growers - getting a healthy balance between care and responsibility:** *Kate Burke*	**Fixing more N - improving the performance of inoculants in suboptimal conditions:** *Liz Farquharson*	**Pest patrol – RQA under the spotlight:** *Elia Pirtle*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

9. 2.40 pm	**Cereal and soil borne disease wrap up:** *Grant Hollaway*	**Cost effective outcomes for ameliorating sandy soils:** *Lynne Macdonald*	**Canola - optimum management strategies:** *Cam Taylor*	**High rainfall zone research forum:** *Nick Poole, Jon Midwood* and *Fiona Robertson*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

10. 3.20 pm	**Providing advice to growers - getting a healthy balance between care and responsibility:** *Kate Burke*	**Sustaining our herbicides options into the future:** *Chris Preston*	**Emerging management tips for early sown winter wheats:** *James Hunt*	**High rainfall zone research forum continued: (as previous)**	**None**

Content relevance /10 Presentation quality /10

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

11. Student session: Disentangling the soil amelioration and plant nutrition effects of subsoil manuring on crop yield: *Corinne Celestina*

Content relevance /10 Presentation quality /10

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

12. Student session: Potential value of damaged lentil seeds as a flour additive in baked products: *Drew Portman*

Content relevance /10 Presentation quality /10

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

13. Evidence and emotion - finding a new way forward for the grains industry: *Richard Heath*

Content relevance /10 Presentation quality /10

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

DAY 2

Concurrent sessions: please circle the session you saw, and review its content relevance and quality

14. 9.00 am	**Fungicide strategies in canola - achieving yield responses to foliar applications:** *Steve Marcroft*	**Mice - status, baiting and forecast threat:** *Steve Henry*	**Liming and limes - managing soil acidity:** *Lisa Miller*	**Sowing into stubble - impact on crop development:** *Michael Straight*	**None**

Content relevance /10 Presentation quality /10

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

15. 9.40 am	**Insects – tools for forecasting risks to enable proactive management:** *James Maino*	**Relative importance of different factors on WUE of wheat in western Victoria:** *Roger Armstrong*	**Understanding alphabet resistant annual ryegrass - where to from here:** *Peter Boutsalis*	**Weed research - chaff lining weed persistance and site specific targeted tillage:** *Mike Walsh*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

16. 10.50 am	**Nitrogen placement application methods - effects on yield, protein and nitrogen use efficiency:** *Ash Wallace*	**Mice - status, baiting and forecast threat:** *Steve Henry*	**Fungicides strategies in canola - achieving yield responses to foliar application:** *Steve Marcroft*	**Sowing into stubble - impact on crop development:** *Michael Straight*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

17. 11.30 am	**Pulse agronomy forum:** *Josh Fanning, Jason Brand and Audrey Delahunty*	**Insects – tools for forecasting risks to enable proactive management:** *James Maino*	**Liming and limes - managing soil acidity:** *Lisa Miller*	**Understanding alphabet resistant annual ryegrass - where to from here:** *Peter Boutsalis*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

18. 12.10 pm	**Pulse agronomy forum continued: (as previous)**	**Weed research - chaff lining weed persistance and site specific targeted tillage:** *Mike Walsh*	**Nitrogen placement application methods - effects on yield, protein and nitrogen use efficiency:** *Ash Wallace*	**Relative importance of different factors on WUE of wheat in western Victoria:** *Roger Armstrong*	**None**

Content relevance ☐ /10 Presentation quality ☐ /10

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

19. Pesticides and regualtory impacts - the road ahead: *Gordon Cumming*

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

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

20. Integrated weed management status - where to from here? *Peter Newman*

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

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

Your next steps

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

22. 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

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

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

24. Overall, how did the Update event meet your expectations?

Very much exceeded	Exceeded	Met	Partially met	Did not meet
❑	❑	❑	❑	❑

Comments

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

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

Thank you for your feedback.